Global Energy Solutions e.V.

For Prosperity and Climate Neutrality

Development of a Reference Solution for a worldwide climate neutral and prosperity-creating energy system

Final Report

Global Energy Perspectives

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Authors and Acknowledgements

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Preface

With this report, Global Energy Solutions e.V. (GES) and Forschungsinstitut für anwendungsorientierte Wissensverarbeitung/n (FAW/n, i.e. Research Institute for Applied Knowledge Processing) present the final result of the *Global Energy Perspectives* project, which has been substantially funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) since 2021. In addition, the project was supported substantively and financially by twelve partners from the private sector. The partners were Bundesverband deutscher Wohnungs- und Immobilienunternehmen e. V. (GdW), Drees & Sommer SE, ebm-papst Mulfingen GmbH, E.L.V.I.S. AG, Heraeus Holding GmbH, Kühne + Nagel (AG & Co) KG, Linde GmbH, Obrist Powertrain GmbH, Progroup AG, Schwenk Zement GmbH & Co. KG, Andreas Viebrock as supervisory board member of Viebrock Holding KG, and VINCI Deutschland GmbH.

The objective of the project was to show a path to a world that in the period 2050 - 2070 would enable ten billion people to live in freedom with adequate prosperity in social balance, an intact environment and a stable climate system. The solution that meets these requirements is called the **Reference Solution.** A priori, it was not clear whether such a solution exists.

In the course of the project work, however, it was possible to develop such a solution. It is described in this final report. The Reference Solution does not claim to be unique. Once it has been shown that there is a solution, it can be assumed that there will be many more.

In addition to this final report, extensive **Basic Documentation** was developed as part of the project work and is available on the GES website.[1] It consists of a "**Technical Toolbox**", which summarises the state of knowledge on the subject areas relevant to the topic from the fields of energy and nature-based solutions, and the part "**Greenhouse Gas-emitting Sectors**", which describes the initial situation and options for action for the main greenhouse gas-emitting sectors.

We would like to thank the BMZ and the twelve partners from the private sector for giving us the opportunity to work on this exciting and challenging project. In the search for knowledge and solutions, we took a number of detours and wrong turns. The fact that a Reference Solution is now available, where previously there was uncertainty about its existence, is gratifying. Despite all the difficulties, there is well-founded hope for implementation. Hopefully this opportunity will not be squandered like so many others before. Both organisations, GES and FAW/n, will continue to work to help avoid mistakes and take advantage of existing opportunities.

[1] Cf. https://global-energy-solutions.org

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List of abbreviations

BECCS	Bioenergy Carbon Capture and Storage
GDP	Gross domestic product
°C	Degree Celsius
CC	Carbon Capture
CCE	Circular Carbon Economy
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Usage
CCUS	Carbon Capture and Usage/ Storage
CDR	Carbon Dioxide Removal
CH_4	Methane
CH_3OH	Methanol
COP	Conference of the Parties (here: climate conferences)
CO_2	Carbon dioxide
CO_{2eq}	CO_2 equivalent
DAC	Direct Air Capture
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
GCCA	Global Cement and Concrete Association
GCF	Green Climate Fund
GW	Gigawatt
GWh	Gigawatt hour
ha	Hectare = 10.000 m^2
HVDC	High-voltage direct current transmission lines
HVO	Hydrotreated Vegetable Oil
H_2	Hydrogen
IEA	International Energy Agency
IMF	International Monetary Fund
IPPC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JETP	Just Energy Transition Partnership
kW	Kilowatt
kWh	Kilowatt hour
LDCs	Least Developed Countries
NDC	Nationally Determined Contribution
NH_3	Ammonia
NO_2	Nitrous oxide, laughing gas

ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PW	Petawatt
PWh	Petawatt hour
SDGs	Sustainable Development Goals
SMR	Small Modular Reactor
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
4R	Reduce, Reuse, Recycle, Remove

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Executive Summary

The Reference Solution described in this report shows a path that enables ten billion people in the period 2050 - 2070 to live in freedom with adequate prosperity in social balance, an intact environment and a stable climate system. The design of the energy system is of crucial importance for this, as it has a major influence on success or failure in climate protection and wealth creation.

A heuristic approach was chosen for the development of the Reference Solution. It was developed with the aim of enabling good development for humankind at a given climate gas mitigation pathway and initially without technological constraints or other (ex ante set) boundary conditions, and at the lowest possible cost for all economies of the world.

The guiding idea is global energy prosperity through innovation and the market, instead of managing energy scarcity. The Reference Solution is embedded in the regulatory framework of a global ecological-social market economy with ecological and social guard rails ("green and inclusive economy") and aims at a full implementation of the 2030 Agenda (Sustainable Development Goals). The aim must be to find consensual paths into the future that can find a high level of approval worldwide.

The Reference Solution is based on a division of the countries into three groups - the group of the **extended OECD** (rich, Western-oriented countries, 47 in total), the **China Club,** which comprises the countries that have historically relied heavily on fossil energies and have the corresponding resources (ten countries), and the **Challenge Group**, predominantly developing and emerging countries (128 countries). At the time of 2025, the starting point for the implementation of the Reference Solution, the countries of the expanded OECD, the China Club and the Challenge Group will each account for about one third of the world's approximately 39 billion tonnes of CO_{2eq} emissions. The countries of the Challenge Group want to achieve prosperity and are facing large population growth. The latter are the focus of the Reference Solution.

The Reference Solution is based on the assumption that energy demand in the Challenge Group will potentially increase by a factor of 2.5 over the next decades, taking into account population growth as well as the targeted increase in prosperity - despite a doubling of energy efficiency over the same period. If the historical energy mix were to be maintained on this path, an additional 20 billion tonnes of CO_2 per year would have to be removed from these countries by 2050. Preventing this is the real challenge in global climate protection.

The **central elements of the Reference Solution** and their interactions are as follows:

An important element of the solution is a comprehensive (1) **expansion of renewable energies combined with reliably controllable sources for the generation of electricity**. No full expansion of renewables is envisaged. Rather, the energy supply should rest on "two pillars". In addition to volatile, renewable energies, reliable, controllable energy sources are of essential importance for ensuring affordable and climate-neutral electricity. These must be provided in a climate-neutral way. To this end, fossil energy sources, especially natural gas, continue to play a central role in addition to a certain amount of nuclear energy.

By using (2) **carbon capture technologies,** they become practically climate-neutral (so-called green fossil energy sources). CO_2 is captured and stored, for example in caverns, or carbonised in silicate-containing rock. **Carbon capture** is the decisive **wild card** of the Reference Solution. A ramp-up to 15 billion captured tonnes of CO_2 per year by 2050 seems feasible. In order not to have to achieve an even greater expansion to, for example, 20 billion captured tonnes of CO_2 per year, electricity generation should be based on natural gas instead of coal wherever possible, as this halves the amount of CO_2 to be captured in each case.

Carbon capture technologies will become more important overall than green hydrogen production, as they are more easily scalable and follow more closely the guiding principle of "conversion instead of demolition". Moreover, the potential for ramping up global electrolyser capacity by 2050 appears to be limited to a maximum of 4,000 gigawatts. This capacity will be far from sufficient to develop electrolysis hydrogen into a global back-up system for fluctuating renewables.

Using fossil fuels with carbon capture in the future also means a less drastic adjustment of the business models of countries that currently live off these resources and/or have significant reserves. This approach should significantly increase the willingness of these countries to cooperate in the climate sector.

Moreover, the immediate capture of CO_2 at point sources is significantly cheaper than its subsequent removal from the atmosphere in the context of removal strategies. Carbon capture technologies can still play an important role in making process industries such as steel, cement, chemicals or aluminium climate-neutral, and are more readily available than hydrogen. In many cases, the use of carbon capture is even unavoidable (hard-to-abate sectors such as cement).

(3) **Climate-neutral fuels and energy carriers** are another important solution element in the energy sector. In the mobility sector, for example, climate-neutral fuels for cars and trucks must be used alongside electromobility in order to be able to use the steadily growing large number of vehicles with combustion engines in a way that does not harm the climate. There are different ways to achieve such fuels. Making climate neutrality possible here is a decisive contribution to future mobility for ten billion people and to global climate protection.

In addition, the (4) **elimination of technical methane leakages** is a central solution element. Methane emissions alone account for 16 % of the global greenhouse gas impact and, due to the limits of replacing molecules with electrons in the energy sector, are a key starting point for reducing greenhouse gases. This involves minimising emissions during the extraction, transport and use of natural gas.

Much more than is the case today, biological systems are put at the service of climate stabilisation through (5) **nature-based solutions** - forests, soils, wetlands and oceans. Currently, at least 14 billion tonnes of CO_2 are stored annually in biological systems and oceans, so they do not pollute the climate. Nature is therefore an important sink for CO_2 emissions. Especially those that are difficult to eliminate. Within the framework of the Reference Solution, the natural buffer for the absorption of more than 10 billion tonnes of CO_2 annually is to be strengthened, among other things through (5a) **consistent rainforest protection.**

In addition, as part of a **gigaprogramme of nature-based solutions,** the (5b) **afforestation in the tropics** (forestry) and the (5c) **improved humus formation** (in agriculture on degraded land), each on an area of 1 billion hectares, are parts of the Reference Solution. If such enhancement succeeds, it will reduce the amount of CO_2 emissions that need to be eliminated annually through technological measures. The Nature-Based Solutions gigaprogramme contributes to value creation, increases overall prosperity and is self-financing.

Furthermore, the gigaprogramme plays an important role in the use of the previously mentioned climate-neutral fuels: Nature must also serve as a sink for CO_2 emitted from volatile sources from the mobility sector in the long term. It is expected that a buffer the size of more than 10 billion tonnes of CO_2 will be possible from a strengthening of biological systems overall. Emissions from remaining fossil sources without CCS and climate-neutral fuels using carbon capture and use with fossil CO_2 (e.g. green methanol based on CO_2 from gas power plants) can thus be compensated. In combination with the other measures, these removals should mean that in the long term, from 2070 onwards, each person will still be able to emit an average of 1 tonne of CO_2 per year (10 billion tonnes of CO_2 - removals for ten billion people) and climate neutrality will still be achieved due to the buffer effect of the biological system.

Another value-adding measure in the area of nature-based solutions is the establishment of (5d) **short-rotation plantations** on 150 million hectares for the production of biomass and the extraction of biogenic CO_2 .

The following elements form the starting points for financing and providing regulatory support for the GES Reference Solution.

A co-financed (6) **global cap-and-trade system** should serve as a catalyst for the reduction of CO_2 emissions on the basis of Nationally Determined Contributions (NDCs) of the countries. To this end, a (7) **revision of the conditional NDCs** of the countries in the Challenge Group, which today are mostly linked to conditions with regard to their financing, is crucial. The conditional NDCs must be subjected to a comprehensive analysis in order to define realistic paths for their implementation. Both the financing of the necessary political processes and the implementation of the measures must be plausibly clarified for each country. In the period up to 2050, the immense projects currently formulated in the NDCs in the field of nature-based solutions will already be activated step by step. In addition to the gigaprogramme mentioned in point (5), this involves, for example, afforestation and the development of agricultural land in arid regions outside the tropics, boreal coniferous forests or the activation of the potential of marine plantations of algae for CO_2 absorption or algae in bioreactors. Here, several more gigatonnes of CO_2 removals can be generated as part of the clean-up of conditioned NDCs. This handling of the conditional NDCs then allows a canonical derivation of a cap-and-trade system from 2025 onwards that reflects the NDCs of the countries. A trading option is created that lowers costs for all.

In the Reference Solution, it is necessary to activate a total of **1.2 trillion US dollars** (1,200 billion US dollars) per year from the **extended OECD,** supplemented by voluntary contributions from non-state actors, in order to fully engage the countries of the Challenge Group in the transformation.

The additional costs caused by climate protection compared to business as usual should - in analogy to the **Montreal Protocol** successfully implemented to close the ozone hole - be borne by the OECD world via (8) **differential cost payments** (CfD). For example, the rich countries must assume the costs of carbon capture technology or the increased use of gas instead of coal to avoid 8 - 12 billion tonnes of CO_2 emissions per year in the ramp-up to 2050 in the countries of the Challenge Group. Here, costs amounting to **600 billion US dollars** per year are incurred. Furthermore, (9) **(transnational) energy infrastructures** have to be co-financed, for example in the field of renewables, which requires **150 billion US dollars** per year.

Further costs are incurred in the context of **nature-based solutions.** Here, upfront costs of **200 billion US dollars** per year need to be borne in order to create the conditions for the private sector to become active on a large scale. The programme to **prevent technical methane leaks** also requires upfront costs in order to create a favourable starting position for the private sector to implement the necessary measures at its own expense on the basis of political requirements.

After all, **revisioning conditional NDCs** and enabling their implementation costs **US$ 250 billion** per year.

If the financial involvement of the extended OECD does not succeed to the extent described above, the necessary global transformation will not be possible, which means that the climate goals and Agenda 2030 will ultimately remain unachieved.

This means that citizens in the enlarged OECD will have to pay an average of 800 US dollars per capita and year. That is a lot, but it should be achievable - in view of the escalating crises worldwide and the steadily rising costs of energy transformation at home, which alone will not be enough to master the global challenges. All the more so because the solution described addresses not only energy and climate issues, but ultimately all 17 Sustainable Development Goals (2030 Agenda).

In this context, international financial flows are not to be seen as classic funds for development cooperation, but as funds for (10) **system services** provided that serve to stabilise ecological and social systems, e.g. climate protection and biodiversity contributions. They serve the implementation of the Sustainable Development Goals in all their economic, ecological and social facets. In the process, parts of the measures finance themselves by leading to new CO_2 emission rights that can be purchased.

The self-interest of the rich countries in the face of looming crises and possible systemic collapses should be a sufficient argument for making the necessary flows of money possible. The annual 1.2 trillion US dollars represent nothing more than a **Marshall Plan for the poorer parts of the world**. Linking all the measures described above together creates significant economic opportunities for the entire world, especially by enabling a GDP increase in developing and emerging countries from 20 to 80 trillion US dollars by 2050.

If the Reference Solution is implemented, it will eventually succeed in achieving global net carbon neutrality and re-achieving the 2°C target by 2070. Under the Reference Solution, it is calculated that the expanded OECD will achieve Net Zero in 2050. The China Club, as publicly announced, will achieve this in 2060. The Challenge Group represents the as yet unanswered but crucial challenge on the path to Net Zero for the world, which will not achieve climate neutrality until 2070.

The Reference Solution relies heavily on consensus and cooperation. It takes into account the essential concerns of the various countries and is in this sense capable of peace. It shows a way out of the climate crisis that threatens the entire world and that no country in the world can prevent alone. It also opens up the chance of a global economic miracle that will make all the costs incurred easily bearable. If it is implemented, there is a realistic chance of achieving the formulated climate, energy and prosperity goals in the period 2050 - 2070.

1 Introduction

The issues of energy, climate and prosperity are closely interlinked. When dealing with the issue of climate protection in depth, it quickly becomes clear that the issue of prosperity is also centrally affected. This is due to the fact that climate protection is essentially a question of the energy system, which in turn is a central prerequisite for creating prosperity. Today, about 80 % of global CO_2 emissions come from the energy-related sector, which is why successful climate protection is crucially dependent on whether we succeed in transforming the energy system in the direction of Net Zero. If one also demands the preservation of prosperity or - in a global perspective - even a massive increase in prosperity, which can only succeed with an increase in the amount of energy, one senses the complexity of the task and the absolute necessity of a wise use of technology.

1.1 Objective of the report

The Global Energy Perspectives project aims to demonstrate that there is a prosperity-compatible solution to the world's energy and climate challenges. Such a solution is called a **Reference Solution.** In the sense of the Brundtland definition of sustainability, it is to be shown that it is possible to combine worldwide the concern of (catching up) economic development with successful environmental and especially climate protection. To this end, a reference model is to be developed that shows for various branches of industry, sectors and countries how they can be transformed towards climate neutrality at economically viable costs. This involves both the provision of energy and the conversion and use of energy. The focus is on limiting the greenhouse gas content in the atmosphere and, wherever sensible, on CO2 cycles - especially technical, but also natural (nature-based solutions). This is where forestry and agriculture come into play which were not studied as a sector in this report.

In the spirit of this task, the project looked for ONE model solution that builds on technologies known today and meets the formulated requirements of prosperity compatibility and climate neutrality. It was not clear a priori that such a solution exists. One can therefore be glad to have worked out such a solution. Once such a solution has been found, it is to be expected that there will be others. Technical progress is of great importance here.

This is even to be expected and hoped for. The course of history has shown that innovation and technology have repeatedly led to the world becoming a different place. The end of this story has certainly not yet been reached. At the same time, a successful implementation of the solution described in the following is dependent on numerous parameters and is not a "no-brainer". Against this background, every further development, every new idea, and every further promising path are very welcome.

The solution described below is a **heuristic**. All data on which the solution is based are initially derived from today's - not always consistent - actual data and are plausibilised on the basis of data known from the past. In the area of CO_2, energy and GDP data, we did not work with data exact to the decimal point, but with rounded estimated data based on official statistics. The reason for this is that very long-term developments from 2025 to 2070 are being considered, which will be dependent on a large number of influencing factors that are individually subject to various uncertainties with regard to their development. No precise data is available today for this period.

1.2 Structure of the report

In addition to the introduction, this report consists of ten further chapters. The most important self-developed content contributions can be found in chapters 4 - 6.

Chapter 2 describes the global context in terms of the initial situation from which the Reference Solution was developed. In addition to the implementation status of the 2030 Agenda, the Paris Agreement on Climate Change is discussed. Its logic is explained and its weak points are named. The latter must be dealt with in the context of developing a solution. Finally, a look is taken at current global political developments, which also have a major influence on the consensus capacity of the proposed solution.

Chapter 3 contains the premises in the sense of requirements, expectations and demands on the solution to be developed. On the one hand, it is about a (delayed) implementation of the 2030 Agenda in all its dimensions and, on the other hand, about achieving Net Zero as soon as possible after 2050.

Chapter 4 then divides the countries of the world into three groups, which is essential for the report. Specifically, these are the "OECD countries", the "China Club" and the "Challenge Group". The latter is of particular interest from a development policy point of view. With regard to climate and energy, it is the group in which the challenges are greatest.

Finally, **Chapter 5** describes the elements of the Reference Solution. On the one hand, this involves technical elements, and on the other hand, solution modules that use nature's CO_2 absorption capacity to contribute to the goal of Net Zero. Chapter 5 is based on more than 700 pages of two-part basic documentation. This consists of a "**Technical Toolbox**", which summarises the state of knowledge on the subject areas relevant to the topic, and the "**Greenhouse Gas Emitting Sectors**" section, which describes the initial situation and options for action for the main climate gas emitting sectors. The basic documentation contains much important background information on the solution elements described in this chapter, the inclusion of which in this report would have gone beyond its scope. It represents a significant substantive foundation for the solution described in this report.

Chapter 6 is dedicated to two further crucial dimensions of the solution, governance and financing. Approaches and instruments are shown on how the technical and natural solution elements described in chapter 5 can be flanked and financed by regulation.

In **Chapter 7,** references are made to other approaches of transforming the energy system towards climate neutrality and to other studies that also focus on Net Zero solutions.

Chapter 8 looks at the implications of the solution in terms of opportunities and possibilities. The question is what positive contributions the solution makes and what goals can be achieved with it.

These positive contributions are countered by the limitations in **chapter 9.** What are the limits of the solution? What restrictions should be taken into account? What can cause implementation to fail? This chapter also deals with BMZ-specific restrictions that were part of the project requirements.

Finally, in the following **chapter 10,** policy recommendations are formulated. These are divided on the one hand into very abstract recommendations that are not aimed at individual particular issues and on the other hand into more specific recommendations that concern future dealings with developing and emerging countries.

The final **chapter 11** contains a conclusion and an outlook for the future.

2 The current context

This chapter describes the initial situation from which the solution model for a climate-neutral and prosperity-creating energy system was developed. The world is in a situation in which a realistic assessment of the current development allows nothing other than the conclusion that neither the 2030 Agenda nor the Paris Climate Agreement can be successfully implemented on the paths taken so far. The topic of energy is of central importance in all of this. In addition, there are signs of major stressful changes and conflicts at the global political level that will have a significant influence on future events and, in particular, on finding solutions that require a high level of international agreement.

2.1 The 2030 Agenda

Since 2016, the 2030 Agenda has set internationally agreed, but legally non-binding, targets of the United Nations that are intended to lead to sustainable development worldwide. Behind the Agenda are a total of 17 Sustainable Development Goals (SDGs). They concern the well-being of all people in the world (Goals 1-6), economic goals (Goals 7-12), climate and environmental protection (Goals 13-15) as well as helpful or even absolutely necessary preconditions for the successful achievement of the goals (Goals 16-17).

Figure 1: The 17 Sustainable Development Goals of the UN 2030 Agenda

2.1.1 Past history

The past history of the 2030 Agenda can be traced back to 1972. In that year, the first global conference on the environment took place in Stockholm. But environmental protection did not remain the only topic there. The then Indian Prime Minister Indira Gandhi put much more important issues on the agenda from the perspective of the developing countries: the well-being of the people and their right to catch-up economic development, which should not fall victim to environmental protection. The idea of sustainable development was born: the simultaneous pursuit of (catch-up) economic development AND environmental and climate protection. This was laid down in the Brundtland definition in 1987: *Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs and freely choose their own lifestyles*.[2] Both concerns are reflected today in the 17 Sustainable Development Goals.

The immediate reason for the adoption of the 2030 Agenda was the non-achievement of the 8 Millennium Development Goals, which were pursued in the period from 2000 - 2015 and were thus the predecessors of the 17 Sustainable Development Goals. Their primary objective was to provide international support to developing countries in their economic catching-up processes while simultaneously taking environmental and climate protection into account. It was about overcoming poverty and hunger, education, health - and thus about issues that still preoccupy the global community today and are still waiting to be solved. Despite the focus on poor countries, not much was achieved in the 15-year term from a global perspective. In contrast to the Millennium Development Goals, the scope of the 2030 Agenda is global. Moreover, it clearly goes beyond pure development concerns.

2.1.2 Implementation challenges

The implementation challenges surrounding the 2030 Agenda are great.[3] Unfortunately, the global community is miles away from successfully achieving the goals. On the contrary, when viewed in the light of day, it is moving further and further away from successful implementation. The reasons for this are manifold and complex. In the following, important aspects that are significant for the development of solutions are described.

A key factor influencing global events is the continuing global **population growth**. At the end of 2022, the eight-billion threshold was exceeded. In April 2023, India overtook China as the world's most populous country and has since become the new "frontrunner" with more than 1.4 billion people. [4]

There are many **conflicting goals** that have not yet been overcome. The global pursuit of prosperity exacerbates the challenges on the environmental and climate side.

[2] Cf. World Commission on Environment and Development (1987).
[3] Cf. Herlyn (2019).
[4] Cf. UNFPA (2023).

The existing conflicts of goals can only be overcome through innovation and technology. However, **technology deficits** prevent progress. These exist, on the one hand, with regard to the fundamental availability of technologies and, on the other hand, with regard to technology transfers that do not take place.

There is also a lack of **funding**. It is true that the threshold of 200 billion US dollars in state funds for development cooperation was exceeded for the first time in 2022. However, this is solely due to the fact that substantial funds were raised for Ukrainian refugees and that Ukraine as a country also received extensive financial support, especially from Western donors, which were declared as development cooperation funds.[5] In an overall view, the phrase "from billions to trillions" still clearly describes the magnitude of the lack of funds, especially for co-financing by developing and emerging countries.[6] The need for extensive co-financing was a matter of course in the context of the Millennium Development Goals and an essential component of the agreement. In this sense, the 17 Sustainable Development Goals can be seen in retrospect as a step backwards compared to the predecessor goals.

Many people forget the **international dimension** and the need for **global cooperation** and focus solely on domestic measures. In the climate field, such an approach corresponds to the dominant current discourse. It may also seem "more obvious" in the truest sense of the word to get involved locally. However, this does not serve the cause and its innermost core.

Finally, the goals are **not legally binding** and there are **no sanctions** if the goals are not achieved. Progress can only be expected if consensual paths to the future can be outlined that are agreeable to all because they are perceived as fair and open up advantages for all involved.

2.2 The Paris Climate Agreement

One of the 17 Sustainable Development Goals of the UN 2030 Agenda is Goal 13 - Climate Action. This goal is the driving force behind the development of the Reference Solution, as the need for a rapid transformation of the global energy system towards climate neutrality is based solely on climate change, which must be contained to a manageable level. The Paris Agreement on climate change was adopted in December 2015 by almost 200 countries and the European Union. It entered into force in November 2016 and is thus the successor to the Kyoto Protocol.

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[5] Cf. OECD (2023).
[6] Cf. World Bank & IMF (2015).

2.2.1 Logic of the agreement

At the 15th Conference of the Parties on Climate Change (COP15) in Copenhagen in 2009, the goal of introducing a global CO_2 emissions trading system had to be abandoned, and with it the hope for a market-based and global approach that would have shown the world a much easier way to tackle climate change than anything that followed, taking the principle of climate justice to heart.

Instead, the task of climate protection was shifted to the national level: the core of the Paris Climate Agreement is formed by voluntary CO_2 reduction pledges (Nationally Determined Contributions, NDCs) from almost 200 countries and the European Union. The pledges of the industrialised countries differ from those of the developing countries. While industrialised countries have made **absolute reduction pledges**, the pledges of developing countries are usually **relative** - in the sense of a reduction in CO_2 - intensity of their economic growth. The EU, for example, has announced its intention to reduce its emissions by 50% by 2030 and to be the first continent in the world to be climate neutral in 2050. China - still a developing country - has pledged to reduce the CO_2 intensity of its growth by more than 65% by 2030 and to achieve climate-neutral status before 2060.[7]

The pledges of the developing countries are characterised by another peculiarity: As a rule, they are **conditional** on very high payments from the industrialised countries. Without external financial inflows, the pledges will never be met. Kenya - one of over 50 countries in Africa - is a good example. Kenya alone requires a good 50 billion US dollars in external financing if it is to comply with its NDC.

In addition to the very individual pledges of the countries described above, a common overarching objective was agreed in Paris - namely, initially to comply with the 2°C target, which was tightened to a 1.5°C target at the request of some island countries.

The financial side of the Paris Agreement is quickly described: It was agreed that from 2020 onwards, 100 billion US dollars should be provided annually by the industrialised countries to support developing countries in their measures against and adaptation to climate change.

The other issue of loss and damage, which has become so important in the meantime - and thus the question of liability for losses and damage already incurred as a result of climate change in developing countries - was merely noted as an item of information in the Paris Climate Agreement - without any concrete indication of how this other financially very important area is to be dealt with in future.

2.2.2 Weaknesses of the agreement

Even the mere description of the logic of the Paris Climate Agreement reveals that it has various weaknesses and can at best be described as "half the battle".

[7] Cf. Climate Action Tracker (2023).

While many voices repeatedly emphasise the binding nature of the Paris climate agreement under international law, practice shows that this does not exist in terms of content, that non-compliance with commitments made has no consequences whatsoever and that it is even possible to withdraw from the agreement without consequences in order to rejoin it later under a new government, as happened in the case of the USA.

First, it should be noted that even if all previous national pledges were met, neither the 1.5°C target nor the 2°C target would be reached. Meeting them would lead to up to 2.8°C warming.[8] The reality, however, is that even the insufficient pledges are overwhelmingly not being met and the world is on a path towards more than 3°C warming. There is no obligation under international law to actually achieve the targets.

The fact that the situation is like this has a lot to do with the nature of the **NDCs of the developing countries.** They are the **Achilles' heel of the Paris Agreement**. The fact that they have "only" made relative reduction pledges, against the backdrop of the economic growth taking place in many developing and emerging countries, means that emissions there are increasing in absolute terms. In relative terms, this means that the developing countries (only) reduce the CO_2 intensity of their economic growth. As a result, global emissions, with the exception of the Corona year 2021, also continue to rise to date. In sum, the savings in the industrialised countries are smaller than the increases in the developing and emerging countries. Looking at the NDCs of the developing countries, an end to this development can at best be expected in 2030.

In addition, the Net Zero targets of developing countries are often set in the second half of this century, for example in the case of the two most populous countries on earth India (Net Zero 2070) and China (Net Zero before 2060).

Another characteristic of the NDCs of the developing countries that is little discussed by the general public, but at the same time unresolved and difficult, is their **conditioning**. In total, trillions of US dollars would have to flow from the industrialised countries to the developing countries in order to make it possible to achieve the goals there and to convince the countries to seriously embark on the path towards net zero. For these populous and in some cases very poor countries, the central objective is to catch up on prosperity, not to prevent CO_2 emissions. According to international logic, they may even increase these emissions.

The monetary claims that are still open today are offset by far too small sums raised so far in the context of the Green Climate Fund (GCF) to support developing countries in climate protection and adaptation to climate change. The amount of 100 billion US dollars per year pledged from 2020 has never been reached.

[8] Cf. IPCC (2023).

Broad-based cross-financing of developing countries, which a global cap-and-trade system would have brought about "on its own" because market forces would have directed large sums to those parts of the world where CO_2 abatement costs are low, is not laid out in the Paris Climate Agreement.

This also applies to the third major area of international climate financing, namely the area of loss and damage, which is only listed as a "noted item" in the treaty. At the last climate conference, the COP27 in Egypt, this area was given its own fund for the first time - without, however, specifying who pays into it, when and in what amount.

2.2.3 Resulting status quo in climate protection

As a result of the situation described above, the world is facing further increases in CO_2 emissions. Climate protection efforts to date have been anything but successful and effective.

Global gross greenhouse gas emissions (expressed as CO_2 equivalents - CO_{2eq}) amounted to around 53 billion tonnes in 2020.[9] A good 34 billion tonnes of CO_{2eq} were attributable to the use of fossil energy and energy use in the process industry sector (e.g. cement and chemicals). Around 5.5 billion tonnes of CO_{2eq} resulted from agriculture and land use changes, e.g. the destruction of rain-forest.[10]

Besides CO_2, methane is of particular importance. In terms of its effect over 100 years, it is at least 24 times more harmful to the climate than CO_2. Methane emissions in 2020 amounted to about 8.5 billion tonnes of CO_{2eq}, of which about 60 % are man-made and result from methane leakage from industry on the one hand and from agriculture on the other.[11] Other climate-relevant contributions come from nitrogen and fluorine compounds.

2.3 The situation in the energy sector

Of greatest influence on the climate protection situation described above is the issue of energy, as the combustion of fossil fuels is the decisive cause of CO_2 emissions . As mentioned above, this currently involves around 34 billion tonnes of CO_2 worldwide. Primary energy consumption in 2020 totalled 157 PWh.[12]

To complement these figures for the world as a whole, consider the situation in developing countries described by the United Nations in its latest progress report on SDG 7 - *Affordable and Clean Energy*:

[9] Cf. Climate Watch (2023).
[10] Cf. IPCC (2021).
[11] Cf. IEA (2020).
[12] Cf. IEA (2021a).

"*Access to electricity and clean fuels for cooking has improved in many parts of the world. However, 675 million people are still not connected to an electricity grid and 2.3 billion people still cook with inefficient and polluting fuels. The war in Ukraine and global economic uncertainty continue to cause significant volatility in energy prices,* leading some countries to increase their investment in renewable energy while others rely more on coal, putting the green transition at risk. *If the current pace continues, by 2030 some 660 million people will still lack access to electricity and nearly 2 billion people will continue to rely on polluting fuels and technologies for cooking*."[13] Existing energy poverty threatens to continue.

2.4 Non-cooperation and new bloc formation

Chapters 2.1 and 2.2 have shown that a lack of cooperation is one of the most important reasons for the lack of success in the field of sustainable development and especially in the field of climate protection. Cooperation between the "Global North" and the "Global South" as well as between governmental and non-governmental actors is an absolutely necessary prerequisite for successful implementation of the 2030 Agenda and successful climate protection.[14] Neither is taking place to a sufficient extent today. Unresolved justice issues are a decisive reason for the lack of cooperation between industrialised and developing countries. Human history shows that justice is a prerequisite for cooperation, which is voluntary and not coercive.[15] Since it is hardly possible in today's world to force cooperation in the area of climate protection, only those solutions that are generally perceived as fair have a chance. Today, no one has the necessary means of power to enforce coercion - unlike, for example, at the time of colonialism.

The interrelationships described are applicable to a situation characterised by numerous conflicts (e.g. Ukraine - Russia, China - Taiwan) and new bloc formations.

Thus, Asian-African relations are in flux. One facet of this development is that China is increasingly successful in its efforts to project a positive image on the African continent and is on its way to being accepted there as a new world power.[16] A US study recently revealed that the response of African and South American recipients to contributions from the Chinese state media is more positive than to those from the industrialised nations. At the same time, the Western world is losing sight of the emerging global picture out of long-standing scepticism towards China.[17] Thus, it went largely

[13] UN (2023a).
[14] Cf. Herlyn et al. (2023).
[15] Cf. Radermacher (2023).
[16] Cf. Ziltener; Suter (2023).
[17] Cf. Mattingly et al. (2022).

unnoticed that a great many countries of the Global South joined China in not imposing sanctions against Russia in the wake of the Ukraine war. [18]

The world is also changing in the area of business and finance. In 2020, for example, the Chinese replaced the USA as the world's largest trading nation. For the vast majority of countries in the Global South, China is now the largest trading partner.[19] There are many indications that the country is in the process of gathering around itself countries that are critical of the Western world. These include the oil countries, Brazil, Argentina and Indonesia, but also India. One of the aims is to form a group of countries that shuns the US dollar. Within the framework of the mBridge project, a new international payment system is being created that bypasses the American currency. The West risks losing financiers from these countries, which in turn could keep interest rates high and further fuel inflation.[20]

Today's world can be described as a multipolar world. The bipolarity of earlier times with regard to the USA and China, or previously the USA and the Soviet Union, is history. In this world, geopolitics is gaining enormous importance and also has a significant influence on decisions in other policy areas, for example energy policy.

2.5 Emerging developments until 2050

As far as population development is concerned, today's eight billion people will become ten billion by 2050, an increase of 25%. This growth will occur primarily in Africa and Asia, i.e. in countries of the Global South with low levels of prosperity today. The countries of the Global North, on the other hand, will stagnate in terms of population size and continue to age.

It is thus clear that billions of people will continue to strive for greater prosperity in the future. What they all have in common is that their initial economic situation is poor. Against this background, a further significant increase in global GDP is to be expected.

The dimension of what can be expected for the coming years and decades is conveyed by a statement made by the current UN Secretary-General Antonio Guterres in the context of the Global Cement and Concrete Association (GCCA) in 2021: "*Three quarters of the infrastructure that will exist in 2050 has yet to be built*.[21] The fact that this is an exaggerated statement about construction, an extremely energy-intensive and therefore CO_2 intensive sector, underlines the relevance of such a forecast for the energy and climate sector.

[18] Cf. Castellum.AI (2023).
[19] Cf. Ghosh (2020).
[20] Cf. Stelter (2023).
[21] Cf. GCCA (2021).

Not only due to the expected developments in the field of construction, the global primary energy demand will continue to increase until 2050. Various sources cite values of up to 230 PWh.[22]

CO_2 emissions, especially those of the Global South, will also continue to rise, in line with the Paris Climate Agreement. As previously described, the world is on a path of warming by far more than 2.5°C. A 2°C target or net-zero situation seems achievable at best after 2050.

[22] Cf. Shell (2021).

3 Framework and requirements of the solution

On the one hand, this chapter is about outlining the economic system that should contribute to producing the described solution. On the other hand, the requirements placed on the solution are to be described: What are the expectations of the solution? What demands must it meet?

3.1 Ecological-social market economy as framework

The Reference Solution to be developed is to be designed in the spirit of an ecological-social market economy - an economic system that combines market and competition as well as sustainability concerns.[23] In such a system, the **four great freedoms** are guaranteed - freedom of property, freedom of contract, freedom to innovate and freedom to borrow or lend.[24] Central elements of such a system are innovation, balanced income distribution, regulatory policy and fair taxation of all value-creating processes.[25] Despite all the implementation challenges at the global level, which result, among other things, from the trilemma of globalisation,[26] the goal of the community of countries should be to operate worldwide in the sense of an ecological-social market economy and, on the one hand, to make use of the forces of the market and, on the other hand, to take ecological and social concerns into account to the necessary extent by setting a clever framework.

Significant elements of an ecological-social market economy are **innovation and technology**. History shows that they are crucial prerequisites for the creation of prosperity and growth. Within the framework of a market economy system, no technological paths are prescribed, but targets are formulated (for example in the area of climate protection) for which the best solutions for achieving a target are to be found within the framework of a technology-open competition in the market. Of course, it should be noted that technological development in recent decades has repeatedly revealed its Janus-faced nature: On the one hand, technological progress is an absolute must; on the other hand, it can also create new problems that are potentially greater than the previous ones. An example of this is the phenomenon of the rebound effect, where savings achieved through efficiency improvements (per unit) ultimately do not materialise or only partially because the number of units is constantly growing faster than the savings effect per unit.[27] It is therefore advisable to take a holistic view of the technological development taking place in the sense of a forward-looking technology assessment.[28]

[23] Cf. Radermacher et al. (2011).
[24] Cf. Herlyn; Radermacher (2014).
[25] Cf. Radermacher; Beyers (2011).
[26] Cf. Rodrick (2011).
[27] Cf. Kapitza (2014).
[28] Cf. Grunwald (2022).

Balanced income distribution is also a central feature of an ecosocially regulated system. In this context, a look at history reveals that balanced societies are better positioned in many respects than societies with high inequality. For example, it can be seen that countries are well positioned in terms of growth and prosperity when they are in the so-called *efficient inequality range*.[29] Broad prosperity is to be had when social inequality is neither too small nor too large.

In the international context, one often finds the term *green and inclusive economy* or *inclusive green economy*.[30] These terms have been part of the international agenda since the Rio+20 conference held in Johannesburg in 2012. The world financial crisis in 2009 was the impetus to question the existing economic model of a largely unregulated market and to look for alternatives. A *green and inclusive economy* represents such an alternative economic model, in which there is no externalisation of ecological and social costs to the detriment of the environment, the climate and people. Despite all the conceptual discussion of this model, a green and inclusive economy has not yet been accepted on the regulatory side.

In the German context, an ecological-social market economy can be interpreted as a further development of the social market economy, which is supplemented by an ecological dimension against the background of the ever-increasing importance of environmental and climate protection in recent decades.

An ecological-social market economy ultimately leads to environmental and climate protection becoming economically viable, because previously externalised environmental costs are internalised into market activity and thus become directly relevant to decision-making. At the same time, social costs are also no longer externalised and the idea of cross-financing takes on great significance. In an ideal form of such a market economy, prices tell the ecological and social truth.[31]

In Germany, it can be observed that the concept of an ecological-social market economy has been used more frequently in recent times - but often in a different interpretation, namely with less market and consequently more state influence. [32]

3.2 Requirements for the solution

This subchapter describes various requirements that exist for the Reference Solution. What must the solution do? Which goals should it help to fulfil? Because in a global perspective the development side of sustainable development has to be prioritised over the environmental side, the development dimension is addressed before the climate requirements.

[29] Cf. Cornia; Court (2001).
[30] Cf. UNEP (2023).
[31] Von Weizsäcker (1992).
[32] Cf. FÖS (2023).

The requirements formulated are extremely ambitious, since the ultimate goal is to enable all people to live a good life in prosperity and at the same time to stabilise the environment and the climate system in such a way that environmental and climate changes are kept at a manageable level. It is about nothing other than a full implementation of the 2030 Agenda, although it is completely unrealistic that this will be achieved by 2030. At best, this is possible in the period between 2050 and 2070.

3.2.1 Requirements in the area of development

In essence, the developmental requirement for the solution is that it should enable all people worldwide to live in prosperity and freedom. Such a huge transformation has never succeeded so far - prosperity and freedom have only ever existed for smaller parts of the (world) population.

On the energy side, this translates into a demand for **energy wealth,** because the availability of energy is an absolutely necessary condition for the emergence of prosperity. Today's energy poverty as described above - almost 700 million people live without access to electricity - is to be overcome.

As far as the topic of prosperity is concerned, gross domestic product (GDP) and thus the sum of goods and services produced is the decisive variable. It is also of central importance in the context of the UN Sustainable Development Goals (cf. SDG 7). The Reference Solution should also enable global GDP growth in the future. In this context, a considerable increase in prosperity is necessary in developing countries, which translates into a corresponding GDP growth.

The Reference Solution is claimed to deliver strong GDP growth for developing countries (excluding China). In this part of the world, the aim is to **multiply economic output** in order to achieve annual growth of around 6% in these countries. China, the role model for many developing countries in their own catching-up processes, has often had much higher growth rates over the last 30 years, staying just below 15 % in the best years.[33]

For the least developed countries (LDCs), which are home to more than one billion people, the 2030 Agenda sets a target of at least 7% GDP growth (sub-goal 8.1).[34] The Reference Solution should make it possible to achieve this target for this category of countries. However, since the LDCs have a very small share of the economic output of developing and emerging countries anyway (far less than 10%), we can speak in a good approximation of 6% economic growth for the entire group of countries.

[33] Cf. statista (2023).
[34] Cf. UN (2023a).

It should be noted that the continuing population growth in developing countries puts these figures into perspective. A growth rate of 6 % per capita for five billion people corresponds roughly to a growth rate of 4.9 % per capita if the five billion people become seven billion in 25 years.

The fact that the target growth is not set higher is due to restrictions in the area of financing, which in turn have an influence on the available technologies and the amounts of energy that can be generated.

It is also assumed for all developing countries that they can improve the energy intensity of their economies by the same amount as in the period 2000 - 2019. This seems feasible because for all scenarios aiming at a climate-neutral world, an enormous technology transfer from the richer countries to the poorer countries is an absolute prerequisite.

For non-developing countries and China, growth rates in the Reference Solution are projected to evolve according to the official OECD projections. This corresponds to an increase by a factor of 1.5 (annual growth of 1.6%) to a factor of 1.8 (annual growth of 2.3%) over the period 2025 - 2050 (depending on the region). The non-developing countries and China are also assumed to improve the energy intensity of their economies, and to do so by a factor of half more than they improved in the period 2000 - 2019.

3.2.2 Requirements in the area of climate

In the climate sector, the goal is to achieve **Net Zero by 2070** against the backdrop of a realistic consideration of the NDCs of the countries. The NDCs of the emerging economies, especially China and India, are key influencing factors.[35] China, as the world's largest emitter of CO_2 and accounting for almost a third of global emissions, is aiming for Net Zero by 2060. India, the third-largest CO_2 emitter behind China and the USA, with high growth ambitions, has not planned to reach Net Zero until 2070.

Another requirement of the solution is to **achieve the 2°C target**. It is quite possible that the world will not succeed in reaching this target. Even a temperature rise of 3°C cannot be ruled out within the uncertainties of the projections. A (at least) temporary overshoot of the 2°C limit is to be expected. Not surprisingly, there are more and more voices saying that it is too late to reach the 1.5°C target - no matter what paths are taken in the future.[36] Nevertheless, the aim should be to continue to remove greenhouse gases from the atmosphere even after the 2°C target is eventually reached, in order to get as close as possible to the 1.5°C concentration level.

[35] Cf. Climate Action Tracker (2023).
[36] Cf. UNEP (2022a), IPCC (2023).

3.2.3 Further requirements

In addition, there are further requirements for the solution, which are described below.

The world community must be able to assess the necessary **financing** of the solution as **feasible**. This is particularly a question of the economic capacity of the Global North and thus of the OECD countries, which have to co-finance the transformation of the Global South to a considerable extent ("From Billions to Trillions"). The burdens on the citizens and other actors of the rich countries must be bearable. At the same time, achieving such sums seems feasible for the first time in history, because continued inaction threatens to become even more expensive. In this respect, the contributions of the rich countries are not to be understood as charity, but as financing **system services** of the countries of the South that serve to stabilise ecological and social systems, for example climate protection. This means that payments are only made if the measurable system services in the countries of the South also demonstrably take place and the intended effects are also achieved. The contributions of the South are intended to protect the world, and thus also the rich countries, from the consequences of a "climate catastrophe" that they cannot prevent with measures on their territories alone.

Although not yet implemented, the approach of system services is not a completely new idea. The World Business Council for Sustainable Development (WBCSD) mentions a necessary "regeneration" mindset in the context of its Vision 2050. *Business has to move beyond a "doing no harm" mindset. It's time to unlock the potential of living systems - social and ecological - that business depends on, and build their capacity to regenerate, thrive and evolve*."[37] Again, this is about the ecological and social systems that need to be stabilised or regenerated for a good future of business. Within the framework of the Reference Solution, the aim is to pursue this approach across all stakeholders.

Because warlike conflicts massively impede the achievement of any goal, the solution must be **peace-preserving** and, in some parts of the world, even **peace-making.** It must therefore be characterised by a **very high degree of agreeability.** It can be ruled out that in the next 50 years an entity with dictatorial power can impose on the world what has to be done, can implement this in an all-encompassing way and that everyone will go along with it. Instead, a multipolar world is emerging in which development and climate issues can only be tackled by consensus through cooperation. Otherwise, the path will continue unabated towards an ever-worsening climate change and the resulting loss of prosperity all over the world.

In particular, the solution must avoid a conflict between the OECD and Russia, China and other countries that have large reserves of fossil fuels. It must open up a path that is also viable for

[37] WBCSD (2021).

countries for which the use or sale of these energy sources represents an essential element of their own financing base.

The Reference Solution claims to make a decisive contribution to solving the global energy and climate problems. Of course, this does not mean that the world will move towards the solution. But it could do so and would thus be on a path that can succeed in achieving the described goals. The point is to show that there is a solution at all that can meet global concerns about energy, climate and prosperity. If there is a solution, there will certainly be others. Technological progress alone is constantly expanding the scope of possibilities.

The aim is to "be on the safe side", not only technologically, but also economically and politically. In the sense of a "conservative" approach, the solution described should **not** contain **any overestimations of solution contributions,** but on the contrary be cautious in the assessment of solution-relevant parameters, such as the CO_2 effect, costs of individual components of the solution, technical readiness level or also political enforceability.

4 Extended OECD, China Club and Challenge Group

It has already become clear in the previous chapters that the current situations of the countries with regard to the issues of energy and climate are very different. The same applies to their roles in the development of solutions. These global conditions must be taken into account in their economic, social, geographical, ecological and demographic dimensions.

This is because the different circumstances result in different initial situations and interests that need to be taken into account if a holistic solution is to be found.

In order to make the crucial differences transparent and to take them into account appropriately in the development of solutions, the approximately 200 countries of the world are divided into three groups. These are the **extended OECD**, the so-called **China Club** and the **Challenge Group**.

The total countries included in the three groups - the expanded OECD, the China Club and the Challenge Group - cover more than 99% of the world's population and more than 98% of the world's GDP. The three groups are described below.

In the final sub-chapter, the Challenge Group is divided into three sub-groups on the basis of a self-developed "challenge index". The aim is to classify the states according to the size of the challenge to achieve Net Zero.

4.1 The extended OECD

The Organisation for Economic Co-operation and Development (OECD) is the organisation of the "rich" countries. Its 38 member countries are spread all over the world.[38] Their total population size is about 1.5 billion people. This will not change significantly until 2050. All OECD countries are working towards the goal of climate neutrality in 2050 (or even earlier) with their own financial resources. The only exception is Turkey, whose NDC aims for climate neutrality in 2053, makes only vague statements in the area of climate finance and expects help from other countries.[39]

Besides the OECD, there are nine other countries in a comparable situation with similar plans in the area of climate protection. These are Bahamas, Bermuda, Greenland, Liechtenstein, Malta, Monaco, Puerto Rico, Singapore and Cyprus. Together with the OECD countries, these nine countries form the **extended OECD**. In total, this group thus comprises 47 countries. [40]

These countries will follow their path to net zero by 2050 (or even earlier) according to current estimates and put together a mix of measures according to their own ideas. In doing so, they can choose from established solution modules, e.g. (1) old renewables, (2) new renewables, (3) carbon capture

[38] Cf. Annex A.1.
[39] Cf. Climate Action Tracker (2023).
[40] Cf. Annex A.1.

and usage as well as storage, (4) direct air capture, (5) nuclear energy, (6) heat pumps, (7) low-carbon hydrogen, (8) synthetic fuels, (9) nature-based solutions, (10) efficiency gains, (11) lifestyle change, (12) contingent mobility and (13) induced or accepted impoverishment/new concepts of wealth.

Which mix of measures is chosen depends very much on the specific circumstances in the countries. Everywhere, different types of restrictions resulting from local conditions have to be taken into account (cf. here Chapter 9 - Limitations). Some of these restrictions are of a political nature. This concerns, for example, national reservations about certain technologies (e.g. no nuclear power) and corresponding narratives that ultimately shape concrete policies on the ground. It is clear that political decisions for or against individual measures have a major impact on the prosperity prospects of the respective countries. Some countries may even "drive out" their industry. But it is also clear that the authority of state systems, including democracies, lies in precisely these national decisions. They are allowed to decide, even for losses in prosperity, if it corresponds to the majority opinion. Losses of prosperity can occur above all if energy-saving targets are set by law that cannot be achieved through energy efficiency gains.[41]

In sum, the enlarged OECD is a relatively uncomplicated environment for the Reference Solution. There is a box of measures that can be used, cf. chapter 5. There are the necessary financial means. The countries must choose their own path and find majorities for it. With the Reference Solution, solution modules and measure mixes are subsequently proposed, which the OECD can of course also make use of. Assuming the success of the energy and climate policies of the countries under consideration, the concrete policies of these countries on the path to Net Zero form the part of the Reference Solution that relates to these countries.

Against the background described, the expanded OECD is not the primary target field of the Reference Solution, not even in relation to current disputes such as the EU dispute over whether electrolysis hydrogen based on electricity from nuclear power plants is green or not. From the perspective of the Reference Solution, such a question is not a question of the solvability in principle of global problems in the energy and climate sector. These are rather local phenomena resulting from the respective prehistory, dominant narratives as well as the struggle for interpretive sovereignty and political power, which have to be dealt with locally.

Nevertheless, the enlarged OECD has two important roles to play in the development of solutions. Firstly, it must contribute significantly to its financing and secondly, it continues to act as a major supplier of innovation and technology, as a large part of the technologies required for climate

[41] Cf. Fuest (2023).

neutrality in 2070 are not yet available today. These, in addition to achieving their own climate neutrality in 2050, are crucial contributions for a successful implementation of the Reference Solution.

4.2 The China Club

The emerging superpower China will have a central influence on the future of the world. This is especially true in the climate and energy sector, as China is the world's largest emitter of CO_2 and at the same time the largest producer and user of coal. There are many indications that China is about to become the centre of a new bloc formation, cf. chapter 2.4. Other influential countries to be mentioned in this context are Russia and Saudi Arabia. For them, too, fossil energy sources are of great importance. In addition, there are other countries that are also rich in fossil energy sources and for which these energy sources are a central basis of their existence and financing. They are organised in **OPEC**, the Organisation of Petroleum Exporting Countries. The countries are Bahrain, Hong Kong, Kuwait, Macao (CN), Oman, Qatar and the United Arab Emirates. These ten countries in total form the so-called **China Club** within the framework of the Reference Solution. The population size of this group is about 1.5 billion people in 2025. It will not change significantly until 2050.

The new bloc formation around China described in chapter 2.4 is even more far-reaching and reaches into the developing countries. This phenomenon will be taken up later.

Without cooperation with the countries of the China Club, the world's climate and energy problems will not be solvable. Against the background of their socio-cultural ideas and their plans for the future in the energy sector, the ten countries often represent different positions than large parts of the expanded OECD.

It is instructive to take a closer look at China, Russia, Saudi Arabia and the United Arab Emirates - as hosts of the next climate conference COP28.

Saudi Arabia is a heavyweight in the field of fossil fuels, which is reflected by the state-owned company Saudi Aramco. It is by far the largest energy company in the world. In the 2022 financial year, the company achieved a record profit of 161 billion US dollars.[42] That the country will continue to rely on fossil energies in the future already became clear in the context of the G20 summit in 2020, which Saudi Arabia hosted and at which a **Circular Carbon Economy** (CCE) platform was launched, centred on the **4R Framework** "Reduce, Reuse, Recycle and Remove".[43] It is clear that fossil fuels will continue to play a role and that carbon capture will be a key to achieving Net Zero. This assessment is also reflected in statements by Sultan Al Jaber, President of the upcoming

[42] Cf. statista (2023b)
[43] Cf. Climate Transparency (2020).

COP28 from the **United Arab Emirates,** and in the final document of the Petersberg Dialogue 2023, which talks about a **"phase-out of fossil emissions" but not about a "phase-out of fossil energies".**[44]

Russia is the country with the largest territory in the world. It is a leading power in fossil fuels and has very large natural gas reserves, which are central to the country's financing. In addition, there are very large biological resources. Russia benefits in many ways from climate change, for example in the Arctic, where resources that were previously inaccessible are becoming accessible as a result of global warming. The opening Northwest Passage also offers new development opportunities. Where the Ukraine conflict will lead cannot be judged today. Russia is orienting itself away from Europe.

China is the emerging superpower. The West, like many immediate neighbours, feels threatened by China's ambitions. China is rapidly arming itself. It is threatening Taiwan, which is not recognised internationally as an independent state and which China wants to incorporate into its empire, like Hong Kong before it. China claims large parts of the South China Sea, even against the claims of other countries, such as Vietnam and the Philippines, not even taking note of the ruling of the Permanent Court of Arbitration in The Hague on legitimate claims in this region.

China is the world's largest energy consumer and at the same time continues to claim its status as a developing country. This allows it to increase its CO_2 emissions until 2030, which the country intends to do. China is pursuing many parallel approaches in the climate sector, but is also the largest consumer and producer of coal, followed by India. Together, the two countries consume about 80 % of the world's coal. Burning it produces about 14 billion tonnes of CO_2 per year , which is more than one third of global emissions in the energy-related sector.

At international conferences, China and India are repeatedly pressured to phase out coal. In fact, at the G20 summit in Rome in 2022, the participating countries agreed to phase out coal in the coming decades. However, this only applies to **unabated coal,** i.e. coal combustion without carbon capture (CC). This is stated in the final communiqué from Rome. The USA has adopted a similar position. The same applies to the final communiqué of the 2022 Climate Change Conference in Sharm El Sheikh, Egypt. It is important to note that in both China and Russia carbon capture is an essential part of their own plans to achieve Net Zero. Both countries, as well as Saudi Arabia, have declared this goal for 2060. Given the challenges the countries face, this is an early date. Whether the goal will be achieved is difficult to judge.

The OECD world will not be able to exert much influence on the achievement of these countries' goals. But if the demands on these and other countries are increased too much, for example in the

[44] Cf. Federal Foreign Office (2023).

direction of total defossilisation, it is to be expected that these countries will end the debates with the "West" and pursue their own ideas.

So far, **no demands for financial support** have been made by China and Russia for their paths towards Net Zero. However, China opposes paying for loss and damage in the other developing and emerging countries. Russia probably sees it similarly.

The countries of the China Club will shape their own path towards Net Zero. Whether reaching the goal in 2060 is realistic can hardly be estimated today. China and Russia in particular, to which large parts of the world are currently orienting themselves, will hardly accept regulations from the West. As in the case of the expanded OECD, the possibility of exerting influence in the form of considerations on a Reference Solution is thus small. In principle, countries can achieve Net Zero by 2060. Fossil fuels, however, will remain of central importance in the China Club. Carbon capture will be a central element in this. New renewables have potential for China and Russia, but it is limited due to climatic and other conditions. Energetically and financially, it is existential for both countries to maintain their great power status. Those who want to tackle climate change should seek a cooperative path with these two countries and, if possible, not jeopardise their stability.

Based on the above, the expanded OECD as well as the China Club are not the primary objects of investigation for the reference solution. The enlarged OECD can achieve prosperity and Net Zero with the available instruments on its own by 2050, for the China Club this applies to 2060. The development prospects of the Challenge Group countries should not be affected by this.

4.3 The Challenge Group

This leaves the remaining countries, namely the developing and emerging countries, which are referred to as the Challenge Group, as the central challenge. They are the central subject of this report. The situation in these countries is much more difficult than in the expanded OECD and the China Club. They form the third group, which is central because of the challenges there in the climate and energy sectors.

In many countries of the Challenge Group, poverty and high population growth prevail. Still others have already developed a middle class in recent years and see prospects for things to get even better in the years to come. Young families here already have fewer children, often as few as two per household. All countries in the Challenge Group have high expectations of prosperity. China is often the model for what they would like to achieve.

Unlike most other studies, the GES Reference Solution focuses on the **prosperity perspective for the Challenge Group**. The term "challenge" here encompasses all three dimensions of sustainability: the ecology, the economy and the social sphere. The challenge in achieving the United Nations

Sustainable Development Goals (SDGs) is to overcome the trade-offs between these three dimensions. This is the Challenge. In this respect, the countries in the Challenge Group are very diverse. Depending on the country, one or more of the three dimensions stand out as a particular challenge.

Countries in the Challenge Group with moderately high incomes have already developed mechanisms to build prosperity. What matters here is that further growth takes place with as few emissions as possible. The economic and social dimension seems manageable. Climate-neutral growth is the challenge, especially when GDP growth per year is high. In the case of countries with particularly high population growth, the social side comes to the fore, especially because these countries are usually still very poor. Also from a humanitarian point of view, the decisive factor here is how many people are added in absolute terms per year.

In Africa, the situation is particularly dramatic. In 30 years, the population there will double from 1.2 billion to 2.4 billion. Nigeria, with 400 million people, will be the third most populous country behind India and China and ahead of the USA. In each of the next three decades, as much will be built in Africa as in Europe in the last century.

The aim of this report is to show a solution that brings prosperity to all people. We are talking about five billion people in 2025 and seven billion people in 2050. The rich world and the two major non-Western powers, China and Russia, with a total of three billion people, are (increasingly) less important in terms of population. Conflicts of goals between ecology, economy and social issues arise particularly where justifiably high expectations of prosperity for many people potentially lead to high emissions and thus to a further acceleration of climate change. As an international community of countries, we need to focus our actions on these countries.

Of course, the conditions in the countries of the Challenge Group are very different. A look at the World Bank's World Development Indicators makes this clear. [45]

For example, there are countries that are characterised by a particular development dynamic that must be taken into account when finding solutions. These **"heavyweights"** are characterised by high population growth and/or a high GDP per capita for a developing country.

If we use the World Development Indicators to select the countries with a **GDP per capita of more than 10,000 US dollars** or a **population growth of more than 900,000 people per year** or a **population growth of more than 500,000 people per year** and a simultaneous **GDP growth of more than 3.5% per year**, we obtain a total of 40 countries.

A GDP per capita of over 10,000 US dollars indicates that the starting position is relatively good. Corresponding countries are, for example, Argentina or Malaysia. However, a GDP per capita of this

[45] Cf. World Bank (2023).

size also indicates that these countries are in a position to base their further growth in prosperity on climate-damaging fossil fuels in the short term, should no cross-financing for carbon capture and renewable energies be provided.

A population growth of over 900,000 people per year indicates a very high dynamic also in the area of future GDP growth. If this growth were to be based on fossil fuels (without carbon capture), as is the case in China, any climate protection efforts by the rest of the world would be undermined. Countries that meet this criterion include Afghanistan, Bangladesh, Brazil, Congo, Dominican Republic, Egypt, India, Indonesia, Kenya, Nigeria, Pakistan and the Philippines. Among them are obviously some countries with great global political importance.

Of course, the Challenge Group also includes the countries that are among the poorest in the world. At UN level, these are called "Least Developed Countries" (LDCs). These countries often have very specific problems, such as civil war, no access to the sea ("land locked"), etc. Currently, 41 countries are LDCs.

The Challenge Group comprises a total of **128 countries**. An overview, in which the LDCs are highlighted in red, can be found in the appendix. [46]

4.4 Key data of the three country groups

For the three groups of countries described above, this chapter summarises the key data on which the Reference Solution is based. These include **population growth**, **GDP development**, corresponding **increases in the amount of energy** and the **resulting CO_2** emissions. They all result from the contents of Chapters 2 and 3. In chapter 2, the status quo was described and future developments, for example in the area of population development, were discussed. In chapter 3, the requirements for the solution were formulated.

The following tables provide an overview of the central parameters that were taken into account in the development of the Reference Solution. The calculated values are given in brackets. The values in front of the brackets are rounded to make the figures easier to communicate.

Table 1 shows how the population figures in the three groups under consideration will develop in the period from 2025 to 2050 according to current knowledge:

[46] Cf. Annex A.1.

	2025	2050
Extended OECD	1.5 (1.40)	1.5 (1.40)
China Club	1.5 (1.56)	1.5 (1.44)
Challenge Group	5 (5.1)	7 (6.7)
World total	**8 (8.06)**	**10 (9.53)**

Table 1: Population figures in 2025 and 2050 (in billions)

Table 2 shows which GDP developments the Reference Solution should enable in the coming years from 2025 to 2050 in the three groups under consideration. In particular, it should be possible for the Challenge Group to achieve GDP growth from 20 trillion US dollars in 2025 to 80 trillion US dollars in 2050. In this part of the world, we are thus talking about a quadrupling of economic output, which corresponds to annual growth of about 6 %. Values are given for the years 2025 and 2050 as well as increases for the period between these years:

	2025	GDP growth from population growth	GDP growth from other factors	2050
Extended OECD	75 (72.8)	2 (2.6)	35 (33.8)	110 (109.1)
China Club	30 (28.7)	-4 (-3.8)	25 (26.3)	50 (51.1)
Challenge Group	20 (18.5)	10 (11.2)	50 (51.0)	80 (80.7)
World total	**120 (120)**	**10 (9.6)**	**110 (110)**	**240 (241.1)**

Table 2: GDP developments from 2025 to 2050 (in trillions of US dollars)

The calculated GDP values in 2050 are based on the following projections:

[1] Expanded OECD: 25 years á 1.6 % growth per year; factor 1.5; per capita 1.6 %

[2] China Club: 25 years á 2.3% growth per year; factor 1.8; per capita 2.6

[3] Challenge Group: 25 years 6% growth; LDCs 7% per year; factor 4.4; per capita 4.9%.

According to SDG 8.1, the LDCs should be enabled to grow by 7%. Due to this slightly higher growth in the LDCs, the Challenge Group has a GDP that is 1.5 trillion US dollars higher in 2050 than if they also had "only" 6% growth. It amounts to 80.7 instead of 79.2 trillion US dollars.

Furthermore, it must be taken into account that GDP growth requires energy. In order to estimate how much energy is needed to reach the projected GDP figures, it is necessary to look at the expected efficiency gains in energy use. For the expanded OECD and for the China Club, it is assumed that they will improve the energy intensity of their economies - becoming half better than they were in the period 2000 - 2019. With regard to developing countries, it is assumed that they will be able to achieve, on average, as high efficiency gains in the period 2025 - 2050 as in previous years (2000 - 2019). This seems realistic because for all scenarios aiming at a climate-neutral world, an enormous technology transfer from the richer countries to the poorer countries is an absolute prerequisite.

These assumptions lead to the distribution of GDP increases between volume effects on the one hand and efficiency effects in the area of energy production on the other hand, as shown in Table 3 below.

	2025	**Quantity effect**	**Efficiency effect**	**2050**
Extended OECD	75 (72.8)	10 (11.5)	25 (24.9)	110 (109.1)
China Club	30 (28.7)	5 (5.3)	15 (17.1)	50 (51.1)
Challenge Group	20 (18.5)	30 (30.8)	30 (31.3)	80 (80.7)
World total	**120** **(120)**	**10** **(9.6)**	**110** **(110)**	**240** **(241.1)**

Table 3: GDP growth based on energy quantity and efficiency effects (in trillions of US dollars)

Energy consumption in the expanded OECD grows by 20% from 75 PWh to 90 PWh from 2025 to 2050. For the China Club, consumption also increases by 20 % from 50 PWh to 60 PWh. Here we assume that these countries will achieve another half of the energy efficiency increase per unit of GDP as happened in the period 2000 - 2019. For the expanded OECD, this means a transition from 1 kWh to 0.8 kWh per US$1 of GDP. The China Club moves from 1.75 kWh to 1.2 kWh per US$1 GDP.

For the countries in the Challenge Group, we assume that they can achieve the same increase in efficiency in the period up to 2050 that they have already achieved between 2000 and 2019. This seems plausible, as they need to build more modern energy systems in order to increase their prosperity. In our approach, international cooperation towards Net Zero and the implementation of the Sustainable Development Goals plays a central role. This includes huge cash transfers and offsetting differential costs for the Challenge Group's energy programme.

In the process, the Challenge Group's energy consumption increases by a factor of 2.5 from around 20 PWh to around 50 PWh. GDP increases by a factor of 4 from 20 trillion US dollars to 80 trillion US dollars in comparison. Energy efficiency improves from 1 kWh to 0.625 kWh per 1 US dollar GDP.

The relevant key data for the three groups of countries naturally also include the expected CO_2 quantities to be dealt with in the period under consideration between 2025 and 2050.

Based on past developments, the Reference Solution for 2025 assumes that global CO_2 emissions are evenly distributed among the three groups of countries. A decisive point in time in the past that is characteristic of global developments was the year 2019, in which China reached the same emission level as all OECD countries together for the first time. [47]

The Reference Solution is based on the following distribution of global CO_2 emissions in 2025 and in perspective for the coming years.

	2025	**In perspective**
Extended OECD	13	0
China Club	13	0
Challenge Group	13	33
World total	**39**	**33**

[47] Cf. Rhodium Group (2021).

Table 4: Net CO_2 emissions of the groups of countries in 2025 and in perspective

The perspective values are explained as follows: It is assumed that the enlarged OECD and the China Club will achieve Net Zero on their own, the OECD in 2050, the China Club in 2060. On the other hand, taking into account the calculated GDP increases, the increase in the amount of energy and the achievable efficiency improvements, the emissions in the Challenge Group will increase to about 33 billion tonnes CO_2 if no countermeasures are taken, to which the enlarged OECD will have to contribute significantly financially. The Reference Solution explicitly addresses how these 33 billion tonnes of CO_2 can be reduced to a net 3 billion tonnes of CO_2 by 2050 and achieve Net Zero by 2070.

4.5 Subdivision of the Challenge Group for differentiated cooperation in climate protection

As mentioned before, the challenges on the way to achieving Net Zero vary greatly from state to state. Especially within the Challenge Group, the circumstances are very different. Using a **"challenge index",** the countries in the Challenge Group are divided into three sub-groups, depending on the size of the "challenge" to achieve Net Zero. The index is derived from data on various variables that influence the challenges to be overcome. These include **GDP per capita**, absolute **population growth**, **availability of fossil fuels**, **potential of solar energy**, **potential for nature-based solutions** and a value with a statement on **good governance**. Of course, the Challenge Index cannot replace a detailed analysis of each country's situation for an individual pathway to Net Zero while promoting the SDGs. A case-by-case analysis must be carried out for each country. However, this goes far beyond what is possible within the framework of this work, in which individual countries were subjected to a more detailed analysis as examples and principles were derived on this basis. The Challenge Index provides a rough orientation for dealing with the different groups of countries, for example in the context of the governance and financing approaches proposed in Chapter 6, including their technological and intellectual requirements.

The Challenge Index is built up by adding six individual values, i.e. it is a so-called composite indicator. Higher values mean greater challenges, whereby the three dimensions of sustainability (economy, ecology incl. climate protection and social issues) play a different role depending on the country. If GDP per capita is high, this is a good starting situation from a socio-economic perspective. However, it is very likely that these countries will continue to rely on fossil fuels if there is no cross-financing for carbon capture, increased use of gas or nuclear energy or renewable energies. The higher the GDP per capita, the higher the challenge. The more people a country adds per year, the higher the challenge from a social, economic and also from a climate point of view, since the aim is to increase prosperity, which should be realised for all people. The availability of fossil fuels is seen as an opportunity and a challenge at the same time, because these countries will develop them as a matter of priority in order to build up prosperity. The challenge is therefore high. A low potential for solar energy, representative of renewable energies, is a challenge. If the potential for nature-based solutions per capita is high, this is helpful and the index value is therefore low. There is then also a potential for negative emissions that can be used profitably in a cap-and-trade system. Good governance is the linchpin of any concept, which is why the index value is high if good governance performs poorly.

For each of the six sizes, a system is used that awards points from 1 - 10 for each country. The higher the score, the higher the Challenge. Since the points for each country are added up, the minimum possible index value is 6 points and the maximum possible value is 60 points.

Finally, a key distinguishing feature of the three subgroups is the point in time at which they reach Net Zero. Subgroup 1 reaches Net Zero in 2050, subgroup 2 in 2060 and subgroup 3 in 2070.

Subgroup 1 includes, for example, Brazil, which has great potential in the field of bioenergy and nature-based solutions, among other things.

Subgroup 2 includes, for example, Iran, which is struggling with various territorial and political problems and will certainly resort to carbon capture technologies.

Subgroup 3 includes, for example, India, which is characterised by huge absolute population growth and still great poverty. In addition, India has the means to base its economic development to a large extent on fossil energy sources. At the same time, the availability of biocapacity per capita is low.

Further information on the data sources, the point system developed and the classification of the countries into the three subgroups can be found in the appendix.[48]

[48] Cf. appendix A.3.

5 Technical and natural elements of the reference solution

This chapter describes the technical and natural elements of the Reference Solution, which can be used to achieve Net Zero. In addition to a number of technical elements that directly affect the energy system, nature-based solution elements are also part of the basic mix, which can be applied in very different combinations depending on the local conditions. In this chapter, reference is often made to the 700-page basic documentation consisting of the two parts "Technical Toolbox" and "Greenhouse Gas Causing Sectors".[49]

5.1 Initial situation and characterisation of the required solution modules

After describing the global conditions in their economic, social, geographical and demographic dimensions, the focus now turns to technical questions. What can a climate-neutral energy system of the future look like for a world with around ten billion people living in freedom and prosperity? In the following, an alternative to a solution that relies on extensive decarbonisation is developed. It is justified why an "electricity-only" solution cannot work without extreme losses of prosperity. This is not admissible for a Reference Solution in the sense of the project. Next, the technical elements of the Reference Solution will be considered. Let us start with a status report of the global energy system and the resulting greenhouse gas emissions, i.e. the status quo.

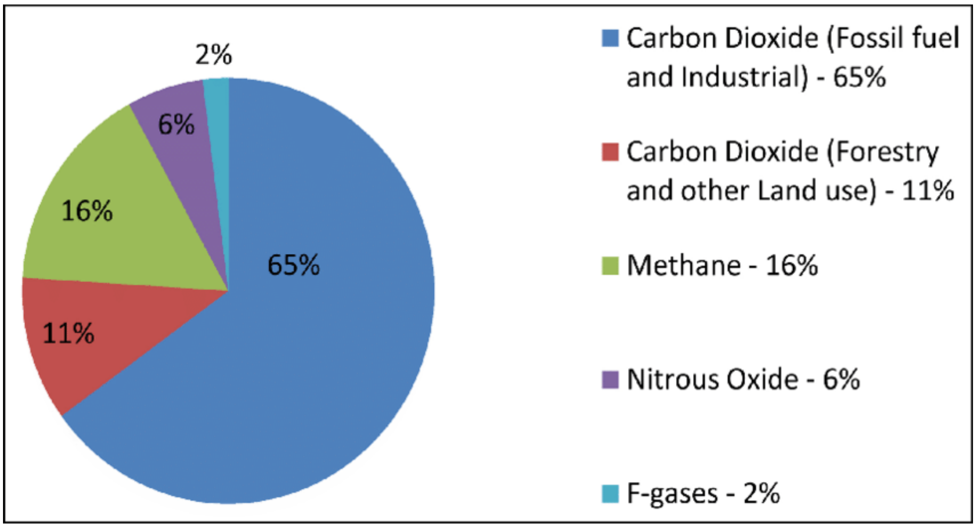

Figure 2: Shares of the most important greenhouse gases in global emissions

[49] An overview of the contents of the basic documentation can be found in Appendix B.

Source: IPCC Report (2014)

The shares of the most important climate gases worldwide (shown in CO_2 equivalents) are shown in Figure 2.[50] CO_2 is the most important, with a share of almost 65 % from fossil sources and industrial reaction processes. The significance of CO_2 is further increased by another 11 % from agriculture and forestry, so that in total around 76 % of the emissions are directly from CO_2 . Methane is in second place with a climate impact of 16 % CO_2 equivalents: Other important gases with a climate-damaging effect are nitrous oxide (N_2O) and fluorine-containing gases. The climate impact of hydrogen is discussed separately below.

As part of its work, GES has used the IEA's 2020 data to develop Figure 3 which provides an overview of global primary energy use and presents the key baseline data for energy flows for electricity production and for energy use in the transport, industry and non-energy sectors. [51]

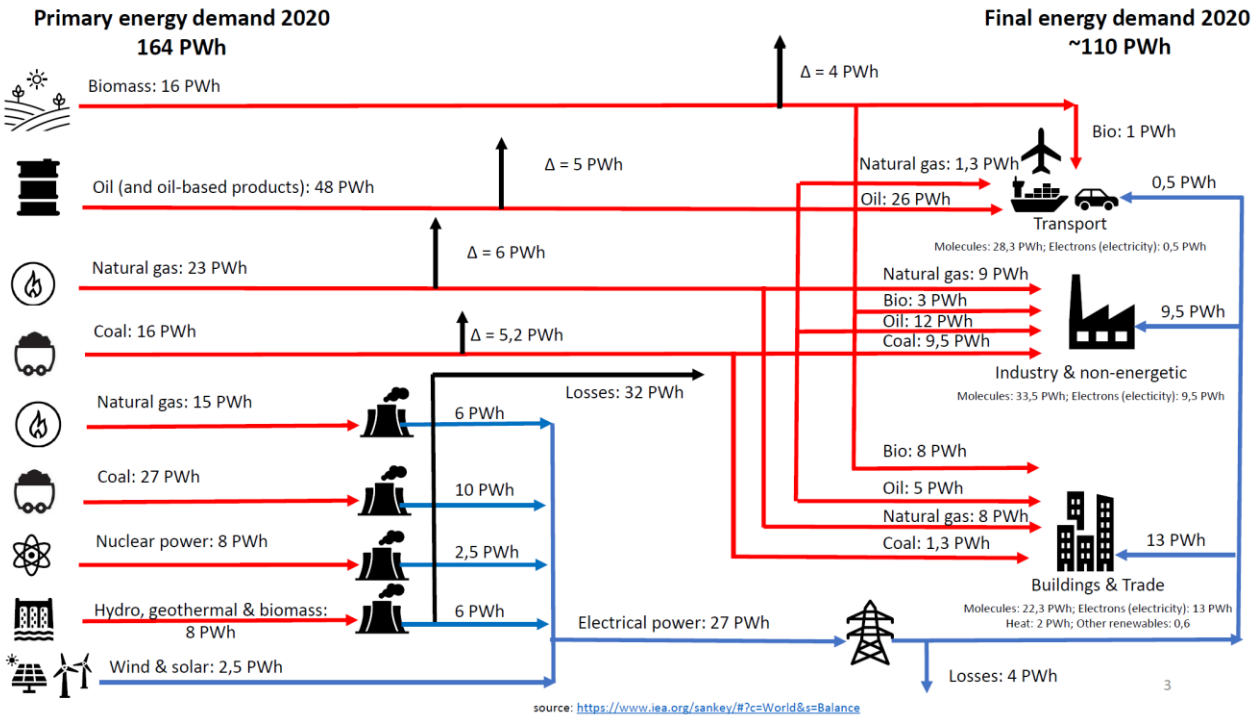

Figure 3: Sankey diagram for primary energy and final energy use 2020

Source: IEA and own representation

From this it can be seen that in 2020, 60.5 petawatt hours (PWh)[52] of primary energy were used to generate 27 PWh of electricity, 13 PWh (57 %) of which, after losses, was used in the buildings and commercial sector on the one hand, and 9.5 PWh (41 %) in the industrial (non-energy) sector on the

[50] Cf. IPCC Report (2014).
[51] Cf. IEA (2020a).
[52] 1 petawatt hour is equal to 1 trillion kilowatt hours or 1,000,000,000,000 watt hours.

other. Only 0.5 PWh (< 2 %) of the generated electricity was used in the mobility sector. In view of the objective to increase the direct use of electricity in the various sectors, the question of which electrification shares can actually be achieved in the individual consumers is particularly relevant. This will be addressed as part of the development of the Reference Solution.

These figures from the IEA show a direct share of fossil fuels in total primary energy use of 79 % in 2020.[53] In the transport sector, the share of oil in final energy use is 90 %, in the industry and other sector it is still 71 %. GES has used the IEA's figure documentation as basic data for the energy flow correlations for the plausibility check of the development of its reference model.

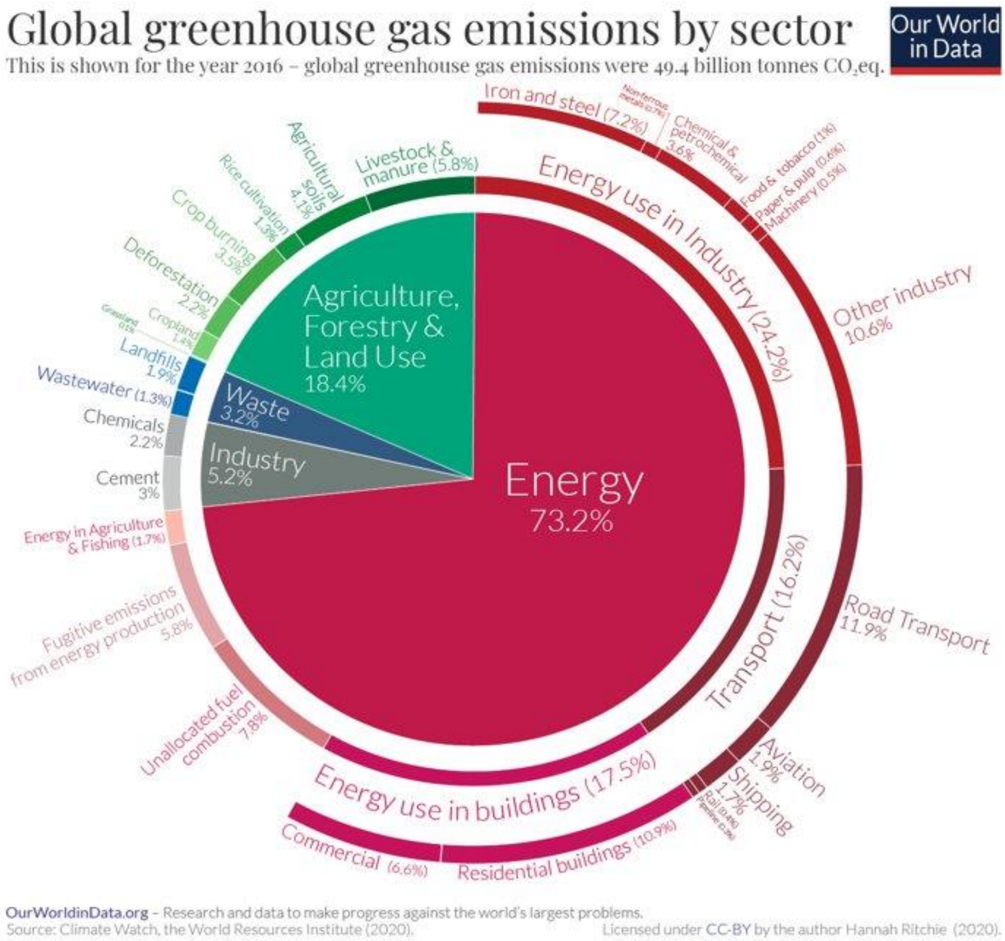

Figure 4 Sectors causing climate gases

Source: Our Word in Data (2022)

In addition to the emissions caused by energy use, figure 4 shows further CO_{2eq} emissions from different sectors. Industrially, these are the chemical industry and the cement sector. In waste treatment, landfills and sewage treatment plants are explicitly mentioned. In addition, agriculture and forestry as well as land use caused significant emissions.

[53] Cf. IEA (2020a).

In 2020, there were about 34 billion tonnes of CO_2 per year globally from 157 PWh of primary energy use in the energy-related sector that have an impact on the climate.[54] In addition, there are 7 billion from the cement, chemical, wastewater and landfill sectors. Approximately 80 % of primary energy use results from fossil energy sources, i.e. coal, gas and oil. In final energy consumption, 20 % is used in the form of electricity (electrons) and 80 % in the form of energy carriers (molecules).

Primary energy consumption will still increase significantly by 2050; in our projections, we expect consumption to reach 210 PWh in 2050. In this context, energy consumption will increase significantly, especially in developing and emerging countries with rapidly growing populations (see **Challenge Group**). From GES' point of view, this is where it will be decided whether the world can achieve the Net Zero emissions targets - and if so, when this will be the case.

In Chapter 4, it is derived that energy consumption to build the Challenge Group's aspirational wealth will increase to such an extent that CO_2 emissions would increase from 13 billion tonnes of CO_2 in 2025 to 33 billion tonnes of CO_2 in 2050 under the current energy mix if no effective action is taken. This is despite the assumption that half of the group's wealth increase from 20 trillion to 80 trillion US dollars will be made possible by higher energy efficiency and lifestyle adjustments/changes.

Ensuring climate neutrality in the area of developing and emerging countries is the focus of this text. Not surprisingly, most of the instruments of the GES Reference Solution therefore start at this point. The interaction of the five technical and nature-based elements (1) electricity system on "two pillars", (2) carbon capture, (3) climate-neutral fuels and energy sources, (4) avoidance of technical methane leakage and (5) nature-based solutions means a reduction/offset of CO_2 emissions in 2050 by about 50 billion tonnes CO_2, from a total of 39 billion tonnes of CO_2 worldwide in 2025 (the share that is absorbed by nature anyway, 14 billion tonnes of CO_2, is not considered in this analysis). The expanded OECD thereby reduces its emissions from 13 billion tonnes CO_2 per year to zero, the China Club reduces from 13 billion to 2 billion and the Challenge Group reduces its 13 billion from 2025 to 3 billion. In the meantime, during the ramp-up from 2025 - 2050, the Challenge Group would have added the above-mentioned additional 20 billion tonnes of CO_2 by 2050, which, however, are also eliminated through the aforementioned interaction of the elements of the Reference Solution. In total, 13 + 11 + 10 + 20 = 54 billion tonnes of CO_2 will be eliminated within the 25 years of the model. This is the order of magnitude of the global greenhouse gas emissions of 53 billion tonnes of CO_{2eq} assumed in 2025, of which 14 billion tonnes of CO_2 are absorbed by the existing natural systems, as described above.

Reference Solution means that the described path is possible. It is designed in such a way that, on the one hand, no impoverishment strategy is pursued and, on the other hand, no politically

[54] Cf. IEA (2020a).

unacceptable financial transfers are required. Economy and freedom are promoted, it is an (ecosocial) market economy approach along the view of successful economic systems (ecosocial/ **green and inclusive**) that dominates worldwide today.

What should be paid attention to? In a Reference Solution, one usually switches to the "more difficult" side. So we assume a relatively high growth in energy consumption for developing and emerging countries, especially for Africa. **These countries should all be able to develop fully industrially, if they so wish**.

We assume an energy system in which primary energy conversion to electricity is significantly expanded, with the goal of approx. 35 % of final energy consumption being used in the form of electricity in 2050. This requires a substantial expansion of the new renewables wind and solar, which in our projection must be expanded from 2.9 PWh of primary energy generation in 2020 to 46 PWh in 2050.

In line with the insight resulting from our analyses that a balanced power generation system should tend to consist of half new renewables and the other half reliably controllable energy sources, we assume such an energy mix. In this context, the expansion of natural gas-based power generation with carbon capture will have to play a special role, as the possibilities for using electricity-based hydrogen are limited both in terms of efficiency and the availability of electrolysers (see Chapter 5.3.3). In addition, coal (with carbon capture), nuclear energy, hydropower, geothermal energy and biomass will continue to be used to generate the required amount of energy as electricity.

For a Reference Solution, it is irrelevant whether the share of renewables (even in individual countries) can be raised to 70 % if a 50:50 ratio is already working. It should be noted that in this constellation the **hourly contribution** of the new renewables will fluctuate between 0 and 150 % of the hourly average. Still the capacities of the reliably controllable energy sources must move towards full expansion in order to ensure a sufficient supply of electricity at all times, even if only half or less of the available capacity is used on an annual average.

Our Reference Solution is therefore based on the fact that a **clever mix** of different forms of energy generation is important for the coming decades if the goal is a climate-compatible world in prosperity. **The mix must meet country-specific restrictions in each case** (cf. Chapter 9.1.1).

The following five points explain why a solution such as the one developed by GES is imperative.

1) Required growth

For a prosperous world, we calculate 6% GDP growth per year for the Challenge countries in the period 2025 - 2050, because wealth creation and implementation of the SDGs in 2050 - 2070 is explicitly part of the target of the Reference Solution. This leads from a GDP of about 20 trillion US dollars in 2025 to about 80 trillion in 2050. For the poorest countries (Least Developed Countries) we set 7% growth as postulated in SDG 8. The GDP for the Challenge Group in 2050 thus grows by an additional 1.5 billion US dollars. If we take into account the high growth of the population of the Challenge countries in the period 2025 - 2050, GDP growth per capita is reduced from about 6 to 5 %. By way of comparison: In China, growth has been above 10 % in almost every year over the past 30 years, and in some cases even significantly higher.

For the other country groups considered, the OECD projections were adopted. Details can be found in the appendix.

2) An "electricity-only" world is not possible

Our projection gives a primary energy demand in 2050 of 210 PWh, of which we expect about 50% to be used to produce electricity, compared to 27% in 2020. We see the final energy demand at 172 PWh. There are many reasons why, besides electricity (electrons), molecules will continue to play a central role, for example in the transport sector and in industry. Vaclav Smil, in his book "How the World Really Works", lists the four most important material components in terms of volume, without which our civilisation would not be possible.[55] All four need a lot of energy, especially those of the molecular type. They are cement (almost 4 billion tonnes annually), steel (almost 2 billion tonnes annually), plastics (about 850 million tonnes annually) and ammonia for fertiliser production (about 350 million tonnes annually).

If one wanted to realise the entire primary energy demand in 2050 with new renewables, the electricity input for energy consumers would have to be significantly increased again compared to these figures. Since numerous applications (e.g. aircraft) cannot realistically be supplied with energy on an electricity basis, there remains a high residual demand for energy that must be available chemically in the form of molecules. At most, we consider it achievable that two-thirds of the final energy demand is covered by electrons, compared to a demand of one-third as molecules.

This would mean that 114 PWh could be used directly by means of electrons, and 57 PWh would have to be produced on the basis of hydrogen molecules from electrolysis. With an efficiency of 75% from electricity to hydrogen and hydrogen derivative, the demand for new renewables to produce these 57 PWh of hydrogen is 67 PWh. Added to this is the effect that the volatility of the new renewables must be compensated for by additional energy storage requirements. We calculate a factor of 130 % here. Overall, in an energy system that relies two-thirds on electricity, primary energy

[55] Cf. Smil (2023).

production would have to amount to 224 PWh of new renewables compared to the expansion state described by GES for 2050.

In 2020, a total of 2.9 PWh of electricity was generated with a worldwide installed capacity of 733 gigawatts of wind power and 714 gigawatts of solar power, i.e. the average annual runtime over wind and solar was 1,979 hours with this installed capacity. This corresponds to a capacity factor of 23 % in relation to one year.[56] To generate the required 224 PWh of energy, the expansion would have to be increased by a factor of 77 if the mix remains unchanged compared to 2020, i.e. 6 times more than in the ambitious GES reference scenario. Even though there is considerable manufacturing capacity for photovoltaics in China, significant raw material bottlenecks would have to be expected, also because the raw material requirements of the wind turbines would be considerable.[57]

And already the conversion of 67 PWh of electricity into 50 PWh of hydrogen meets the expansion limit of electrolysis: the production of hydrogen from 67,000 TWh of electricity requires 10 terawatts (TW) of electrolyser capacity at an efficiency of the use of the electrolysers of just under 75 % (6,570 hours out of 8,760 hours per year). This does not yet cover the further electrolysis demand, which lies in the creation of chemical energy storage facilities that would have to compensate for the volatility of such a gigantic system of new renewables.

Even with a rapid ramp-up (which is hardly to be expected), however, at most **4 TW of electrolyser capacity** are possible by 2050. This is described in more detail in chapter 5.3.3. Therefore, a successful path into the future must continue to use molecules as primary energy carriers to a high extent - we expect two thirds instead of the current 80 %.

Chapters 2.1 - 2.3 of the basic documentation cover all aspects of renewable electricity generation, nuclear electricity generation and electricity storage. Chapter 2.4.3 deals with the production of hydrogen based on electrolysis and the challenges and limitations of upscaling.

3) The molecular world needs carbon capture

Global society needs energy in the form of electricity (electrons) and in the form of molecules (e.g. fuels and other energy sources). The second group of users includes industry (such as steel, cement, chemicals, etc.) and transport or mobility (fuels, etc.).

We calculate about one third of the primary and about one third of the final energy demand based on electrons. Approximately 67% of energy use remains in fossil form (over 80% today) and requires

[56] Cf. IEA (2020a).
[57] Cf. Radermacher, F. J., Dollinger, J. (05.02.2021): Energiewende 2050-2070 - Die PV-Modulseite, GES-Report.

carbon capture wherever possible. We believe that the amount of carbon capture required for this split is feasible over the next 25 years in a linear ramp-up.

4) Power generation must be based on "two pillars

It is in the nature of things that wind and solar plants are volatile. If the wind does not blow and the sun does not shine, there is no electricity. But industrial societies in particular depend on reliable energy supply. Inevitably, new renewables require the constant provision of a reliable and controllable back-up. So that the continuous supply of electricity is guaranteed to an accepted extent.

The **provision costs are to be borne throughout the year**. However, the amount of energy sources required and of CO_2 to be stored depends directly on the period of use. In addition to the process of capturing CO_2, this also applies in particular to the transport and landfilling or injection of the CO_2. The less fossil fuels are used, the lower the variable costs. What remains in any case are the supply costs, the costs for the personnel kept on hand, etc., which is unavoidable. This is because the provisioning is crucial when renewables cannot supply (enough) or the scale-up is limited. The reliably controllable back-up system (e.g. fossil with carbon capture or nuclear energy) must then step in at short notice if necessary on the basis of stored energy.

These system-inherent dynamics require either the allowance of high price peaks to absorb the costs of load fluctuations or the establishment of capacity markets in which the provision of capacity is remunerated.

5) Hydrogen is expensive

Hydrogen - as a gas for power plants to manage volatility - is significantly more expensive and more difficult to handle than natural gas in numerous dimensions (including carbon capture).[58] In addition, the re-conversion of electrolysis hydrogen ends at an efficiency of about 25 %. This is described in chapter 5.3.4.

So one would only use it for this purpose if (1) there is either not enough natural gas or (2) carbon capture does not work or (3) it would be prohibitively expensive. In this context, 100 US dollars per tonne of CO_2 for capture, transport and storage is acceptable.

Cost-relevant fields for hydrogen compared to natural gas:

1) Supply
2) Safe handling
3) Transport

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[58] Cf. Hydrogen Council/McKinsey & Company (2021).

4) Storage
5) Storage capacity
6) Combustion behaviour

5.2 The elements of the Reference Solution at a glance

If global demand for energy increases significantly once again in the future and if, at the same time, an "electricity-only" world is not possible, what technical paths remain to develop a climate-neutral energy system for the world? In developing its reference model, GES named five elements, whose interplay we outline in this chapter. However, the basic elements will not be able to unfold their effect without a political framework. This is shown in the following figure: Only under the condition of sufficient governance structures and the corresponding funding will the other cogs "get going". Before we turn to governance and financing (see chapter 6), we will first look at the technical and natural elements of the solution.

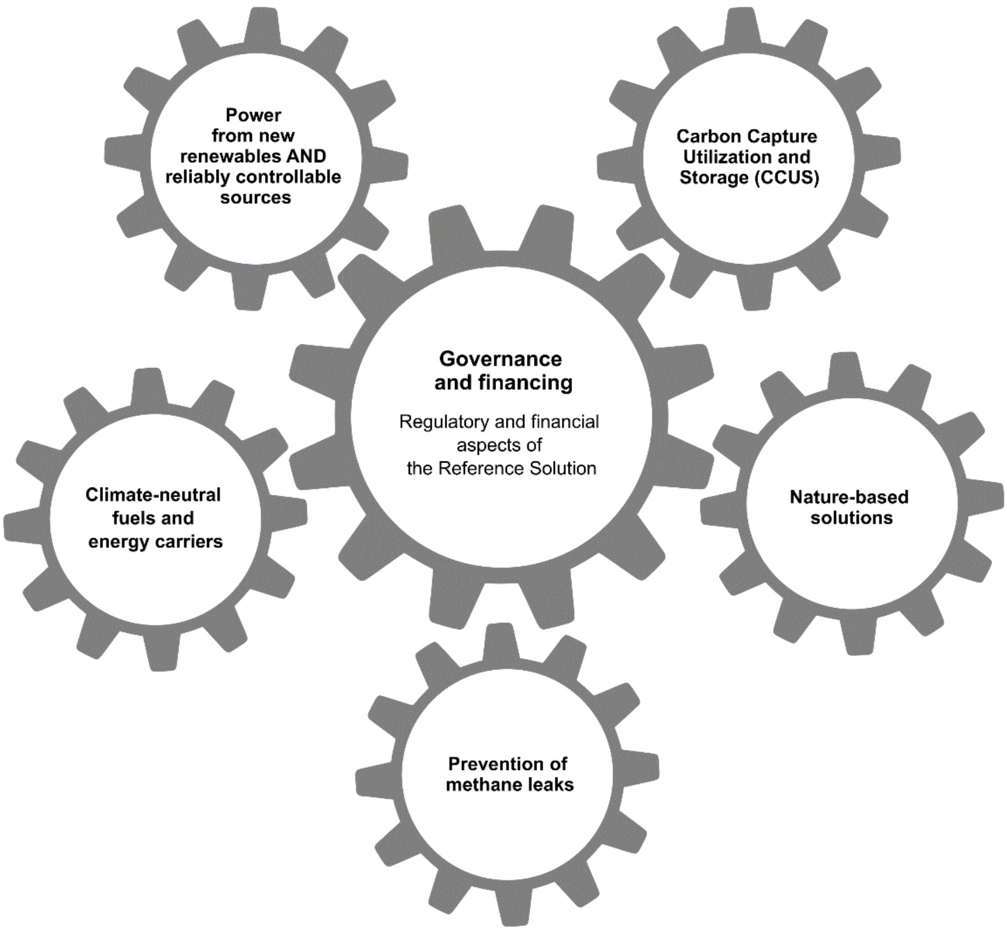

Figure 5 The elements of the Reference Solution

Source: Own representation

1. Electricity from new renewables combined with reliably controllable generation

Renewable energies must be expanded worldwide. This also applies to solutions for many areas of use, e.g. heat, industrial production, mobility etc. The GES proposal is within the scope of today's political discussion in this area, although the proposal does **not focus on full expansion**. This already fails due to the impossibility of supplying the global primary energy demand via new renewables alone (for this, the new renewables would have to be expanded by at least a factor of 6 higher than the most ambitious expansion targets for 2050). Under the hypothetical assumption that primary energy could be generated from new renewables alone, the corresponding available primary energy would drop to about 25 % in the period mentioned. This does not appear to be a viable solution that avoids massive impoverishment. In perspective, the corresponding installations should always be able to cover the entire electricity demand with other, classic renewables alone - or at a high proportion - whenever the sun and wind provide sufficient tappable energy.

However, it must be taken into account that a society must also secure its power supply at times when there is no wind or not enough solar energy available. These periods easily cover several days, occasionally even several weeks.[59]

In 2020, the majority of globally used electricity - about 80 % according to the IEA - was generated on the basis of fossil energy sources.[60,61] Against this background, the GES Reference Solution is based on "two pillars". In addition to **volatile renewables**, which generate no or hardly any CO_2 emissions, the second pillar comprises energy sources that can cover the entire energy demand at any time on their own. Classic fossil energy sources with carbon capture, nuclear energy, hydropower, geothermal energy and biomass are essential elements for the second component. This must be able to be regulated up and down at short notice to any level between 0 - 100 % of the electricity demand.

Hence the term **reliably controllable**. The LDES Council, a non-profit organisation with 60 member companies from 19 countries, shows in an introductory report that storage costs increase disproportionately when renewables account for more than 50 % of electricity generation.[62] Against this background, it appears to be the economic optimum to plan with two energy sources, even in perspective: the new renewables with a significantly increased share and reliably controllable ones to the extent that a society deems necessary for the continuous security of its electricity supply and at acceptable costs.

[59] Own modelling GES (2023).
[60] Cf. IEA (2020a).
[61] Cf. Science Media Center (2021).
[62] Cf. LDES Council, McKinsey & Company (2021).

See chapter 2.1 of the basic documentation for all aspects of generating electricity from renewable sources.

2. Carbon Capture

Carbon capture in fossil fuels, in steel and cement and in chemicals is, in GES' view, probably the **most important wild card** in the next decades to tackle the global energy and climate problems with a freedom and prosperity perspective, much more important than e.g. green hydrogen.[63,64]

CO_2 is captured, used or alternatively injected into old oil and gas fields or numerous caverns, partly under the sea, or permanently bound by mineralisation through injection into silicate rocks.[65,66] At the same time, this will establish or promote a **CO_2 cycle economy**, which countries like the USA and Norway are already promoting with large-scale programmes.

Chapter 2.8 of the basic documentation deals with all aspects of technical capture and storage of CO_2, chapter 2.9 with the utilisation options of CO_2 in terms of usage.

3. Climate-neutral fuels and energy sources

Fuels are of central importance for ensuring **mobility**. This in turn, especially as **individual mobility**, is a backbone for **freedom and prosperity.**

HVO, methanol, methanol petrol, methanol diesel, synthetic methane and possibly also ammonia belong to the category of synthetic fuels. They are based on hydrogen and CO_2, alternatively biomass, e.g. from short-rotation plantations or waste from agriculture and forestry for so-called 2nd generation biofuel processes,[67] i.e. not in competition with the food chain.

Chapter 2.6 of the basic documentation deals with the production and use of hydrogen derivatives and Chapter 2.7 with the production of climate-neutral fuels.

4. Elimination of technical methane leaks

Methane emissions arise from both natural and - to a greater extent - anthropogenic sources.

[63] Cf. McKinsey (2020).
[64] Cf. Skea (2022).
[65] Cf. Mahnke (2015).
[66] Cf. Massey (2021).
[67] Cf. Nagler & Gerace (2020).

Controlling and reducing anthropogenic methane emissions has a high leverage effect with regard to limiting global warming.

The target agreed in the Paris Climate Agreement to limit global warming due to climate change to 1.5°C compared to pre-industrial times is only achievable if current annual methane emissions are reduced by at least 45% by 2030.[4] Over 100 countries signed the Global Methane Pledge at COP26, committing to reduce their methane emissions by at least 30% from 2020 levels within ten years.

The initiators of the Global Methane Pledge speak of a possible reduction in global warming of at least 0.2 - 0.3°C by 2050 if the agreement regarding methane is adhered to globally.[2]

Chapters 2.12.1 to 2.12.3 of the baseline documentation address the status quo and options for reducing methane emissions as well as controlling LNG pre-chain emissions and residual gas flaring.

5. Nature-based solutions

In the sum of the effects, nature-based solutions provide a further lever for solving the problems in the climate sector. This aspect is still mostly overlooked in the political debate. The nature-based solutions discussed in Chapter 5.6 include **consistent rainforest protection**[68] in the southern hemisphere, reforestation on 1 billion hectares of degraded soils in the tropics (ramp-up over 25 years), restoration of mangrove forests, humus formation as part of soil improvement programmes on also 1 billion hectares of depleted agricultural soils, including the use of biochar (ramp-up over 25 - 40 years).[69] New ways are needed here, which are presented in this text.

Chapter 2.10 of the basic documentation deals with nature-based solutions, Chapter 2.11 with the oceans as a sink for anthropogenic CO_2 .

5.3 Electricity from new renewables and reliably controllable sources

An important element of an efficient energy system is the electricity side and thus the dimension of **electrons**. The power supply should rest on two pillars - the pillar of new renewables on the one hand and the pillar of reliably controllable sources on the other. This is justified in this subchapter.

[68] Cf. Mills et al. (2023).
[69] Cf. Griscom et al. (2017).

5.3.1 Potentials and limits of the new renewables

The new renewables have introduced important new elements into the world of energy supply, especially photovoltaics with enormous volume potential. In fact, it is possible to supply the whole world with energy just by using a part of the Sahara.[70] That was the idea behind "**Desertec**".[71] The difficulties, however, lie in the transport of the electricity generated in this way and in volatility, i.e. the question of when the electricity is available. Nevertheless, it could be advantageous to distribute this electricity in Africa over the entire continent, for example. Another idea is to export it to Europe, for example. At the moment, for example, a project is being prepared to bring electricity from Morocco to England with a line. **High-voltage direct current transmission lines (HVDC)** are a good option here, as they cause only low transport losses.

As an alternative to the distribution of renewable electricity, **local grids** made of photovoltaic panels can be a great step forward for people who have so far been without access to electricity, also to achieve the goal that all people have access to electricity - SDG 7 "Affordable and clean energy". **Access to electricity as a human right**: For this goal, a local grid is much more than nothing. **Muhammad Yunus**, the Nobel Peace Prize winner, has been pursuing this issue very successfully in Bangladesh for decades, financed through **microcredits**. The German government is involved in this area as part of its development policy. But none of this is, of course, a basis for further industrialisation, where one wants/needs to have guaranteed electricity available 24 hours a day.

Alongside photovoltaics comes wind - both onshore and offshore. The installation of these wind turbines is accompanied by a high consumption of resources such as steel and concrete. In our latitudes, however, wind farms (capacity factor 25 - 30 %, at some locations up to 40 %) supply electricity that is 2 times greater than photovoltaics (capacity factor approx. 16 %).[72] In addition, the use of wind makes it possible, at least in part, to compensate for the energy fluctuations of photovoltaics.

The challenge of the new renewables is **volatility**. The energy is there when the sun shines, when it doesn't, there is no energy. The situation with wind is the same.

Incidentally, it is also not the case that this energy can be had for free, since the sun supposedly "does not send any bills". The problem is, for example, the "collection" of the "solar radiation" as well as the reliable and demand-oriented provision of the electricity afterwards, which is laborious and time-consuming and of course associated with costs.[73, 74]

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70 Cf. Radermacher, F. J., Dollinger, J.: Energiewende 2050-2070 - Die PV-Modulseite, GES-Report 05.02.2021

71 Cf. Knies, G.: TREC (Trans-Mediterranean Renewable Energy Cooperation) - The clean power from the deserts. The clean power from the deserts; see www.trec-eumena.net

72 Cf. Our World in Data (2022).

73 Cf. Global Solar Atlas (2018).

74 Cf. Wind Energy: The Facts (2022).

The expansion of the new renewables is associated with further challenges, as the controllability in the electricity grid must be increased due to volatility. This creates additional economic burdens that are not present in a conventional system.

The reliably controllable power plants are usually no longer operated in base load mode, but as flexible back-ups. This puts a strain on their economic viability, as the utilisation decreases and there is no incentive for investments. Due to the fluctuations of renewable energies, there is also a need to create additional storage capacities, for example by setting up battery parks of lithium-ion batteries. These can both compensate for load variations to a limited extent and take on additional grid stabilisation tasks (provision of reactive current and ensuring frequency stability), which in historically grown electricity grids are taken on by the flywheels of conventional power plants. In order to increase flexibility, the use of the storage potential of car batteries is also increasingly conceivable in the future, although this is associated with considerable control effort. The new renewables cannot take over the function of stabilising the electricity grid and additional expenses will arise.

In order to overcome longer dark periods, power-to-X plants are also being planned as an alternative as reliably controllable electricity storage systems, in which peak electricity is to be converted into hydrogen, stored and converted back into electricity. This concept is associated with high losses, as only 25 - 30 % of the electricity generated from renewables is available again when it is needed.[75] In addition, the hydrogen must be transported, stored and converted back into electricity in a reliably controllable power plant. It is obvious that this path to reliably controllable electricity is associated with serious costs, since the necessary electrolysers are expensive and require a high, uniform utilisation to improve their economic efficiency. It is of little use that the peak electricity can be available practically free of charge, because its provision and use are extremely costly.

In addition, the expansion of new renewables increases the requirements for the expansion of the electricity grids depending on how close the additional capacities can be built to the centres of consumption. The expansion of the transmission grids, which is necessary in many cases, is both time-consuming and investment-intensive. Demand side management in the sense of switching consumers on and off depending on the generation profile of the new renewables is also necessary: industrial processes may have to be shut down, and back-up power plants may have to be switched on. It goes without saying that all these requirements for an electricity system become more important the larger the share of new renewables in the system. Decisions have to be made about the costs at which the classic reliably controllable fossil energy sources can be made available with carbon capture, relative to the costs of a system consisting of new renewables. The market mechanism, the so-called electricity market design, also plays an important role.

[75] Cf. Prognos (2020).

A high share of volatile producers also requires a much more flexible pricing system, as demand and supply peaks diverge further than in a system with flexible demand and relatively more constant supply, as offered by reliably controllable energy sources. Therefore, there is growing pressure to choose between two extremes: Either high price peaks have to be accepted or capacity markets have to be created that allow for the minimum economic viability of reliably controllable energy.

In sum, the complexity of regulating the electricity grid increases significantly with the increase in the share of new renewables and thus increasing volatility.[76] This higher intensity of regulation also poses a particular challenge for the electricity market design in the countries of the Challenge Group.

The chapter of the basic documentation 2.1 deals with the renewable generation of electricity, 2.14.3 with the inventory and perspectives of the electricity infrastructure.

5.3.2 Potential and limits of electricity storage

With an increase in the share of new renewables, electricity storage is increasingly becoming the focus of discussions in the context of the energy transition. The increasing volatile generation of electricity in wind and solar plants must be supplemented to an increasing extent by electricity storage facilities or demand flexibility must be created. The importance of electricity storage is therefore great, but its possibilities are often overestimated in the public discussion.

There are only a few alternative solution systems for storing electricity: battery systems, which will be examined in more detail below, classic pumped storage power plants based on water and compressed air storage systems, and possibly also gravity storage systems. The only solution available for storing large amounts of electricity for a long time is chemical storage based on hydrogen generated by water electrolysis (power-to-X).

Measured against a country's demand batteries can store relatively small amounts of energy for periods of hours,.[77] Water or compressed air storage systems store larger amounts of energy for days, and chemical storage systems store large amounts of energy for any length of time.

Water and compressed air storage offer the lowest storage costs with efficiencies in the order of 70 - 80 %. Battery storage is comparatively more expensive with efficiencies of 60 - 70 %, but can contribute to frequency stabilisation of the grid and the provision of reactive power.[78] Chemical storage systems such as hydrogen have by far the lowest efficiency, only 30 - 40 %.[79] However, they

[76] Cf. IEA (2021c).
[77] Cf. Lazard (2021).
[78] Lazard (2021).
[79] Cf. Prognos (2020).

are the only solution to cover the demand for energy during dark periods, which can last several days or weeks.

A simple calculation shows the **limited potential** of today's battery power storage systems:

Today, the German electricity grid has to provide an average power of approx. 65 gigawatts (GW). This power for one day results in an amount of electricity of 65 GW x 24 h = 1,560 gigawatt hours (GWh). Germany therefore consumes an average of 1,560 GWh of electricity in one day.

The largest battery power storage system built to date is the Vistra Moss Landing Battery in California, with a storage capacity of 1.6 GWh - about one thousandth of the energy needed to supply Germany with electricity for one day during a dark period.[80]

In order to compensate for **dark lulls** or even the **seasonal fluctuations** in electricity generation from renewable energy sources with battery storage, a storage capacity would be required that is far above what is economically feasible with battery storage.

This analysis is based on today's average power grid capacity of 65 GW. With the electrification of many new areas such as traffic and transport, heating with heat pumps, digitalisation and the electrification of entire industrial sectors, the required electricity capacity in Germany will increase considerably and with it the need to store energy to compensate for fluctuations.

The purpose of existing and future battery power storage systems is not to bridge dark periods and seasonal fluctuations in energy production, but to stabilise the power grid in the short term.[81]

The electricity storage systems must first take over the task of frequency stabilisation. Our grid is operated at a frequency of 50 hertz - mainly by the rotating masses of the generators, they turn 3,000 times a minute. If the frequencies in the power grid are too high or too low, the connected devices, such as electric motors or computers, will not function properly. If more and more electricity comes from renewable sources, the generators lose their stabilising function - and an alternative is needed.

Battery storage systems are therefore necessary and also suitable for stabilising electricity grids with a high proportion of wind and solar power because, on the one hand, they can react very quickly and, on the other hand, the storage sizes required for short-term peaks can be realised.

For regions that have significantly higher solar irradiation than Germany, there is another option for using battery storage apart from stabilising the electricity grid. In regions such as North Africa or California, attempts are being made to secure the power supply for the night when PV does not deliver any electricity.

[80] Cf. Vistra (2022).
[81] Cf. Lazard (2021).

Combined systems of solar plants and batteries with four to eight hours of short-term storage are already being planned today.

By far the largest planned battery storage facility in the world is to be built in Morocco at the end of this decade. It is the Morocco-UK Power project with a 10.5 GW wind and PV plant combined with a battery storage capacity of 20 GWh for four-hour short-term storage. The aim is to ensure that electricity can be supplied for at least 20 hours a day.

For this short-term battery storage alone, investment costs of at least 10 billion euros must be assumed, whereby these costs are based on a further cost degression of battery storage of 50 % compared to copper cell battery storage, although it is very questionable whether there will be any further cost degression at all in the next few years. The **raw material prices for battery technology** are currently rising significantly due to the lack of mines.

It is also completely open whether batteries for short-term storage will be a solution in the future. Battery storage such as the Morocco-UK Power Storage with an investment of at least 10 billion euros is beyond economic imagination.

Battery storage is not suitable for large amounts of energy and even more so for long-term storage because the effort required to scale battery storage is extremely high. This is because the storage reservoir for the electricity or electrons is the battery cell itself, a complex and material-intensive component that is relatively expensive and limited in terms of lifetime. Scaling up the storage reservoirs means scaling up the expensive and material-intensive battery cells.

Alternative storage facilities usually have much more easily scalable storage reservoirs, such as the large upper and lower water basins in pumped storage, large salt tanks in thermal storage, large concrete blocks in gravity storage or, as in hydrogen storage or gas storage, large gas tanks or underground caverns.[82]

Battery storage is suitable and also necessary for stabilising electricity grids with a high proportion of wind and solar power. For short-term storage (storage capacity of four to eight hours), battery storage is unsuitable or uneconomical due to the high scaling costs. Cheaper alternative storage systems still need to be developed or industrialised for this purpose. For long-term storage (storage capacity greater than eight hours), batteries do not offer a solution from today's perspective.

This means that for long-term storage to bridge dark periods and seasonal fluctuations in the electricity grid with a high proportion of wind and solar power, the only options are the high-loss method of storage using hydrogen or the solution with backup power plants that are kept on standby to be

[82] Cf. Mongird (2020).

able to step in. However, this double structure results in double fixed costs, on the one hand for wind and solar plants, and on the other hand for the backup power plants.

Substitute power plants can be either conventional CO_2-free power plants (hydropower, biomass energy) or gas-fired power plants that can be operated with climate-neutral fuels such as hydrogen or natural gas in combination with CCS and, depending on a country's decision, also nuclear energy.

All this together makes a power grid with a high share of wind and solar power very expensive and significantly worsens the favourable power generation costs for wind and solar plants.

Chapter 2.3 of the basic documentation covers all aspects of electricity storage.

5.3.3 The limits of green hydrogen and the alternatives

A universal element of any forecast for future energy supply is **hydrogen**, which can be burnt without emissions. Hydrogen (H_2) is the lightest element in the periodic table. It has a high calorific value. Per kilogram, for example, hydrogen delivers more than twice as much energy as methane (gravimetric energy density). However, because it is so light, the energy yield per cubic metre at normal pressure is very low (volumetric energy density).

Up to now, hydrogen has been produced predominantly from natural gas. This is broken down into hydrogen and CO_2 by heat (**steam reforming**). In the process, a lot of CO_2 escapes into the atmosphere, around 10 tonnes per tonne of hydrogen produced. According to the usual "colour theory", this is grey hydrogen. Of course, this hydrogen cannot be physically distinguished from other hydrogen - just as little as green electricity cannot be distinguished from other electricity. Differences therefore exist (only) in the production process, not in the "hydrogen" itself.

Green hydrogen is produced by **water electrolysis.** Put simply, it is a process in which electrical energy is converted into chemical energy. Only electricity from regenerative sources - and, depending on the view of the subject, also electricity from nuclear energy - is to be used in the process. This makes green hydrogen almost CO_2 -free. A cost-effective and established technology is alkaline electrolysis. However, its efficiency is lower than that of other processes (PEM and high-temperature electrolysis).

What role can so-called green hydrogen based on water electrolysis play in the future up to 2050? This is a key question for a global solution to the climate and energy problems. Because an obvious limit at this point makes a path to Net Zero based solely on renewable energies and electrolysis hydrogen derived from them impossible. We ask: What development of green hydrogen seems possible and what role can green hydrogen play as a secondary energy carrier in the future?

This issue is crucial, as the ability to store large amounts of energy will determine whether powerful, stable and CO_2 -free electricity systems are possible in the coming decades without fossil fuels (and CO_2 capture) or nuclear energy.

In the baseline situation in 2023, water electrolysis plants with a capacity of significantly less than 1 GW are operated worldwide and only significantly less than 1 per mille of the hydrogen produced worldwide is generated with this technology.[83, 84] In February 2023, Sinopec published the commissioning of what is currently the world's largest single plant with an electrolysis capacity of approximately 250 megawatts (MW), for which 270 MW of solar PV and 450 MW of wind capacity were installed at an investment of US$ 828 million. The plant is expected to produce 30,000 tonnes of green hydrogen annually.

Currently, the production capacity available worldwide for the manufacture of new electrolysis plants is in the order of 5 - 8 GW of electrolysis capacity per year.[85] Various countries have announced targets for the development of hydrogen electrolysis capacity: the EU expects 20 GW of installed capacity by 2030, including 10 GW in Germany. The UK has also announced a target of 10 GW of capacity installed by 2030.

As of November 2021, the largest share of global electrolysis projects in the megawatt range has been announced in Europe (261 projects), followed by Asia and especially China (121 projects, half of which are in China), North America (67 projects), Oceania (43 projects), Latin America (10 projects) and the Middle East and Africa (20 projects) - all of which add up to an expansion corridor in the order of **93 GW** of installed **electrolysis capacity by 2030**.[86] The **Inflation Reduction Act** in the USA, with its diverse, uncomplicated funding options (e.g. also for **blue hydrogen**), will probably shift the momentum in this topic to North America.

The IEA predicts that of these announcements, projects with a total capacity of 65 GW will actually be installed by 2030.[87] With a theoretical utilisation factor of 70 %, this capacity would result in a production of about 8 million tonnes of hydrogen per year, i.e. about 10 % of today's demand for hydrogen that is not used to compensate for the volatility of an electricity system based on renewable energies.

In a global perspective, the Fraunhofer Institute has investigated the potential for the production of electrolysis hydrogen. In the PTX Atlas, the institute calculates a **possible production volume** of **109 PWh** outside Europe.[88] If questions of investment security and infrastructure are taken into

[83] Cf. Aurora Energy Research (2021).
[84] Cf. IEA (2021d).
[85] Cf. Hydrogen Council/McKinsey & Company (2021).
[86] Cf. Hydrogen Council/McKinsey & Company (2021).
[87] Cf. IEA (2021e).
[88] Cf. Fraunhofer (2023).

account, the production potential is reduced to about 69 PWh of hydrogen. By comparison, global crude oil and natural gas production is currently equivalent to about 100 PWh. These figures cast doubt on whether hydrogen will ever be able to completely replace fossil fuels. Especially since the global demand for energy continues to rise, as also shown in this report. But even more serious is the following: We see - as do other observers - a maximum expansion potential for electrolysers of 4,000 GW by 2050.[89] This limits the potential of electrolysis hydrogen to about 24.5 PWh by 2050, assuming a 75 % utilisation of the electrolysers. It can be assumed that such a high utilisation rate will probably not be achievable.

What challenges must now be overcome to increase the contribution from green hydrogen and achieve these projections?

The industrial production technologies still have to be partially developed and the hitherto very limited production capacities significantly increased. Then, in a concrete project, renewable electricity must be made available cheaply and electrolysis operation must be made as uninterrupted as possible to reduce the costs per tonne of hydrogen. In this context, politicians, especially in Europe, demand **additionality** and **simultaneity.** This means that a plant for the generation of renewable electricity must be built additionally - in a sense exclusively - for the operation of the electrolysis plant, and the electricity generated there must also be used within a fixed time window (initially one month, later one hour). This is to avoid a "cannibalisation" of the limited capacities for the generation of renewable electricity. However, this significantly complicates the realisation of projects for the production of green hydrogen, since the total investment expenditure is significantly increased by these conditions and also no general grid electricity can be used to secure the utilisation of the electrolysis.

One can also characterise the **challenge for upscaling** as follows: The price for producing grey hydrogen is in the order of 1.5 euros per kilogramme; if the carbon capture consistently demanded by GES is applied, this increases to the order of 3 euros per kilogramme in the case of retrofitting CCS in existing plants (own calculations). By contrast, the costs of new natural gas plants in which CO_2 capture of over 90 % is taken into account from the outset in the process design are even in the order of magnitude of existing grey hydrogen plants.

So what is the situation for green hydrogen based on electrolysis? In addition to the pure investment costs (capex), capacity utilisation as well as electricity and water costs are of decisive importance. McKinsey and the Hydrogen Council calculate electricity costs of 0.5 US dollars per kilowatt hour (kWh) and water costs of 1 US dollar per cubic metre as well as investment costs of 200 US dollars per kilowatt for 2030. They also assume a 50 % utilisation of the electrolysers: In this case, production costs of 3.4 - 5.4 US dollars per kilogram result, i.e. significantly higher costs than are achievable

[89] Hydrogen Council/McKinsey & Company (2021).

with modern natural gas-based technology. Even a significant increase in capacity utilisation and a halving of investment costs would not allow the potential market prices of blue hydrogen to be achieved: The decisive factor here is the electricity purchase costs. According to GES calculations, in order to reach the production costs of fossil low-carbon hydrogen (GES uses the term **low CO_2 hydrogen** for all variants of H_2 that cause few CO_2 emissions), investment costs of 200 euros per kilowatt, a utilisation rate of approx. 75 % and electricity procurement costs of 2 cents per kWh are required.

For a project to produce green hydrogen, there is also the challenge of ensuring a cheap supply of water, since according to the current state of innovation, water of drinking water quality is needed for electrolysis. The production of one kilogramme of hydrogen theoretically requires 9 litres of water; in practice, the water consumption is about 5 - 10 % higher. In the case of electrolysis projects in water-scarce regions, where the water required is compulsorily obtained from desalination plants, the production costs for the hydrogen may increase, but there may also be local difficulties if the additional desalination capacity is actually needed for the local water supply.

Regardless of these issues, installed capacities for the production of green hydrogen are projected to be around 3,000 GW by 2050.[90] Extrapolating the manufacturing capacities projected by the Hydrogen Council of 65 GW for 2030, we arrive at a corresponding figure of 190 GW of manufacturing capacity per year. Depending on assumptions about the lifetime and reuse of parts of used electrolysers, this results in forecast values of 3,000 - 4,000 GW of installed capacities. With an optimistic utilisation rate of 70% for the electrolysers, which are to be operated on the basis of only volatile renewable energy, it should be possible to produce 430 million tonnes of green hydrogen, i.e. the vast majority of the hydrogen demand forecast in three studies (see Chapter 7.3). Depending on the author, this would then have a share of 12 to 21 % of the projected final energy demand.

In addition, a dilemma must be solved: In a country with a high proportion of solar and/or wind energy, hydrogen could be produced in a renewable way at low cost (< 2 euros per kilogram H_2), because the required electricity can be purchased very cheaply from PV or wind plants there, and the investment costs can be supported by subsidies at the same time.[96] However, if the import destinations are associated with long transport routes and thus high costs, this can **ultimately** make the **production of hydrogen uneconomical.** Since hydrogen is very volatile, transport over long distances is a problem. For these reasons, hydrogen is typically transported over long distances in the form of ammonia or methanol, so-called hydrogen derivatives.[91] Established logistics structures exist for both basic materials. When used as a derivative, conversion losses must be taken into account, which occur again if the hydrogen cannot or is not to be used directly in its derivative form.

[90] Hydrogen Council/McKinsey & Company (2021).
[91] Cf. IRENA (2022b).

Alternatively, there remains the possibility of local consumption: Cost-effective green hydrogen is not transported to industrial consumer countries via expensive logistics, but local consumption structures are established, e.g. via hydrogen burners in the transport sector.

All in all, the development of green hydrogen projects is very complex: the entire value chain - from the generation of the renewable energy, the construction and supply of the electrolysers, to the transport of the product and the organisation of the sale of the hydrogen or its derivative in a project for financing - must be brought together. At this point in time (April 2023), the success of these efforts is not assured, even within the framework of government-funded concepts such as H2Global.[92]

Challenges also remain in the handling of hydrogen: H_2 has a low energy density, is highly volatile, easily flammable, leads to embrittlement of steel and supports the formation of nitrogen oxides during combustion. In pure form, its **properties as an indirect climate gas** with an approx. **elevenfold effectiveness** compared to CO_2 must also be taken into account: The uncontrolled escape of hydrogen must be prevented.[93,94]

Part of the predicted electrolysis capacity will also serve to utilise peak electricity from primarily solar but also wind plants: The hydrogen will be produced with peak electricity, stored and converted back into electricity in a gas-fired power plant when needed, e.g. during a dark lull. In addition to the extremely low efficiency of this process chain, in which only about a quarter of the amount of electricity originally used becomes available again as electricity, this route is also extremely expensive in view of the likewise low utilisation times of the electrolysers: running times of the electrolysers of only about 25 % of the season lead to an increase in the production costs of the hydrogen, which can easily be between 30 - 50 % above those in areas of high utilisation. This means that only if the capex costs of the electrolysers fall sharply will hydrogen be able to play a role as a long-term storage medium for excess capacities of green electricity at economically justifiable costs. In many cases, using natural gas with carbon capture will be much cheaper than building a loss-intensive and underutilised hydrogen storage solution, where it will not be easy to achieve costs of less than 50 euros per MWh of electricity when the hydrogen is converted back into electricity. In addition, there is the following: Electrolysis hydrogen has high upfront costs, especially for grid expansion. These costs are prohibitively high for countries in the Global South. Therefore, despite the low cost of renewable electricity, the momentum in the electrolysis-hydrogen sector in the Global South may be much lower than many would hope or expect.

In summary, several points follow from this initial situation and the boundary conditions. First, given the significant scaling challenges, green hydrogen will have a hard time meeting the expectations

[92] Cf. H2 Global (2023).
[93] Cf. Ocko (2022).
[94] Cf. Warwick (2022).

set by the IEA and others. Even if these expectations were met, green hydrogen as a secondary energy carrier would only be able to make an optimistically estimated maximum contribution of 15% to the final energy demand expected in 2050. This is an important contribution, but much less than what is sometimes communicated or hoped for in the media and in politics. Other ways are therefore needed to deal with the great hunger for energy that is inevitably associated with further development if poverty is to be overcome.

So if the potential of green hydrogen is limited, what alternatives are there?

Blue hydrogen, like grey hydrogen, is produced from natural gas, but the CO_2 produced is captured and stored (CCS). An alternative is the gasification of biomass (orange hydrogen) or waste materials. Turquoise hydrogen is produced by thermal cracking of methane (methane pyrolysis). Instead of CO_2 , solid carbon is produced that can be easily stored or used. However, this method is still under development. From a climate perspective, the production method is secondary. The CO_2 footprint is decisive.

The climate gas methane, the main component of natural gas, must also be taken into account when determining the CO_2 footprint. Over a period of 100 years, methane is about 24 times more harmful to the climate than CO_2. It escapes both during the extraction and transport of natural gas, which is why consistent monitoring of technical facilities is necessary.

If one takes the bottleneck in the ramp-up of electrolysers seriously, the only conclusion that remains is that a global climate-neutral electricity system that rests only on "one leg", namely that of renewables and the green hydrogen derived from them, is not feasible.

This may look different from the isolated perspective of a **rich country.** Wealthy countries could supply themselves with so many electrolysers by 2050 that they can become climate neutral this way without fossil energy sources (with carbon capture) and without nuclear energy. However, this will be very expensive and consequently reduce prosperity. But it is possible. Of course, the scarcity problems are then shifted to other (poorer) countries. For them, correspondingly fewer electrolysers are available or affordable, at least not until the middle of this century. GES looks at the world as a whole and therefore advocates a climate-friendly energy system that stands on "two pillars": renewable, volatile energy on the one hand, and reliable, controllable energy on the other, especially fossil fuels with carbon capture.

A note from hydrogen expert Robert Schlögl, who is closely involved as a consultant in the programme of one of our project's industrial partners, is enlightening. Schlögl: "To replace Russian gas with hydrogen, all the factories in the world that produce electrolysers would have to produce electrolysers for 40 years to replace that - but only for Germany."[95]

Since carbon capture is required anyway for blue hydrogen when splitting the natural gas, natural gas can be used for many applications, especially for storage and combustion in power plants. Natural gas is almost always more advantageous than hydrogen if the carbon capture option is not excluded. As a rule, the **natural gas route** is **also significantly cheaper**.

The following observation also shows the limitations of the options in the electrolysis-hydrogen environment: It concerns the path to **climate-neutral steel** propagated in Europe, for example, and especially in Germany. This is to be produced in a climate-neutral way via direct reduction with electrolysis hydrogen. This is significantly more expensive than the current path. GES advocates direct reduction using natural gas in conjunction with carbon capture and storage. Leaving aside the costs, the question arises whether sufficient hydrogen is available at all.

In 2019, just under 72 % of the **world's steel production** of 1,874 billion tonnes was realised via the blast furnace route, i.e. with coke obtained from coal. To produce the corresponding amount of pig iron (1,341 billion tonnes) in a climate-neutral way with hydrogen would require the use of about 67 million tonnes of hydrogen. This corresponds to about 10 % to 15 % of the **expected maximum production** of electrolytic hydrogen in 2050, although world steel production is likely to increase significantly by then, possibly by 50 %. More than 20 % of the green hydrogen would then be consumed for steel production alone. It is good that steel can also be produced by different means in a climate-neutral way.

Electrolysis hydrogen is not a viable substitute for the use of natural gas for many reasons. First and foremost because of the bottleneck situation with electrolysers. As shown, according to all international estimates and also according to our analyses, by 2050 we will be a factor of 5 - 10 below the quantity of electrolysers that would be needed if we were to aim for climate neutrality only via this route. In short, the ramp-up of electrolyser production is simply too small. For this reason, too, there is no way around fossil fuels in the foreseeable future. **Carbon capture** will then play a key role.

Chapter 2.4 of the basic documentation covers all aspects of the production of hydrogen, Chapter 2.5 transport and storage of hydrogen and Chapter 2.6 the production of hydrogen derivatives.

5.3.4 The role of fossil fuels as reliably controllable energy

Today's world is still supplied with a good 80 % of its primary energy from fossil fuels. If fossil fuels continue to play a leading role, many conflicts with countries that produce these energy sources and

[95] Cf. Max Planck Society for the Advancement of Science (2022).

whose national budgets benefit from them will be avoided. These include in particular the countries of the China Club. Without the cooperation of these countries, the climate problem cannot be solved. The superpowers China and Russia will not accept that the OECD countries impose solutions on them and their allies that are diametrically opposed to their interests. This is above all because the climate argument no longer applies because of the "carbon capture" option.

The economies of many countries, including militarily and politically strong ones, are based on the sale of fossil fuels. Other countries are grateful if they can acquire these energy sources at reasonably low prices. In contrast, there is the philosophy of **defossilisation**, the complete phase-out of fossil fuels such as coal, gas and oil. The fear is that CO2 will be released into the atmosphere through their combustion, as has been the case up to now. However, this does not have to be the case.

"Carbon capture" is the alternative. Carbon capture for fossil energy production is, in our view, the **wild card for the future**. This creates reliably controllable energies with which we can complement renewables, if nuclear energy does not take over this role. Carbon capture enables a **smart compromise** that opens up a Net Zero perspective for the fossil fuel producing countries - as well as for the world as a whole. Without these countries, the future cannot be shaped anyway - especially not in a peaceful way.

In this respect, we assume - out of **physical necessity** and **political wisdom** - that fossil fuels will continue to play a major role for many decades to come - albeit no longer the role they play today. If done right, renewables and fossils can even complement each other. The technology opens up the opportunity to extract carbon and recycle it, as nature does. It is possible that the balance between volatile renewables and reliably controllable energy will be about 50:50, all things considered. It may well be the case that renewables have a larger share in electricity production, but that fossil energy sources tend to dominate in the area of energy molecules. The latter especially if one is interested in storing the energy, transporting it easily, using it in industry and, where necessary, for combustion engines. In these areas, the greater part of the energy will probably continue to come from the fossil side for many decades to come. And perhaps this will even remain the larger part of the primary energy mentioned, even if will be no longer as dominant as it is today.

5.3.5 Nuclear energy

Under the concept of "standing on two pillars", nuclear energy will continue to play an important role in the future. In terms of volume, it is today the most important reliable (largely) climate-neutral energy source that is **not volatile.** According to Our World in Data, it accounts for 10 % of global electricity generation and 5 % of primary energy.[96]

While Germany is phasing out nuclear energy, the number of nuclear reactors is increasing in Europe, including Finland, Poland, Sweden, France and the UK. Currently, around 60 nuclear reactors are being built in 15 countries, mainly in China, India and Russia. About 100 reactors are commissioned or planned, and more than 300 others are under discussion.[97]

There is no question that nuclear energy is associated with risks. The dramatic accident in Chernobyl (1986) bears witness to this. Fukushima (2011) is also often mentioned. However, the damage and death toll there were essentially the consequences of a tsunami, not a nuclear accident. The spread of nuclear energy also increases the danger of the proliferation of radioactive substances and thus of nuclear weapons. Ultimately, however, it is the countries themselves that decide whether or not to make use of nuclear energy and whether or not to invest in the construction and operation of this safety-relevant technology.

The development of nuclear technology also continues. Fourth-generation reactors are being tested, which work with very fast neutrons, use the radioactive waste from previous reactors and can generate energy from it.[98] This will reduce the amount of waste produced and shorten final storage times.[99] Meanwhile, Russia has put its first floating nuclear power plant into operation. It belongs to another type, the Small Modular Reactors (SMR), which are supposed to be safer than all previous nuclear power plants. Other SMRs are under construction or in the licensing phase in Argentina, Canada, China, Russia, South Korea and the USA. Whether and when nuclear fusion will be operational cannot be foreseen today and is therefore not taken into account in the Reference Solution.

Chapter 2.2 of the basic documentation deals in detail with all relevant aspects of generating electricity using nuclear energy.

5.3.6 The right combination of power generation types

As described above, an industrialised country cannot be sensibly supplied with electricity from 100 % renewables. In today's technological environment, this would require the use of green hydrogen to store energy and convert the stored energy back into electricity **when** the **sun and wind do not supply enough**. This is a very expensive way, which requires a lot of renewable energy, but also a very high electrolyser capacity. But that is precisely not a realistic option with a view to 2050. We are already failing due to the **electrolyser bottleneck**. This is described in detail in chapter 5.3.3. We

[96] Cf. Our Word in Data (2022b).
[97] Cf. World Nuclear Association (2022).
[98] Cf. Grytz (2021).
[99] Cf. Vahrenholt (2023).

see an upper limit of a maximum of 4,000 GW of electrolyser capacity by 2050. This is not nearly enough to solve the world's future energy problems via electrolysis hydrogen. Nevertheless, the 4,000 GW are of crucial importance, e.g. to secure part of the mobility via synthetic fuels.

Since electricity alone is not sufficient to supply a society with energy, the **Desertec approach** with 100 % renewables does not help either. The Club of Rome's new approach also fails because of this insight.[100] 100% renewables are not feasible - or only if there is widespread impoverishment. But this is exactly what the new report of the Club of Rome proposes. This is combined with massive redistribution programmes and ideas of new prosperity. From GES' point of view, however, it is not to be expected that the majority of people will accept new ideas of prosperity that de facto involve a considerable reduction of living standards as long as there is still an alternative. Our Reference Solution describes such an alternative and is based on the equal use of new renewables alongside reliably controllable energies.

The attempt to build a solution only on the basis of reliably controllable energy components, e.g. for the Challenge Group in the sense of **green-fossil,** would also fail. Although the approach is acceptable in terms of costs at around 100 euros per tonne of CO_2, this is not the case if the OECD countries assume the differential costs for the Challenge Group. If, for example, in the long run, i.e. after a ramp-up from 2050, green-fossil with 24 billion tonnes of CO_2 emissions per year in the area of the Challenge Group would have to be captured and financed via carbon capture. **T**his would amount to **2.4 trillion US dollars** and more annually for carbon capture in the Challenge Group alone, to be financed primarily by perhaps 1.5 billion people in the OECD countries. Apportioned to all working citizens in these countries, an average of **several 1,000 US dollars** would have to be reckoned with, which is hardly conceivable and not necessary. In addition, we see a maximum capture potential of 15-20 billion tonnes of CO2 per year for the whole world by 2050.

We advocate an approximate 50:50 mix of (new) renewable and reliable, controllable energy sources in the Reference Solution.

Only (new) renewables will not do

If one wants to switch the energy supply largely to (new) renewables, the provision of electricity is no longer cheap - as we have had to learn in Germany. This is because managing **volatility** is the main cost, not power generation with (new) renewables itself, although this is not cheap either under unfavourable climatic conditions like in Germany. The real problem is the **storage challenge for**

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[100] Cf. Club of Rome (2022).

electricity. The storage facilities available today are far too expensive. They do not even allow the storage of one percent of the continuously consumed electricity.

The supposed solution is to produce a large excess volume of electricity from new renewable-type plants to generate renewable electricity (instead of 100 % then 130 %). These volumes of excess electricity are to be used to produce **green hydrogen**, which takes over the role of gas in today's energy mix and serves as a chemical energy store. This hydrogen must be transported and stored and used in power plants when needed to close gaps in the electricity supply. If the hydrogen is burned in power plants, more than two-thirds of the original green energy from sun and wind is ultimately lost. This route is more expensive than the gas route, even if the CO_2 is captured during combustion in the power plant.

The costs are **at least twice as high** for hydrogen as for natural gas, as long as one assumes a gas price of around 10 US dollars per MWh, which is the case in many parts of the world. If one takes into account the additional problems of handling hydrogen, this is still true even at double the gas price.

If one switches to other types of hydrogen, the scarcity problem can be circumvented. **Carbon capture is then an unavoidable part of the solution**. And for storage, transport and combustion, natural gas (with carbon capture) is better than hydrogen anyway. However, it is essential to ensure that the methane - the main component of natural gas - does not escape into the atmosphere.

Only Fossil with Carbon Capture

Only fossil fuels with carbon capture would be a "business as usual plus" policy. For India, the African countries and many non-OECD countries, industrialisation à la China would be imminent. Achieving Net Zero sometime between 2050 and 2070 would entail an even more rigorous introduction of CCS. By 2050, this means on average avoiding not only 6 billion tonnes of CO_2 per year in the challenge countries, but perhaps 24 billion tonnes of CO_2 worldwide. In the OECD area and even more in the China Club, a total of at least 15 billion tonnes of CO_2 would have to be avoided. This would **multiply** the **costs** compared to the GES reference model, which would hardly be conceivable without considerable economic and political upheaval given the need for co-financing. In addition, there is the previously discussed limit for carbon capture plants, which suggests a limit of 15-20 billion tonnes of CO2 for capture in 2050, with the lower value being more realistic.

5.4 The great importance of carbon capture and storage

Another key component of an efficient energy system is the **molecular** side. It is about polyatomic particles held together by chemical bonds and, in the context discussed here, mostly containing carbon atoms. The fact that these should also remain in use within the framework of a climate-neutral energy system and how this can be achieved is explained in this sub-chapter.

5.4.1 The key role of carbon capture

Approximately 80 % of the energy used worldwide comes from fossil sources.[101] Many think that the energy transition means a complete phase-out of coal, gas and oil and that renewables will take over step by step, alone and for good. This is an illusion. All serious studies on a climate-neutral world in 2050 assume a high share of fossil-generated energy in the future as well - alongside the steadily growing use of renewable energy.[102,103,104,105] This is not surprising, because global energy demand will continue to rise in the coming decades. If only because the number of people will grow from eight billion today to ten billion soon, and the countries of the Challenge Group are striving to substantially increase their standard of living.

Coal, gas and oil have a CO_2 problem. If it were possible to reliably capture this CO_2 for subsequent disposal or use, the world would be a step further. Carbon Capture and Storage/ Usage (CCUS) is therefore a key issue. The time factor plays a major role here. Because CCUS promises rapid improvements in terms of civilisation's CO_2 footprint. For many applications, technology and business models are mature, and effectiveness and efficiency are high.

It is interesting that the British government is planning to **open a new coal mine** to then use coal massively *with* carbon capture. Norwegian Prime Minister Jonas Gahr Støre offered in August 2022 in Oslo, after a meeting with Chancellor Olaf Scholz, to store all the CO_2 produced in Europe this century at a depth of 3,000 metres under the North Sea. Norway wants to use the CO_2 as a raw material again later. The British want to make similar offers and earn more money from injecting CO_2 than they originally earned from the natural gas in the corresponding caverns. There are other activities of this kind in Europe, they exist in the USA, India, China and Indonesia anyway. They all rely on **carbon capture** for their Net Zero targets. In this context, it is important that both the **G20 summit in Rome** and the last **climate conference in Sharm El Sheikh** have always talked about phasing out coal as far as it is "unabated", i.e. no capture of CO_2 takes place.

[101] Cf. IEA (2020a).
[102] Cf. IEA (2021b).
[103] Cf. IRENA (2021).
[104] Cf. bp (2022).
[105] Cf. Shell (2021).

This point is often not mentioned in the communication in the German media. It is pretended that all countries are saying goodbye to coal. But that is not the case, only to "unabated coal". We need climate neutrality - with carbon capture for fossil fuels. The only alternative way, namely to go directly from electricity, i.e. from electrons to hydrogen and thus to molecules, via the use of electrolysers, is not an alternative, as described in chapter 5.3.3, given the dimensions required.

What does carbon capture do? Carbon capture (CC) can be used to separate CO_2 from so-called point sources, for example at gas power plants or cement factories.[106] There are many technical options for this.[107] Chemical absorption by **amines** is widely used. CO_2 is washed out of the exhaust gases. However, the greenhouse gas can also be separated by membranes.

Carbon capture and storage (CCS) is when the captured CO_2 is permanently stored. There are many possibilities for this, from caverns to former oil and gas deposits to underground mineralisation, i.e. the chemical conversion of silicate rocks into carbonate rocks through the storage of CO_2. If the climate gas is used further, for example for the production of e-fuels or urea, this is called carbon capture and use (CCU). If CO_2 is made usable through CCU, synergy effects are possible. At the end of its use, however, the climate gas often ends up in the atmosphere. This is prevented by dumping CO_2 in CCS, but disposal costs are added.

CO_2 can also be extracted directly from the air using **Direct Air Capture** (DAC). However, the proportion of CO_2 in the atmosphere is very low, only about 0.04 %. Capturing CO_2 here is therefore extremely energy-intensive and prohibitively expensive. The DAC plants contain powerful fans that suck in large quantities of air. The CO_2 is then compressed to be captured. All this costs a lot of energy. This is another reason why DAC is much more expensive than CO_2 recovery from exhaust gases, where the CO_2 concentration is usually more than 10 %.[108] It makes more economic sense to capture the CO_2 where it enters the atmosphere at a high concentration, namely at the stack - and not when it is already distributed in the atmosphere and has to be filtered out at significantly higher costs.

For DAC, at least 500 US dollars per tonne of CO_2 are set today. Hopes aim at perhaps 200 US dollars in a few decades. This would be, scaled up, an upper limit of CO_2 abatement costs for the world.[109] Even if CO_2 is removed from the atmosphere via DAC, there is still the question of what happens to it then. As with CC, we are then faced with the question of using or storing CO_2 .

CDR stands for Carbon Dioxide Removal. CO_2 is removed from the atmosphere and then stored. This is done either technically through DAC or biologically: plants remove CO_2 from the atmosphere

[106] Cf. Skea (2022).
[107] Cf. NASA (2019).
[108] Cf. DENA (2021).
[109] Cf. DENA (2021).

and store it, for example in wood. A combined process is Bioenergy Carbon Capture and Storage (BECCS). In this process, biomass from fast-growing plants, for example, is burned with the carbon it contains from the atmosphere to produce energy. The CO_2 is captured and then disposed of.

Around 30 CCUS projects are in operation worldwide. By far the most are in the USA and Canada. For a long time now, CO_2 has been extracted there in large quantities and injected into oil and gas deposits to make better use of them (Enhanced Oil/ Gas Recovery, EOR/ EGR). A further eleven CCUS projects are currently under construction; Europe and the Middle East are regional focal points. Another 150 projects are under development.[110] The number of CCUS projects worldwide is increasing significantly. Currently, around 40 million tonnes of CO_2 are captured per year.

Injecting CO_2 into gas and oil fields and caverns is ready for the market and has its origins in oil and gas production, as a means to an end to support production, so-called **enhanced oil recovery**. This is not primarily about climate protection, but about increasing the **yield from oil and gas fields**. There, the pressure decreases with increasing production. Often the depots are still half full, and "residual stocks" of oil and gas remain underground. If CO_2 is now injected into the fields, the pressure increases and the field can be exploited almost to its full capacity. This is also reasonable from the point of view of climate and emissions, if carbon capture is consistently used for the additionally extracted quantities of oil and gas, or if they are fully compensated for, e.g. through nature-based solutions. In this case, the economic benefits are so high that they cover the costs of carbon capture (absorbtion, transport, injection) in enhanced oil recovery. As mentioned, Norway is also working on storing CO_2 in former gas fields under the North Sea.

Mineralisation, as is being successfully tested in Iceland, is promising. In this process, CO_2 dissolved in water is injected into basalt rock - where it turns into stone within a few months. The technology is considered very safe. Volcanic basalt rocks are found all over the world. Therefore, theoretically, there are no capacity problems for storing CO_2 .[111] Costs for storing one tonne of CO_2 in basalt rock are reported to be in the range of 20 - 30 US dollars. Another mature technology is to store CO_2 in rock containing salt water.

Carbon capture and storage for reasons of climate protection needs more: a defined degree of capture, for example 90 %, documentation of the injected quantities and monitoring of whether the storage is also safe. CO_2 in the air we breathe is harmful to humans at concentrations above the normal level of about 0.04 %. Unlike natural gas, however, the gas is not flammable. It goes without saying that transport and storage must be carried out according to defined standards.

[110] Cf. NETL (2021).
[111] Cf. Snoebjörnsdottir (2020).

CO_2 can be transported by pipeline, truck, rail or ship.[112] Up to a distance of about 1,800 kilometres, the construction of pipelines is cheaper than transport by ship, despite initially high investment costs. With ships, the transport space is limited, the CO_2 is more compressed and eventually liquefied. However, sea transport can react more flexibly to market demands than a fixed pipeline network. Unlike natural gas, there is no risk of fire or explosion when transporting CO_2. So far, there is hardly any CO_2 transport infrastructure, except in the USA and Canada. Here, there is a CO_2 pipeline network of over 8,000 kilometres in length.[113]

If you want to reduce transport costs, you have to avoid unnecessary transport. Therefore, short distances between capture and storage or use of CO_2 are advantageous. But this depends on many factors. Where are the emitters located? What is the geology like? Where can the CO_2 be injected or consumed? Are CO_2 emitters, such as production plants for chemical products or future synthetic fuels, nearby? There are many starting points for reducing the volume of transport.

If CCUS is to be used on a large scale, the importance of transport and logistics in the entire CO_2 chain will also grow. Thus, the future of CCUS also depends on the willingness of the respective countries to create the necessary infrastructure.

The capture of CO_2 in industry currently costs between 40 - 120 US dollars per tonne.[114,115] The price range applies both to conventional power plants, i.e. essentially coal and gas, occasionally also oil, and to steel and cement production. According to Chinese data, there is much to suggest that **costs will fall to a third by 2050**.

The first business models are emerging in this environment. They require co-financing or a CO_2 price. The price for CO_2 must be higher than the price for disposal. If this is the case, emitters start investing to avoid their emissions - so much for economic theory. In Europe, for example, there is an instrument in the form of the Emissions Trading Scheme that leads to a rising CO_2 price. The situation is different at the global level, where a continuous CO_2 price does not stand a chance in the foreseeable future.

Can CCUS play a leading role in solving the energy and climate problem? The quantities of CO_2 emitted worldwide from the energy-related sector amount to about 39 billion tonnes per year in 2025. In addition, there are about 14 billion tonnes of CO_{2eq} partly from other greenhouse gases such as methane. Natural buffers, such as oceans or forests, store at least 14 billion tonnes of CO_2 at the same time and help us to combat the climate problem. In particular, many emissions in the biological sector, e.g. methane from rice fields, are (conceptually) compensated for in this way. Of the 34 billion

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[112] Cf. Massey (2021).
[113] Cf. Righetti (2017).
[114] Cf. DENA (2021).
[115] Cf. Massey (2021).

tonnes in the energy-related sector, only a little over 1 % is currently captured and stored. Among the "heavyweights" of global emissions, coal-fired power plants, and here especially the plants in China and India, are far out in front; globally, we are talking about about 10 billion tonnes of CO_2 per year.

However, the efficiency losses when using CCS are considerable. In order to achieve the same electricity output, *more* coal must be burned; alternatively, renewable energy must be provided to achieve this goal. At the same time, huge amounts of CO_2 are produced, which have to be disposed of or used. This requires investments: in the plants for capture, for compression and a transport infrastructure adapted to the geography.

But it is not coal-fired power plants alone: gas and oil-fired power plants, steel mills, cement plants, plants in the chemical industry, etc. come into play. If CCUS is to play a decisive role in solving the climate crisis, the question becomes even tougher: Is there a realistic chance of **eliminating 15 - 20 billion tonnes of CO_2 annually** by means of this technology, over three decades, with a capture rate of around 90 %? Is that realistic at all?

The short answer is: technically yes, the sticking points are - as so often - economic and political. The whole thing must be politically desired or at least accepted and financed. And existing infra-structures should be used wisely.

Ultimately, there needs to be a practical will to cooperate, also globally. Take Africa, for example: the continent is blessed with potential for renewable energy, i.e. sun, wind, unused areas in the desert. But Africa also has coal, gas and oil. And that is often the cheaper solution, especially if volatility in the electricity supply is to be avoided. Which in turn is a prerequisite for **industrialisation**. And Africa, for example, urgently needs this with its population set to double to 2.4 billion people by 2050 (five times the population of the EU). In each of the next three decades, as many buildings and infrastructures will be built in Africa as in Europe in the entire last century. Bill Gates describes in his book "How to Avoid a Climate Disaster" that 500 times the size of New York will be built worldwide in the next decades: one New York every month.

In short, if African countries opt for fossil fuels, the rich countries must share the additional costs for CC and take responsibility for ensuring that energy provision in this way is done in a climate-just way. This is in line with the logic of the **Montreal Protocol**, through which the ozone problem has been successfully addressed since 1987. The hole in the ozone layer could be closed again through the use of new technologies. The rich countries have borne the differential costs. In this way, a consensus was reached. Following this model, cooperation with developing and emerging countries on the climate issue can also succeed.

Chapter 2.8 of the basic documentation deals with the technical capture and storage of CO_2 (CCS), Chapter 2.9 with the use options of CO_2 (CCU).

5.4.2 Dealing with process industries using the example of cement

The so-called process or basic industries of steel, chemicals and cement are an important cornerstone of prosperity and value creation. They are cornerstones of a modern society and create numerous jobs and products that are necessary for building and maintaining society.[116] However, they are very energy-intensive and are associated with high CO_2 emissions. Climate neutrality of these industries is therefore necessary to achieve the goals of the Paris Agreement. The challenge is that in the primary industries even a supply of 100% renewable energy would not solve the CO_2 problem. This is due to emissions that are related to industrial processes and not to energy supply.[117] This is why we also talk about **"hard to abate" sectors**, i.e. industries that need technological leap innovations to become completely climate neutral by 2050.

At this point, the cement industry will be dealt with as an example. Other industries are dealt with in detail in chapter 3 of the basic documentation.

The **binding agent cement** is one of the most frequently used materials in the world.[118] It is an important component of concrete and thus occupies a crucial position in the entire value chain of the construction industry. Approximately 4.3 billion tonnes of cement were produced worldwide in 2021.[119] This means that the amount of cement produced since 1990 has roughly quadrupled. Although the consumption of cement has stabilised somewhat in recent years, a further increase can be expected in the coming decades.[120] This is primarily due to strong population growth and urbanisation, e.g. in India and large parts of Africa.

The high CO_2 emissions from cement production are problematic. In 2021, approx. 7 % of global CO_2 emissions were attributable to the cement industry (2.9 gigatonnes).[121] However, **decarbonisation of the cement sector** is a major challenge. This is primarily due to the process-related emissions that inevitably occur during cement clinker production when the CO_2 is expelled from the limestone, the so-called deacidification. [122]

The key raw material for the production of cement is limestone. Together with clay and marl, it is brought from quarries to the cement plants, crushed, and processed into raw meal. In order to obtain the required chemical properties for cement, the limestone must be calcined at around 950 °C and then burned at 1,450 °C. This produces cement clinker, the primary product of cement production.

[116] Cf. Schneider (2019).
[117] Cf. Schneider (2019).
[118] Cf. GCCA Association (2022).
[119] Cf. IEA (2022b).
[120] See IEA and Cement Sustainability Initiative (2018).
[121] Cf. Borenstein, S. (2022).
[122] Cf. McKinsey (2020).

The calcination of the limestone is responsible for approximately two thirds of the CO_2 emissions in cement production.

The cement is then mixed with other raw materials. This is how concrete is produced. The remaining third of CO_2 emissions comes from the fuels needed for calcining and heating the rotary kiln in which the cement clinker is burnt. In contrast to the calcination process, the fossil CO_2 emissions caused by the fuel can be partially avoided by switching from fossil fuels to alternative fuels. However, hydrogen cannot be used in practice due to its combustion behaviour. The complete expansion of our energy supply in the direction of 100% renewable energies cannot solve the CO_2 problem of the cement industry. Other technologies are necessary for this. In cement production, these are new binders, i.e. the replacement or reduction of the clinker content in concrete, and above all Carbon Capture and Usage/ Storage (CCUS). [123]

CCS involves the capture, transport and permanent storage of CO_2 emissions produced during cement clinker production. In CCU, the captured CO_2 is reused, for example to produce methanol. This then serves, for example, as a starting product for the chemical industry or as a precursor for low-carbon fuels. Of course, the CO_2 that may be released during the use of CCU products must be compensated for via natural-based solutions or DAC with storage.

Chapter 3.2 of the basic documentation covers the main process industries, including 3.3.2 the cement industry.

5.5 Climate-neutral fuels and energy sources

5.5.1 Mobility

Mobility is not only **an essential element of freedom**, but also **central to value creation**. In economic terms, at today's prices, mobility is cheap in relation to the potential for value creation and freedom that it unlocks.

Worldwide, a good 26% (29.2 PWh) of final energy was consumed in the transport sector in 2020, of which a good 92% was based on oil; electricity accounted for a share of 1.4% (0.4 PWh).[124] The challenges in the field of mobility can be considered according to the respective contribution of a means of transport to the emissions (approx. 16 % of the globally emitted greenhouse gases or approx. 8 billion tonnes of CO_{2eg}), which correspond to the respective energy input due to the extensive use of petroleum:

[123] Cf. Skea (2022).
[124] Cf. IEA (2020a).

1. Car approx. 7 %
2. HGVs and heavy trucks approx. 5 %.
3. Aircraft approx. 2 %
4. Ships approx. 2 %

Developments to date show that it is particularly difficult to reduce CO_2 emissions in the mobility sector. And worldwide, emissions are still increasing because mobility will be significantly expanded if two billion people are added in the economically lagging countries (Challenge Group) by 2050 and - also according to the SDG programme - prosperity is to be massively expanded, as is also the goal of our reference scenario. The pursuit of greater prosperity will automatically be linked to the desire for more mobility. We expect the final energy demand in the various mobility sectors to increase by a total of approx. 37% to over 40 PWh by 2050.

In this context, massive growth processes are expected in the area of (heavy) trucks for use in Africa. There are corresponding forecasts from the African Union. Up to 1 million medium and heavy vehicles are expected by 2030.[125]

In order to achieve global climate neutrality, one must reduce the emissions caused by man's need for transport and make them as climate-neutral as possible. From today's perspective, aircraft and ships seem predestined for re-fuels. By re-fuels we mean either electricity-based e-fuels or bio-fuels produced on the basis of biomass. Both are renewable in this sense. In the foreseeable future, alternative solutions such as the use of hydrogen or electricity are not economically viable for either shipping or aviation. The crucial question is: what will become of cars and trucks, and what will become of the huge existing fleet? Today, CO_2 emissions from this sector are about three times higher than those from shipping and aviation combined. That is why solutions for these sectors are important.

Basically, the question of reducing emissions in the mobility sector is a question of the possibilities of replacing the petroleum and the fuels based on it that are predominantly used today.

Options are:

Electricity (power/electrons): Advantageous is the good drive efficiency, disadvantageous are the complex raw material situation of the batteries, the lower energy density by a factor of 5 - 8 compared to chemical fuels and the required extensive, expensive electrical infrastructure to enable efficient charging of the batteries. In addition, the range limitation of battery-electric drives restricts their range of application. Furthermore, in many cases the CO_2 balance is worse than that of a combustion engine as long as the electricity mix has a negative CO_2 balance, e.g. due to a high proportion of

[125] Cf. African Union (2017).

fossil fuels. The significantly higher purchase costs of electric vehicles compared to combustion engines also make them unaffordable for many people, especially in emerging and developing countries.

Climate-neutral fuels (re-fuels/molecules): The starting material is always hydrogen, which can be used pure or in combination with other molecules (hydrogen derivatives), e.g. as methanol, synthetic petrol/diesel or paraffin, possibly also as synthetic natural gas or ammonia. The hydrogen must be produced with minimal CO_2 emissions; electrolysis, reforming, gasification or pyrolysis are the competing processes. E-fuels can be stored cost-effectively, transported and mixed with fossil fuels to ultimately replace them. In terms of climate, e-fuels have an immediate effect - the higher the admixture to conventional fuels, the better. The **existing energy and mobility infrastructure can continue to be used**. This includes pipelines, tankers, petrol stations, as well as aircraft, ships and, above all, the world's existing fleet of cars and trucks. It is already foreseeable that e-fuels will have to play a decisive role in solving climate and energy issues. Among the renewably produced fuels, there are not only e-fuels but also biomass-based fuels (e.g. from maize or preferably from waste such as straw, liquid manure or waste wood), in short: bio-fuels. Both groups of materials can be produced in a climate-neutral way.

In the case of the use of carbon-containing derivatives such as methanol or e-gasoline, etc., the origin of CO_2 is at the centre of the debate. In a strict defossilisation philosophy, only CO_2 from **direct air capture** or **biogenic CO_2** (burning biomass and capturing the CO_2 - BECCS) are permissible. These processes fall under the concept of Carbon Dioxide Removal (CDR). A closed carbon cycle is created because only as much CO_2 is released again as was previously captured. In other words, the fuel brings with it a CO_2 credit. Climate neutrality is then a given from a scientific point of view. This is the case with Brazilian ethanol, which is produced from **sugar cane.** In Brazil, it was possible in 2020 to cover 24 % of final energy consumption in the entire transport sector on the basis of biofuels and waste fuels.[126]

An alternative is to use the captured CO_2 from combustion processes, especially point sources (fossil power plants, steel mills, cement plants). In this case, the carbon produced later during the combustion of the e-fuel must be bound for complete climate neutrality via nature-based solutions (reforestation, humus formation in agriculture) or by direct air capture with subsequent storage of the CO_2, also in the form of mineralisation. These removals should have already been carried out (or initiated) and paid for before the e-fuels are used. Clean accounting is necessary. I.e. a CO_2 credit is created and financed. This is a main proposal in the GES reference scenario and currently involves up to 5 - 8 billion tonnes of CO_2 per year for total transport worldwide. In positive terms, this creates a source

[126] Cf. Hamburg Open Online University (2021).

of funding for removals. The gigaprogramme Nature-based Solutions of the GES proposal can be used during the ramp-up of e-fuels.

In some cases, the use of CO_2 from point sources of fossil fuels is rejected because of fears of persistence in "old" technologies (a **lock-in effect**).

At present, e-fuel produced by means of electrolysis on the basis of renewable energies costs about twice as much as a comparable amount of energy from fossil fuel. However, with larger production volumes, good location conditions and falling electricity prices, fuels produced in this way can become significantly cheaper. However, this requires billions of dollars of investment in production facilities. Optimistic forecasts assume that costs for e-fuels of 1 - 2 euros per litre are achievable, excluding taxes. Transport costs only account for a few cents of this.

It is scientifically proven that e-fuels can be produced on a large scale, that there is enough renewable energy, sufficient land and resources. The difficulties of ramping up e-fuels lie elsewhere: in creating the legal framework that recognises the climate neutrality of e-fuels and exempts them from climate levies, in expanding production capacities, for example of electrolysers, in providing the capital, in shaping global supply chains, especially with the emerging and developing countries of the Challenge Group, and last but not least in financing the avoidance and compensation of CO_2, in other words: CCUS and nature-based solutions.

In the EU, a compromise was reached in March 2023 after fierce wrangling, which prevents a ban on combustion engines from 2035 (no more registration of vehicles with combustion engines) that had almost already been decided. The development could be relevant for the upcoming regulation of the **energy use of trucks** (especially heavy trucks).[127,128]

5.5.1.1 Passenger Car

The subject of much debate is the world's large fleet of passenger cars, more than one billion in number. This number is expected to grow towards 1.5 billion by 2050, while at the same time **battery electrics** are ramping up. In some of the Challenge countries, there are opportunities to provide renewable electricity. However, they lack the means to purchase expensive electric vehicles. Also, the conditions for charging the vehicles are usually lacking. In addition, second-hand vehicles that were previously used in industrialised countries are often used there. They are comparatively cheap to purchase.

In the GES Reference Solution for cars (and regional distribution transport for trucks), we see a role for battery electrics for vehicles that move over comparatively short distances, such as in cities, and

[127] Cf. Global Energy Solutions (2022).
[128] See European Federation for Transport and Environment (2022).

can access a solid power grid infrastructure with low-carbon electricity. This includes fossil-based electricity with carbon capture and nuclear power. The charging infrastructure must be right.

If a cross-border expansion of the power grid is successful, battery electricity may also play a relevant role in the future in the rapidly growing cities of Africa and in other cities in developing and emerging countries, since renewable electricity can often be produced cheaply. If the volatility problem is then solved via nuclear energy (used by India or Brazil, for example) or green-fossil solutions, solar power will be really cheap.

In rural areas, for long distances, in difficult weather conditions and with insufficient infrastructure, passenger cars with e-fuels are also an **alternative**. Porsche is showing the way with its **Haru Oni** project in southern Chile, even if the use of direct air capture has been very expensive so far. Haru Oni is to produce 350 tonnes of e-methanol and 130,000 litres of e-gasoline per year. The plant went into operation in December 2022.[129] A similar approach is being pursued by the company Obrist.[130] Obrist has presented a concept for climate-neutral methanol production. This is then to be used in a serial hybrid also developed by the company. The vehicle's battery is designed in such a way that even longer distances can be driven purely electrically.

But there is also the way via **biogenic CO_2**, so-called BECCS. We see the special programme for **short-rotation plantations** with a potential of at least 3 billion tonnes of CO_2 per year according to the UN in full expansion. Otherwise, CO_2 from fossil sources is also used in the plans of many countries, especially from coal-fired power plants, which today emit 10 billion tonnes of CO_2 per year. If the CO_2 is captured and used to produce e.g. methanol (the target substance in the Obrist project), the CO_2 is recycled once before it is released into the atmosphere with the combustion of the fuel. Thus, a halving of new emissions is achieved (depending on the consideration, the coal-fired power plant or the combustion of the fuel is climate-neutral, or both applications half). To make the entire process completely climate-neutral, the remaining half is additionally removed from the atmosphere via removals. These must have already been carried out and paid for before the fuel produced in this way is used.

Methanol, methane or methanol petrol produced in this way reduce the individual CO_2 capture costs, because these can be shared between, for example, the coal-fired power plant operators and the purchasers of methanol petrol. The CO_2 can be taken over from power plants on site - there is no need for further transport and injection - and is later released into the atmosphere when it is burned. E-fuels thus considerably reduce the cost of carbon capture at some of the power plants (several billion tonnes of CO_2 per year), while at the same time they channel the necessary financial resources into **financing removals** to achieve complete climate neutrality. Due to the central

[129] Cf. Stölzel, T., Martin, S. (2022).
[130] Cf. OBRIST Group (2023).

importance of mobility, we expect that a significant part of the emission rights from nature-based solutions (forest and humus formation) already made available in the GES reference proposal until 2050 will be invested in the climate neutrality of synthetic fuels.

This area would then also use a substantial part of the electrolysis hydrogen that we estimate can be produced by 2050. The prospects of soon having sufficient renewable electricity available for numerous applications and, in addition, also being able to supply 100 % of a pure battery-electric fleet the size of today's fleet are unrealistic.

Last but not least, there is the important **special case of tuk-tuks and very small vehicles** (also two-wheelers) in many emerging countries. For them, battery-electric solutions present themselves, especially in conurbations. This process is already underway, especially in big cities like Delhi or Dakar. These are very light vehicles and taxi-like services to reduce costs and increase capacity. In these megacities, especially in developing and emerging countries, the high levels of **air pollution** and **noise** are already enormous burdens on the population. The tuk-tuks cover a lot of inner-city traffic. Their electrification helps to reduce air pollution and lower road noise. The vehicles are usually very light, so comparatively small batteries are sufficient. The required (green) electricity can partly be generated on site, partly also via local grids.

However, it should also be noted that there are still around 600 million people in the Challenge countries without an electricity connection. In these predominantly rural areas, the electricity infrastructure must first be built or sufficiently strong local grids must be established before the use of a battery-electric small vehicle is possible.

5.5.1.2 Truck

Trucks are the backbone of our economy, with around 2 billion tonnes of CO_2 per year worldwide. There are 300 million trucks worldwide, and in the EU 85% of goods are transported by road. The number of trucks will continue to grow; the cumulative CO_2 emissions are almost as high as those of one billion passenger cars with internal combustion engines. The question is in particular how a transformation of the truck sector towards climate neutrality can look. The use of hydrogen in fuel cells or in a largely unchanged combustion engine, batteries, electricity from overhead lines on motorway routes and re-fuels are being discussed.

In Europe, the EU is about to take another regulatory step. Following the model of the passenger car, the internal combustion engine is to be banned, albeit over a longer period of time. Hydrogen and batteries in particular are seen as alternatives. In the case of trucks, the battery route in particular is considered almost unrealistic, and in any case impracticable.

At GES, we have been arguing for combustion engines with re-fuels for a long time - for cars as well as for trucks. Our partner in the truck sector is E.L.V.I.S. AG, an organisation of about 200 haulage companies with a total of about 20,000 heavy trucks. There is a document on this entitled "Consideration of different forms of drive for heavy trucks". [131]

Summary assessment on trucks

Battery electrics and overhead lines do not offer a viable solution. The first step will be to concentrate on hydrogen and synthetic fuels in the internal combustion engine and, in the further course, on the fuel cell.[132, 133] This will enable us to cover long distances with our own fuel, to travel across Europe at will and to be able to operate everywhere. **HVO**, a **climate-neutral** fuel based on used fats, etc., is currently of interest. It is currently being tested in the truck sector,[134] e.g. Bosch is currently conducting a large-scale trial.

5.5.1.3 Aviation

In the decarbonisation of aviation, there is no way around re-fuels in the foreseeable future. Batteries are too heavy and the power density of hydrogen propulsion is too low. The EU Parliament demands a blending quota of 2 % re-fuels to conventional paraffin by 2025, and as much as 70 % by 2050.

In aviation, there are special approval procedures for blended, non-fossil fuels (SAF - Sustainable Aviation Fuels) for safety reasons. Kerosene-like components can be produced e.g. CO_2 -neutral with synthesis gas from biomass gasification and subsequent Fischer-Tropsch synthesis or by mild hydrocracking of natural fats and oils (also used fats and oils). Availability is currently low, and investments must be made in corresponding production capacities, also in view of the legal requirements.

5.5.1.4 Maritime Shipping

In maritime shipping, too, there is no serious alternative to re-fuels in sight. The most promising candidates are ammonia (NH_3) and methanol (CH_3OH), and as an intermediate step LNG instead of heavy fuel oil.

The requirements of the IMO, the International Maritime Organisation, are: By 2050, the CO_2 emissions of ocean-going vessels should be largely climate-neutral, despite the predicted additional

[131] Cf. Global Energy Solutions (2023a).
[132] Cf. H2Accelerate (2022).
[133] Cf. International Transport Forum (2022).
[134] Cf. Wernicke (2022).

increase in ship transports in the coming decades. Whether this can be achieved depends on the availability of the corresponding low-carbon fuels.

After all, the first methanol-fuelled ships are in operation and shipping companies such as Maersk have begun to build up their own supply of green methanol. Ammonia is currently still in the trial phase, but is also attracting increasing interest.

Chapter 2.7 of the basic documentation deals with climate-neutral fuels, Chapter 3.3 with all aspects of climate neutrality of the different transport sectors.

5.5.2 Situation for buildings

Globally, a good 30% (33.4 PWh) of final energy was consumed in the private and public buildings and public services sectors in 2020, of which 32.5% was already consumed using electricity, mainly for air conditioning but also in the form of heat pumps in some countries. Biofuels and the use of waste-based energy generation have also made a significant contribution with a share of 24.3%, followed by natural gas with 23.2%. Oil also still played an important role globally with 7.4 %, followed by heat use with 5.1 %.[135]

In perspective, the further expansion of electricity-based supply to buildings will certainly play an important role. We expect this share to increase to well over 50 % by 2050. We also expect the trend to be a global doubling of heat use, which should be further promoted in its importance due to possible efficiency effects. In many countries, district heating has so far been generated predominantly on the basis of fossil energy sources; in this case, continued use is possible in the future if the CCS infrastructures are expanded accordingly.

In addition, the use of biofuels and waste-based energy generation will remain significant, even if a further increase in their contribution is not expected. Whether hydrogen will establish itself as an energy carrier for supplying real estate on a large scale remains to be seen. On the one hand, the availability of electrolytically produced hydrogen is limited, so that the focus here will tend to be on the mobility sectors; on the other hand, the requirements for an installation that eliminates all safety risks remain high. We also expect that in the long term a significant proportion of buildings will still be supplied with energy from natural gas, as both availability and logistics favour this. Ultimately, emissions remaining on the basis of natural gas will have to be compensated via natural-based solutions, unless e-fuel-based methane is used, in which case the quantities will remain limited in the long term.

[135] Cf. IEA (2020a).

The role of wood as a building material is emphasised from various sides today. However, there are narrow limits to the possibilities in this area.[136]

Chapter 3.4 of the basic documentation deals with the relevant aspects on the topic of housing and buildings in detail.

5.6 Elimination of technical methane leaks

Methane is one of the most important climate gases with a negative climate impact many times greater than that of CO_2. Methane is today the second most important climate gas (16 % of global emissions). The concentration of methane in the atmosphere, like that of CO_2, has been steadily increasing since the beginning of industrialisation. Methane emissions arise from both natural and - to a greater extent - anthropogenic sources. Controlling and reducing anthropogenic methane emissions has a high leverage effect with regard to limiting global warming.
The target agreed in the Paris Climate Agreement to limit global warming due to climate change to 1.5°C compared to pre-industrial times is only achievable if current annual methane emissions are reduced by at least 45% by 2030.[137] Over 100 countries signed the Global Methane Pledge at COP26, committing to reduce their methane emissions by at least 30% from 2020 levels within ten years. The initiators of the Global Methane Pledge speak of a possible reduction in global warming of at least 0.2 - 0.3°C by 2050 if the agreement on methane is adhered to globally.[138]

Methane emissions

The methane content of the atmosphere has risen from 730 ppb (parts per billion) in 1750 to over 1,800 ppb today. This is a 150 per cent increase and, as with CO_2, the highest level in at least 800,000 years, as determined by analysing gas inclusions in drill cores. The increase in methane concentration in the atmosphere has reached a record value of 1,876 ppb in 2021, whereby the proportional allocation to anthropogenic or natural emission sources is not clear.

Methane emissions come from wetlands, lakes, but also from the extraction of coal, oil and gas, from landfills and, above all, from agriculture.. Total emissions are estimated at around 600 million tonnes (year 2017), of which around 370 million tonnes are from anthropogenic sources and around 230 million tonnes from natural sources.

[136] Cf. Global Energy Solutions (2022).
[137] Cf. Copernicus Climate Change Service (2022).
[138] Cf. COP26 (2021).

Methane sinks, methane balance and forecasts

In connection with the changes in methane concentration in the atmosphere after the eruption of the Pinatubo volcano in 1992, natural methane sinks were investigated in more detail. Essentially, methane is degraded by chemical reaction with OH radicals and ozone in the troposphere (approx. 80 %), to a lesser extent in the stratosphere (15 %). The most important sink is the chemical reaction with the hydroxyl radical OH in the troposphere: $OH + CH_4 \rightarrow CH_3 + H_2O$

The reaction of methane with OH radicals leads to the formation of water and methyl radicals, which are ultimately converted to CO_2 via a few more intermediate steps. This process removes about 500 million tonnes of methane from the atmosphere per year. The uptake of methane in the soil or oceans and bacterial degradation, on the other hand, is negligible (5 %). The total amount of methane degraded via sinks is estimated to be less than 600 million tonnes per year.

Options to reduce methane emissions

Methane emissions are often diffuse in nature compared to CO_2 emissions and therefore more difficult to capture and mitigate. In the USA alone, 600,000 natural gas and oil wells, a global livestock population of about 1.5 billion cattle and 6,000 abandoned coal mines emit methane.
Concrete measures are essentially the sealing of leakages and the capture of residual gases in fossil energy production and landfills. Gradual reductions in methane emissions are possible in agriculture and livestock farming. With known measures and technologies, methane emissions could be reduced by up to 57% in this decade, a quarter of this at no net additional cost through increasing efficiencies, closing leakages and methane recovery. This would only be achievable if all emission sources were addressed simultaneously, globally and at high financial cost.

Oil and gas

Methane emissions arise from the conventional extraction of natural gas and crude oil as associated gases as well as from unconventional sources such as shale gas, so-called "tight gas" from gas-permeable sediments and coal associated gas.

Methane losses in the oil and gas industry are estimated by the IEA at around 75 million tonnes per year. For natural gas, the loss rate is up to 1.7 % of the total volume produced; in Russia, the losses are said to be up to 2.5 % of the volume produced.

Emissions from fracking due to methane losses are particularly high, estimated at up to 3.7 % for the USA. Leaks extend into urban networks; for example, around 286 tonnes of methane are released into the atmosphere each year via the Hamburg gas network alone.

From a loss rate of 3.2 %, natural gas contributes more to climate change than coal. The main measures to reduce methane emissions are the search for and closure of leaks at wells, pipelines, pumps and compressors along the entire natural gas and oil process chain. This mainly concerns the recovery of associated petroleum gases, renewal of flares and methane recovery from tanks and blowdown vessels to filling stations and local gas networks.

Coal

Emissions of methane from coal mining, both underground, in opencast mining, but also from disused mining, are considerable. Estimates by the IEA are around 40 million tonnes per year, a study by the US JBCRI cites 114 million tonnes per year from active and disused coal mining. Only a small part is captured and used for energy. Thus, coal-related emissions would be higher than those of the oil and gas industry.

China is the geographical focus of emissions. The removal of mine gases ("firedamp", coal seam gas) during underground coal mining by ventilation ("ventilation") has long been state of the art for safety reasons. However, the methane content is too low for further utilisation and can be oxidised to CO_2 via catalytic waste gas purification.

However, mine gas also escapes from coal mines that have already been shut down but not flooded. This can be extracted and thermally utilised. In Germany, the amount is estimated at about 1.5 million cubic metres per year and generates 200 MW of power.

Summary and outlook

The most detailed study on the status and mitigation measures of methane emissions is the UNEP/ CCAC study "Global Methane Assessment and Costs of Mitigating Methane Emissions" published in 2021. With known technical options, methane emissions could be reduced by 180 million tonnes per year by the end of the decade. This would correspond to a reduction of the greenhouse effect by 0.3°C. Measures already planned and initiated include about 120 million tonnes per year, with the oil/gas/coal sector contributing half - also because they are the least diffuse emission sources.

Several other studies put the methane emission reduction potential by 2030 at 29-57 million tonnes per year for oil and gas, 12-25 million tonnes per year for coal, 29-36 million tonnes per year for waste and wastewater, 6-9 million tonnes per year for rice cultivation and 4-42 million tonnes per year for livestock. This would be an average of about 113 million tonnes per year with wide ranges in each case.

Relevance for the Reference Solution

Methane is the second most important climate gas after CO_2. Reducing methane emissions along the value chains, especially the so-called upstream emissions, are relatively easy to achieve in less diffuse anthropogenic sources such as in the oil and gas sector and some areas of agriculture such as rice cultivation and livestock farming, and have a great leverage effect. A well thought-out strategy to reduce methane emissions must therefore be an imperative part of today's climate protection activities, even if "methane neutrality" is ultimately unachievable. To be considered, but difficult to quantify, are the risks of uncontrolled methane release from natural sources in the course of general climate changes leading to thawing of permafrost areas and warmer ocean currents and decomposition of methane hydrates.

5.7 Nature-based solutions

In addition to the technical options for avoiding CO_2 described above, nature-based solutions for climate protection play a decisive role in the realisation of Net Zero. This chapter describes the solution components that can be assigned to the nature-based solutions for climate protection. Nature is a **significant CO_2 sink** and it is important to **preserve, relieve and expand** this **absorption capacity of the biosphere**. Today, terrestrial and marine ecosystems store a total of up to **20 billion tonnes of CO_2** per year.[139] Furthermore, there is an additional storage potential of at least 10 billion tonnes of CO_2[140], which corresponds to about a quarter of today's global CO_2 emissions in the energy-related sector. Other sources suggest that nature's additional storage potential could be expanded by 15 billion tonnes of CO_2 by 2050 if appropriate measures are taken.[141]

In this paper, we assume an annual absorption of 14 - 20 billion tonnes of CO_{2eq} and an additionally exploitable potential of about 10 billion tonnes of CO_{2eq} . For the further course of the considerations, especially the initial situation for the GES Reference Solution, we use the conservative value of 14 billion tonnes of CO_{2eq} . In the course of offsetting the emissions generated under normal circumstances by the wealth creation of the Challenge Group, this value is successively increased.

However, the high importance for climate protection is not the only reason why nature-based solutions are a central component of the Reference Solution.[142] They are also predestined to enable **development in the sense of the 2030 Agenda**.[143] Agriculture and forestry are important economic sectors, especially in developing countries, which is why they represent an important lever for improving the economic situation in developing countries. According to estimates by the World

[139] Cf. Friedlingstein et al. (2022), FAO (2022).
[140] Cf. Girardin et al. (2021).
[141] Cf. UNEP (2022a).
[142] Cf. ILO, UNEP & IUCN (2022).
[143] Cf. Smith et al. (2019).

Economic Forum, targeted support and framework conditions for nature-based solutions in these sectors could create 10 trillion US dollars in new value added and 395 million new jobs by 2030. [144]

Nature can be understood in a much more fundamental way as the **basis for value creation**. If it is described in economic terms as natural capital, it becomes clear what is meant. Like other types of capital, e.g. financial, physical and human capital, it is a necessary precondition for any form of value creation, even beyond agriculture and forestry. The following figures illustrate the extent to which total value creation is dependent on nature: According to the World Economic Forum, more than half of the world's gross domestic product, i.e. more than 44 trillion dollars, depends on nature, i.e. on forests, oceans and other habitats.[145] Against this background, some voices estimate the danger of biodiversity loss for the stability and prosperity of humanity as probably greater than climate change.[146] To a certain extent, (human) life can adapt to climate change. However, if life in the form of biodiversity is destroyed, adaptation is difficult. Stabilising ecosystems must therefore be the order of the day.

In the following, the approaches from the field of nature-based solutions are described that are part of the Reference Solution and contribute to achieving Net Zero by 2070 at the latest. This does not mean that there are no other influential developments in the field of natural CO_2 sinks that should definitely be positively influenced. Examples include peatland protection and the protection of the boreal forests in the northern hemisphere. A look at the world's largest peatland area in the Congo region, which is threatening to collapse, alone illustrates the great importance of peatlands for climate protection: around 30 billion tonnes of CO_2 are stored there.[147] As a result of drought and forest fires, the boreal forests released more CO_2 in 2021 than ever before.[148] It is essential to avoid this.

The described elements from the field of nature-based solutions are accompanied by a **gigantic land requirement of more than 2 billion hectares**. These areas exist: Of the quarter of the world's land that is degraded today, more than 2 billion hectares have the potential to be restored.[149] Deforested areas alone that could be reforested account for 2 billion hectares. [150]

The following figure visualises the major changes in land use over the last 10,000 years, which today mean that the extensive measures in the field of nature-based solutions do not fail in any case due to a shortage of land:

[144] Cf. WEF (2020).
[145] Cf. Gelinsky (2022).
[146] Cf. IPBES (2019).
[147] Cf. Garcin et al. (2022).
[148] Cf. Zheng et al. (2023).
[149] Cf. WVI (2022).
[150] Cf. WRI (2014).

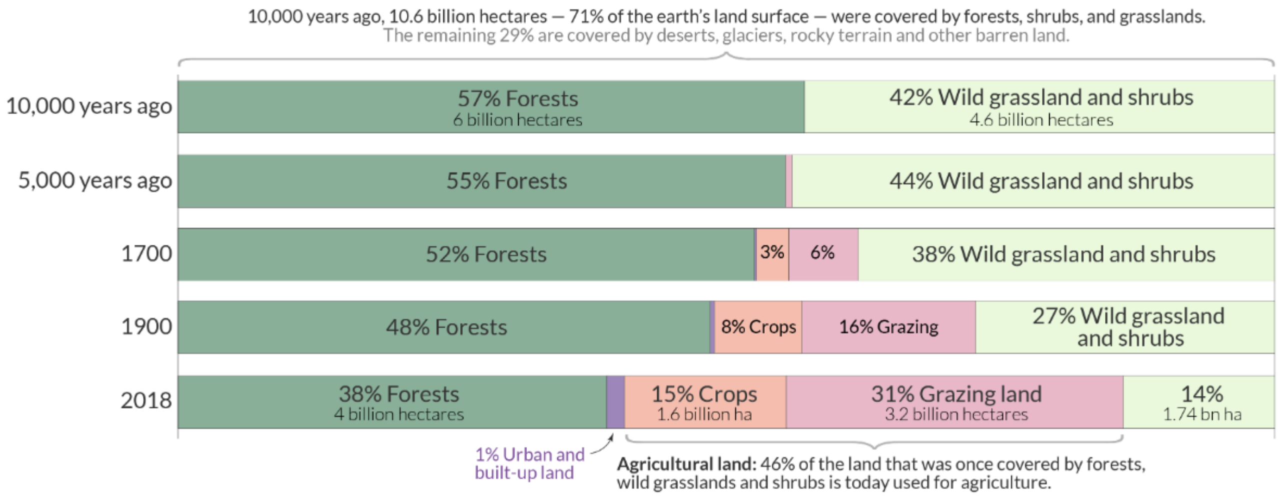

Figure 6: Land use change over the last 10,000 years

Source: FAO

Chapter 2.10 of the basic documentation explains important aspects of the nature-based solutions in detail.

5.7.1 Conservation of the tropical rainforests

A broad-based programme to preserve the remaining tropical rainforests is of great importance. From the perspective of climate protection, the aim is to **preserve their CO_2 storage capacity**. From a **biodiversity** perspective, it is about preserving the ecosystems with the highest density and biological diversity. The tropical rainforest stores up to 700 tonnes of CO_2 per hectare. Another rule of thumb is 1 tonne of CO_2 per cubic metre of rainforest. On average, tropical forests store 400 tonnes of CO_2 per hectare (including the forests surrounding the rainforest, e.g. secondary rainforests).

In recent years, an average of 10 million hectares of forest have been lost per year,[151] including about 4 million hectares of tropical rainforests.[152] A good 10 % of global emissions are due to deforestation. They amount to about 4 billion tonnes of CO_2.

Today, the world still has about 1.8 billion hectares of tropical rainforest.[153] Conservatively estimated (500 tonnes of stored CO_2 per hectare), preserving this would correspond to a CO_2 emission avoidance of about 900 billion tonnes of CO_2 compared to complete deforestation.

Preserving the remaining forests, and especially the rainforests, is therefore an indisputable imperative. In addition, there are further arguments that underpin this necessity. Forests and especially

[151] Cf. FAO (2022a).
[152] Cf. statista (2022).
[153] Cf. FAO (2022a).

rainforests are not only the "hotspots" of biodiversity, but also the basis of life for 1.6 billion people worldwide.[154]

Rainforest conservation is the only component in the Reference Solution that is about a **negative duty**, not a positive duty: it is about refraining from doing something harmful, not about doing something beneficial. It is thus obvious that this component - at least in principle - is the one that is quickest to implement: there are no preparatory measures, no development times and no ramp-up curves. However, if one looks at the situation in the affected countries, especially Brazil, Indonesia and Congo, it quickly becomes clear that crucial preconditions for the preservation of the rainforests are not fulfilled today.

To achieve Net Zero worldwide in 2070, rainforest conservation in the Reference Solution contributes to the reduction of greenhouse gas emissions from land use change to the extent of 3 billion tonnes of CO_2 per year. In the 45-year period from 2025 – 2070 a total of about 135 billion tonnes of CO_2 could be avoided. In this way, the natural CO_2 buffer is both preserved and relieved.

Recent developments show that the situation regarding rainforest conservation is coming to a head. Brazil, Congo and Indonesia formed an alliance at the end of 2022 to demand compensation from industrialised countries for reducing deforestation in their forests. If these funds do not flow, they threaten to auction the land for other uses.[155] Part of the solution to the existing climate challenges must be to find a way forward that includes the required payments. Conversely, the concentration of rainforests in essentially only three countries means that it should be easier to negotiate appropriate treaties on rainforest conservation than if, as with the climate issue, the entirety of the community of countries is involved. Viewed soberly, a small group of the financially strong countries could tackle the rainforest together with the three rainforest countries.

5.7.2 Reforestation on 1 billion hectares of degraded land

Another element is the afforestation of 1 billion hectares of degraded soils for the long-term storage of 5 billion tonnes of CO_2 per year, which will be achieved in a ramp-up of 25 years until 2050 (afforestation). This means that on average 40 million hectares per year must be afforested. The trees are harvested after an average of 40 years. In order to reach a "steady state", new trees should be planted directly after harvesting.

It is about **commercial forests** and thus about the production of **cultivated biomass**, which should be used cascade-like, i.e. several times over many years, in order to achieve **permanent CO_2 binding**. The wood should not be burnt, but used as a material and pyrolysed into biochar at the end of

[154] Cf. BMZ (2017).
[155] Cf. FAZ (2022).

its life cycle and incorporated into the soil. In this way, genuine CO_2 removals are created. The CO_2 is permanently removed from the atmosphere. In addition, the biochar makes a significant contribution to soil improvement, cf. chapter 5.6.3.

If residual wood is used thermally, it should be burnt in a climate-neutral way, e.g. as pellets. The resulting CO_2 should be captured. It has an economic value and as biogenic CO_2 represents a starting point e.g. for the production of synthetic fuels, cf. chapter 5.5.

If managed forests are optimised in terms of "maximum CO_2 effect", it is possible for them to bind significantly more CO_2 than natural forests can.[156] One reason for this is that falling and decaying trees release CO_2 again. A sensible balance must be found here between economic management and demands for the preservation of biodiversity, e.g. with regard to the planting of monocultures.

It goes without saying that such a large-scale afforestation programme generates **added value** and creates many **jobs**. The extensive development effects resulting in addition to the positive climate effect underline the importance of such an element for the overall solution.

5.7.3 Restoration of 1 billion hectares of degraded soils

Another very land-intensive component is the restoration of 1 billion hectares of degraded soils for the long-term storage of 5 billion tonnes of CO_2 per year, which will be achieved in a ramp-up over a period of 25 years until 2050 (Soil Improvement). This size of area covers only a small proportion of the world's land, for which there is great potential to increase the CO_2 content of the soil, which has continued to fall in recent years as a result of soil degradation.[157] The target of 5 tonnes of CO_2 per hectare is also a conservative estimate, as it is possible to store up to 25 tonnes of CO_2 in one hectare of soil. [158]

The central issue is the **build-up of humus**, which not only stores carbon, but also important plant nutrients and water, and contributes significantly to a balanced, healthy soil. There are three ways to build humus. These are maximising the diversity of plants and crops grown, maximising photosynthetic capacity by promoting plant growth, and minimising soil disturbance through frequent tillage and chemical fertilisers. It is about horticultural tillage of soils in an agricultural context.

Another element is the incorporation of **biochar/phytochar** into soils. The plant charcoal is produced by pyrolysis of, for example, crop residues and other biogenic waste materials that are not needed in the food sector. If the biomass is prevented from being burnt and is instead introduced into the soils as charcoal, genuine CO_2 removals are created in this way. The CO_2 is permanently removed

[156] Cf. Luick et al. (2021).
[157] Cf. FAO (2022b)
[158] Cf. Model Ökoregion Kaindorf (2023).

from the atmosphere, as the plant charcoal is essentially stable for decades to centuries and does not degrade. Depending on the quality of the charcoal and regional conditions, 0.3 % degradation per year can be expected.

The impact of such a programme can hardly be overestimated. As in the area of afforestation, **value creation** and **jobs** are created. In addition, a major contribution is made to food security because the yield capacity of the soils is decisively improved. In addition, soils contain a huge amount of biodiversity, which has not yet been adequately researched due to its complexity.

We see 5.7.2 and 5.7.3 as another wild card in our solution. In the ramp-up, after 40 years at the latest, about 10 billion tonnes of CO_2 per year will be removed from the atmosphere in addition to all our other activities. The programmes make the ambitious targets much easier to achieve. After all, the closer we get to Net Zero, the more expensive it becomes to avoid each additional tonne of CO_2. If we use the potential of the approaches described, we can forget about that challenge. It is as if we are creating an outlet for ourselves.

Interestingly, under sensible regulation, which is favoured globally, private actors will pay a lot of money for the corresponding emission rights. So the programme pays for itself if the governance conditions are created. In this way, the programme facilitates the achievement of targets in our ambitious Reference Solution. Of course, there is also a chance to use the programme to achieve Net Zero for the world even faster and also the 2°C target near 2050. However, one must be aware that this will be very expensive, as the payments of so-called emission rights will be eliminated. The buffer would then be gone, and instead major costs would be added.

5.7.4 Further potential in the area of nature-based solutions

In addition, there is further potential for negative emissions from nature-based solutions beyond the aforementioned 1 billion hectares each for afforestation and soil improvement. The huge **boreal forests** have already been mentioned. Burned areas and additional areas should be restored, especially in the large areas in Russia and Canada, where enormous areas have been destroyed in recent years.

Furthermore, there is also great potential for negative emissions outside the tropics. These are often found in the NDCs of the countries of the Challenge Group within the framework of the Paris Agreement. Overall, GES considers the targets listed there to be extremely ambitious. Nevertheless, it shows that the potentials for nature-based solutions proposed in the following could be included in the NDCs of the countries and thus do not require an additional mechanism for their realisation. All this needs to be clarified if a serious attempt is made to transform the usually conditional NDCs of developing countries and emerging economies into robust NDCs that are no longer conditional. As explained in more detail in Chapter 6.4.1, this will require a lot of money and a lot of intellectual input, but at the same time it is the basis for the cap-and-trade system proposed by GES (cf. Chapter 6.4.2).

The above-mentioned potentials concern, for example, further areas where soils can be enriched with humus and thus with carbon (Soil Organic Carbon/ Soil Organic Matter). Most agricultural land today has only small percentages of these indicators of food quality and soil resilience to impending climate change, including in Europe, North and South America, as well as in arid and semi-arid areas that are more affected by climate change.

There is also a lot of research and experimentation in the area of **maritime solutions** for storing CO_2 from the atmosphere in biomass and its further use. This mainly concerns the use of algae, which, similar to trees on land, can be "reforested" on large floating devices off the coasts in the world's oceans. Some algae have enormous possibilities to extract large amounts of CO_2 from the air. These can be harvested and, for example, pyrolysed into synthetic fuels or, again, into vegetable charcoal and put into the soil.

The importance of mangrove forests was frighteningly demonstrated by the effects of the tsunami in the Indian Ocean in 2004, which was triggered by a seaquake and led to hundreds of thousands of deaths, especially in Indonesia. Mangrove forests off the coasts had previously been extensively deforested and economically exploited, which would otherwise have formed a natural "protective shield" against the deadly water masses. Moreover, it is also true here that mangroves have a high biodiversity and produce positive effects far beyond their climate impact if they are planted.

In total, these elements of the nature-based solutions contribute with about 5 billion tonnes of CO_2 in removals in 2050 to the fact that the CO_2 emissions of the Challenge Group will then drop to 3 billion tonnes. In combination with CCUS, the development of an energy system on 2 pillars with new renewables and reliably controllable energies as well as the possible use of nuclear energy, the Reference Solution thus makes the necessary contributions to the approximately 54 billion tonnes of CO2 in 2050 that must be eliminated, cf. chapter 5.1.

5.7.5 Short-rotation plantations on 150 million hectares

Another component that cannot be described as a nature-based solution in the narrower sense, but which also relies on nature's CO_2 storage capacity, is the establishment of short-rotation plantations on degraded areas of 150 million hectares (ha). The CO_2 storage potential of such plantations is up to **20 tonnes of CO_2 per hectare**. Fast-growing plants that can be harvested every 6 - 10 years, e.g. eucalyptus, are cultivated on these plantations.

The biomass obtained can be used, among other things, for the production of **climate-neutral fuels**, using the biogenic CO_2. Alternatively, the biomass can be gasified and in this way also be the starting material for climate-neutral fuels and energy sources, see also Chapter 5.5.

Of course, short-rotation plantations will not make a significant contribution to the preservation of biodiversity. In an overall view, land use must be designed in such a way that, on the one hand, biodiversity is ensured, but on the other hand, land is also set aside for industrial biomass production. These are necessary in order to fulfil global prosperity ambitions.

6 Governance and financing - regulatory and financial aspects of the Reference Solution

Chapter 5 has made it abundantly clear that the Reference Solution is a mammoth global programme whose implementation requires conducive framework conditions and sums of money in the trillions.

A realistic assessment includes the clear statement that such sums have never been raised in the past. In particular, it has never been possible in history to provide corresponding sums for the Global South. There are gigantic financing gaps, cf. chapter 2.

OXFAM recently put the **debt** owed by the G7 countries alone to the countries of the Global South for damage **caused by climate change** and the fight against it at **13 trillion US dollars**.[159] This is made up as follows: 8.7 trillion US dollars in losses and damages resulting from climate change, 4.5 trillion US dollars for missed payments in terms of the 0.7% target within the framework of development cooperation, and 72 billion US dollars for unfulfilled commitments to international climate financing within the framework of the Paris Climate Agreement. These figures cannot be verified in detail, but they show the financial dimension of the challenge.

At the same time, today's reality implies that the countries of the Global South will have to repay the G7 countries 232 million US dollars in debt every day until 2028. The need for debt restructuring or even debt cuts is repeatedly raised in this context, as is the demand that countries of the Global South, despite their poor ratings, need access to cheap capital for effective investments. [160]

In the run-up to the summit on a "New Global Finance Pact" at the end of June 2023 in Paris, numerous voices again called for a mobilisation of global financial resources for the Global South in the trillions, including the German Council for Sustainable Development, which called for a reform of the global financial architecture, debt relief and a much higher international deployment of capital for climate and sustainable development.[161] Despite all the demands, however, this meeting also ended without any concrete new course being set.

A **paradigm shift** is therefore still **necessary**. Such a paradigm shift can only succeed if there is a widespread conviction in the countries of the Global North that the necessary enormous flows of money to the Global South should ultimately be made out of sensible egoism, are unavoidable and also represent an economically sensible solution for the people in the Global North.

Against this backdrop, this chapter describes approaches in the area of governance and financing that hold out the chance of succeeding in closing the gigantic financing gaps in the area of international cooperation and international climate financing that exist to date. **The question is therefore**

[159] Cf. OXFAM (2023).
[160] Cf. Gates (2023).
[161] Cf. RNE (2023).

how it can be possible to finally raise the sums necessary to achieve the measures described for achieving Net Zero and the targeted high growth rates in the Challenge Group.

It is assumed that both the enlarged OECD and the China Club will overcome the existing domestic financing challenges with their own resources. These two groups of countries are not the subject of this chapter insofar as it is about the financing of measures that take place in the respective countries themselves. However, the enlarged OECD is of crucial importance for the financing of measures in the Challenge countries.

6.1 Derivation of governance and funding requirements

Taking into account the status quo and the requirements formulated for the Reference Solution, the following section summarises the governance and financing requirements and how the individual measures and programmes interact with each other to ensure that the Reference Solution can meet the requirements described above, both in terms of climate protection and global prosperity expectations.

The "linear" or sequential presentation of the necessary measures represents the result of a non-linear search process, the details of which cannot be fully described.

The following figure shows the **parameters** that have been used to derive the necessary measures, in particular the governance and financing requirements. These are the **population growth**, the targeted **GDP growth**, the **energy demand**, the **CO_{2eq}-emissions** to be eliminated and the available **technologies**.

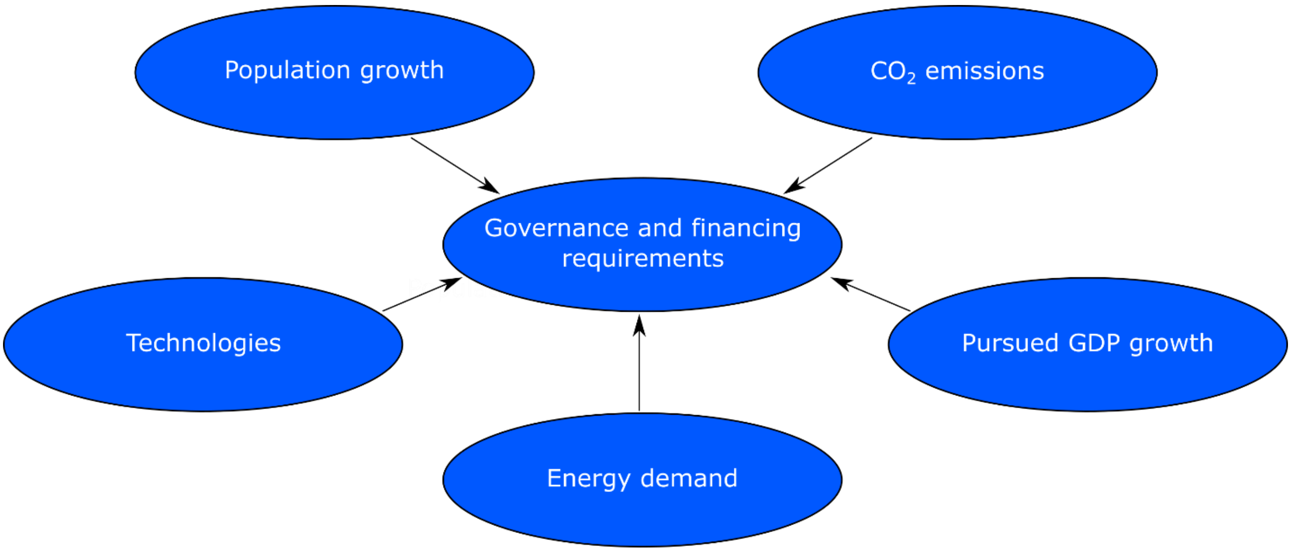

Figure 7: Factors influencing governance and financing requirements

Quantities of CO_{2eq} to be eliminated in the Challenge Group countries

In the baseline situation in 2025, about 53 billion man-made tonnes of CO_{2eq} are produced. Due to the increase in prosperity in the countries of the Challenge Group, emissions will increase from 53 to 59 billion tonnes of CO_{2eq} by 2050 (cf. Chapter 6.3.2 for the derivation).

Of the 53 billion tonnes of CO_{2eq} in 2025, about 14 billion tonnes of CO_{2eq} will be absorbed by nature. This leaves 39 billion tonnes of CO_{2eq}. Compared to a business-as-usual scenario, a total of about **720 billion tonnes of CO_{2eq}** must be eliminated **from 2025 onwards** if the 2°C target is to be achieved.[162]

It is possible to reduce this figure by a total of **200 billion tonnes of CO_{2eq}** directly by forcing the use of certain nature-based solutions (**consistent rainforest protection, short-rotation plantation programme**, other potentials in this area mentioned in Chapter 5) and indirectly by avoiding technical **methane leaks** (Chapter 6.2.4).

The nature-based solutions described play only a partial role in achieving Net Zero. This is especially true for the programmes for afforestation and restoration of soils on 1 billion hectares each described in chapters 5.7.2 and 5.7.3. These assume the role of a **buffer** in the Reference Solution because their CO_2 effect is not included in the calculations for achieving Net Zero. This buffer is a 40-year build-up of natural CO_2 sinks, which in the final expansion stage will lead to a CO_2 sequestration of 5 billion tonnes of CO_2 each through afforestation on degraded soils in the tropics on the one hand and restoration of degraded soils of extremely low productivity on the other, especially in countries of the Global South. In total, we are talking about 10 billion tonnes of CO_2 removals per year. It goes without saying that such large-scale measures in the area of forestry and agriculture create urgently needed jobs in large numbers in the countries of the Challenge Group, thus increasing prosperity, promoting biodiversity and also contributing to food security. The potentials described in Chapter 5.7.4 are to be raised in the course of adjusting the NDCs and are thus included in the Net Zero calculation.

The further calculation for achieving Net Zero is based on **520 billion tonnes of CO_{2eq}.**

In line with the assumptions made that 39 billion tonnes of CO_{2eq} in 2025 will be evenly distributed among the three country groups at 13 billion tonnes CO_{2eq} each, this means that the total amount of 520 billion tonnes of CO_{2eq} will also be evenly distributed among the country groups at about **173 billion tonnes CO_{2eq} each**: The expanded OECD will eliminate its share by 2050, the China Club by 2060.

162 Cf. IPCC (2021).

In the countries of the Challenge Group, measures need to be financed and provided with conducive governance to help manage this CO_{2eq} amount. It would be **much higher in** a **business-as-usual scenario**.

The GDP growth of the challenge countries is expected to average 6 % in the Reference Solution and to grow from 20 trillion US dollars in 2025 to 80 trillion US dollars in 2050. Such growth seems possible in the context of a massive transformation and financing programme. At the same time, 6% growth represents an upper limit of what is feasible. It is on the same scale as the **Marshall Plan** after World War II, which lasted four years. In the context of the Reference Solution, we are talking about a time horizon of 45 years (2025 - 2070).

Past experience shows that GDP growth means an increase in energy demand**.** In "Hard truths about green growth"[163] , with reference to studies by the International Monetary Fund since 1990, it is stated that a GDP increase of 1% resulted in a 0.7% increase in CO_2 emissions of the country concerned. In the Reference Solution, we consider a GDP growth of the developing and emerging countries of 300 %. This would then correspond to an increase of 210% in CO_2 emissions, based on 13 billion tonnes of CO_2 and a total of 27.3 billion tonnes of CO_2 emissions. In our estimates, we are more cautious with regard to the increase and more ambitious with regard to the decoupling of GDP growth and CO_2 emissions, and expect an increase of 20 billion tonnes of CO_2 .

A more in-depth article on the topic, "Development v Climate"[164] also refers to research by the International Monetary Fund regarding the use of coal: here it is estimated that **357 billion US dollars per year** will be needed for India, Indonesia and South Africa by 2030 if these countries are to **phase out** their **coal-fired power plants by 2050**. We are talking about about 1.8 billion people in these countries. In the GES reference solution, we consider about 200 US dollars of support per capita per year to be necessary, which amounts to a similar amount. So the estimates are going in the same direction.

The Reference Solution is based on the assumption that half of the GDP increase (60 trillion US dollars), i.e. 30 trillion US dollars, does not require an energy increase due to efficiency improvements and lifestyle adjustments. The second half requires energy growth. CO_{2eq} emissions rise proportionally - from 13 billion tonnes of CO_{2eq} with a GDP of 20 trillion US dollars in 2025 to **33 billion tonnes of CO_{2eq} in 2050**. The energy increase used as a basis is based on the experience of the industrialised countries and China and is also tightly calculated. 30 trillion US dollar GDP growth through energy growth is accompanied by 20 billion tonnes of CO_{2eq} , which corresponds to the same ratio as 13 billion tonnes of CO_{2eq} at 20 trillion US dollars in 2025.

[163] Cf. The Economist (2023a)
[164] The Economist (2023b)

An examination of the NDCs of the countries in the **Challenge Group** and the net zero deadlines contained therein leads to the conclusion that, even with great efforts, a maximum of only 30 billion tonnes of CO_{2eq} can be eliminated by 2050, this in orientation to central net zero pledges, e.g. of India (2070), as well as in view of the net zero target of China (2060).

Elimination of the remaining **3 billion tonnes of CO_{2eq}** must be postponed until **after 2050,** as must 2 billion remaining tonnes of CO_{2eq} from the China Club.

20 % of the 30 billion tonnes of CO_{2eq} to be eliminated by 2050 are to be covered by a further expansion of the old renewables (hydropower, bioenergy, geoenergy), leaving 24 billion tonnes of CO_{2eq}.

Following the two-pillar approach of the GES Reference Solution, it is assumed that 12 billion tonnes of CO_{2eq} will be covered by new renewables. A further 12 billion tonnes of CO_2 will be generated in the fossil energy sector - unless nuclear energy is used as an alternative reliable, controllable energy source or a further expansion of renewables beyond 50 % can be realised due to local conditions. The increased use of gas instead of coal for power generation should also make a contribution here, since gas has a lower CO_2 intensity. In addition, the other nature-based solutions from Chapter 5.7.4 have an impact here.

The average CO_2 pollution per year from fossil fuels in a linear ramp-up to 2050 is therefore a maximum of about 6 billion tonnes of CO_2 and should be reduced as far as possible by the other options mentioned.

An absolute necessity: Winning over the Challenge Group for participation

The countries of the Challenge Group must be persuaded to significantly reduce their CO_2 emissions, although they do not have to from a UN perspective. Their current NDCs are of limited use for various reasons and should be differentiated, cleaned up and used so that, for example, parts of the nature-based solutions are included in them. This situation is one of the main challenges in finding a Reference Solution. Appropriate measures must be taken to deal with this situation. They represent crucial and non-trivial elements of governance and financing. In the field of the energy system, it is a matter of **co-financing transnational energy infrastructures** and **bearing differential costs** compared to remaining in the status quo. Finally, "systemic" measures are required: **the NDCs of the countries in the Challenge Group, which have not been very resilient so far, must be reviewed and their implementation must be made possible.**

Successful implementation of the measures described above would also make it possible to derive a canonical global **cap-and-trade system** based on the adjusted NDCs. The 'whole deal' approach must be accepted as fair and sustainable by all actors. The cap-and-trade system facilitates the path to net zero for all participating countries and unlocks cost advantages for each participant.

6.2 Programmes for the preservation, expansion and relief of natural systems as CO_2 reservoirs and the prevention of technical methane leaks

The programmes described in these sub-chapters serve to preserve, expand and relieve the burden on natural systems as CO_2 reservoirs. In total, they reduce the annual CO_2 pollution by 200 billion tonnes between 2025 and 2050 or 2070 (rainforests). In detail, this involves classic nature-based solutions, namely the conservation of the remaining rainforests, a gigaprogramme in the area of reforestation and the restoration of soils in the tropics, further potentials, e.g. in the area of boreal forests, mangroves and algae, as well as a focus programme for short-rotation plantations. In addition, there is a programme to prevent technical methane leaks.

All the programmes mentioned are to be privately funded under the Reference Solution. In the area of governance, however, there is a requirement to bear upfront costs on the one hand and to create a conducive environment for the private donors on the other, which in particular enables them to become active effectively and without reputational risks. We calculate that the upfront costs of all the programmes described below will total **200 billion US dollars** per year. They are needed for the establishment of corresponding UN processes and capacity building.

6.2.1 Regulatory flanking of the preservation of the remaining rainforests

There is no doubt that the remaining rainforests should be consistently conserved for many reasons. Although the realisation of the urgency to act is not new, the world has still not managed to stop the destruction of the rainforests. At the same time, preserving the rainforests is the cheapest and, in principle, quickest way to protect the climate, since it is ultimately "only" a matter of no longer doing something. The fact that no success has been achieved has a lot to do with the fact that the rainforests are located in countries of the Global South and thus - as in many other contexts - there is a lack of funding to make protection possible.

The latest development is closer cooperation between the countries of Brazil, Congo and Indonesia to "motivate" the rich countries to finally raise substantial financial resources to protect the tropical rainforests. Should this not happen, they want to gradually use more and more rainforest areas for other purposes or auction off areas for use.

Previous approaches to raise funds for rainforest conservation via the voluntary CO_2 market never brought the hoped-for success. Despite elaborate certification procedures, forest projects are repeatedly criticised.[165] The issues are CO_2 measurement methods, permanence requirements for CO_2 sequestration and questions of carbon leakage. Companies that support such projects fear greenwashing accusations and are concerned about their reputation. In addition, many financial resources are spent on costly certification processes and occasionally on legal disputes with critics. For rainforest protection, then, only parts of the already far too small funds remain.

Against this background, a different approach is proposed, which is much simpler to implement than anything that has been done so far and attempts to pragmatically reduce bureaucracy to what is absolutely necessary: private actors, e.g. companies and philanthropists, are to be persuaded to pay **100 US dollars** ex post, i.e. after the end of the year, to the corresponding rainforest country **for every hectare of rainforest** that is kept intact in its natural state for one year without any loss of quality.

In total, a sum of about **100 billion US dollars per year** appears necessary if all the rainforest areas that still exist today are to be preserved within the framework of the approach described.

The areas are recorded in a cadastre using geoinformation systems via aerial and satellite images. This could be, for example, the software "EarthRanger".[166] The condition at the beginning of the year is documented. A contract, which the respective state can sign, assures payment of the 100 US dollars - under the condition that the hectare of rainforest in question still exists at the end of the year in at least the quality of the starting situation at the beginning of the year. In addition, it takes into account the potential of the rainforest for agroforestry and tourism in an appropriate manner.

The contract relies on the effect of money: it guarantees a secure income of 100 US dollars per year for one hectare of rainforest as long as it is conserved. This is a different path than has been taken so far: Although there is no permanence requirement, it still opens up a great opportunity for permanent conservation of most hectares of rainforest. The leakage question also does not arise due to the holistic annual consideration of the rainforest stock and the accompanying remuneration.

On the governance side, there is a requirement to bear upfront costs on the one hand, and on the other hand to create an enabling environment for private donors to become active effectively, sustainably and without reputational risks. Here, UN agencies should work in cooperation with professional private organisations active in the field of rainforest conservation. On the private side, this could include African Parks or WWF.

[165] Cf. The Guardian (2023); Fischer, Knuth (2023).
[166] Cf. Earth Ranger (2023).

6.2.2 Regulatory flanking of reforestation and restoration of degraded areas

Chapters 5.6.2 and 5.6.3 described the two measures that together are referred to as the gigaprogramme in the field of nature-based solutions: On the one hand, in the area of forestry, it is about reforestation on 1 billion hectares of degraded soils in the tropics; on the other hand, in the area of agriculture, it is about the restoration of another billion hectares of degraded soils of low productivity, also primarily in the countries of the Global South, which is to be achieved in a 40-year ramp-up. In both cases, these are value-adding activities that pay off economically - via the resource wood gained and via the increase in agricultural yields. This is all the more true if CO_2 is finally reliably given an appropriate price within the framework of a cap-and-trade system and measures are rewarded with which CO_2 is permanently removed from the atmosphere.

In the described **gigaprogramme** in the area of nature-based solutions, **10 billion tonnes of bound CO_2** are involved at the end of the 40-year ramp-up beginning in 2025. As far as possible, this amount of CO_2 emission reductions does not flow into the achievement of Net Zero under the Reference Solution, but serves as a **buffer**. Financing is provided by the private sector.

However, government funds from the expanded OECD are needed to initiate the programme and to guarantee an environment with a secure reputation for the private actors. It must be ensured that strict sustainability principles are adhered to and that the CO_2 remains permanently bound (**removal**), e.g. through a cascade-like use of the wood. It is to be expected that corresponding CO_2 certificates will fetch good prices, which will benefit the people in the countries of the Challenge Group. Such certificates could become very important for the mobility sector, where it will be a matter of also achieving the status of balance-sheet climate neutrality for volatile CO_2 sources (e.g. vehicles powered by certain synthetic fuels).

Financing is provided through a cap-and-trade system set up specifically for this purpose, in which all people - through their countries - participate on balance with 1 tonne of CO emission rights. $_2$

If the gigaprogramme is successfully built up in the area of nature-based solutions, a buffer of about 1 tonne of CO_2 per person will build up for humanity, which will take some of the pressure off the process of reducing CO_2 emissions.

6.2.3 Regulatory flanking of short-rotation plantations

A system of short-rotation plantations is envisaged on a suitable 150 billion hectares of land. The UN Climate Change Secretariat calculates that up to 750 billion hectares are available.[167] The

[167] This figure was given by Panna Siyag (UNFCCC) in a discussion on the potential of bioenergy. Cf. Lenton (2014).

plantations are harvested after seven years and replanted. They are a good source of energy (electricity and heat), of about the same quality as lignite. This provides solid financing for all countries in the South that realise such plantations. For climate reasons, biogenic CO_2 is captured. It is just as suitable as CO_2 from direct air capture to be used in combination with hydrogen for the production of re-fuels. **This generates income, as well as energy and an important raw material.** The UN expects 150 billion hectares of suitable land and a CO_2 capture of 25 tonnes per hectare, i.e. a total of 3.75 billion tonnes per year.

A positive **example**, which has its beginning in the 1960s, are large-scale forest plantations for commercial timber production in **Brazil**, which do not exist at the expense of the rainforest. Fast-growing tree species such as eucalyptus are used there. Productivity averages 38.9 cubic metres per hectare per year. The plantations are established on former cattle pastures, mostly degraded areas. No rainforest is cleared.

In 2021, the total area of natural forests in these forest mosaic plantations was 6 million hectares, resulting in a richer biodiversity than the former pasture land had. Some of the new natural forests now consist of rare and threatened ecosystems. Agroforestry now covers an area of 17.4 million hectares and is expected to increase by another 9 million hectares by 2030.[168]

There are various possible uses for the wood obtained: Biochar based on charcoal is one form of utilising the yields from short rotation coppice. **Waste wood is pyrolysed**. Here, only little energy is produced, but a lot of biochar or charcoal is produced. These are real removals and thus valuable contributions. They are suitable for soil improvement, which directly pays off economically in the harvests on these areas.

Finally, wood can be taken out of the cycle in the long term and used in the construction industry, for example. In such a process, the CO_2 also remains permanently stored and added value is generated.

In the environment of short-rotation plantations, too, policy-makers should provide a regulatory environment that promotes scaling. In addition, positive communication is also important here. Short-rotation plantations should not be perceived as soil leachers and destroyers of biodiversity, but as a positive contribution to climate protection and value creation if they are operated conscientiously.

6.2.4 Regulatory flanking of the elimination of technical methane leaks

Immediate prevention of further methane emissions is urgent and should be implemented quickly where feasible.[169] In the context of the Reference Solution, the elimination of technical methane

[168] Cf. Sollinger (2023).
[169] Cf. Wernicke (2023) Avoidance programme technical methane and gas leaks

leaks is an element that has a major impact on the greenhouse gas content of the atmosphere, since we are talking about emissions of currently about 600 million tonnes annually, of which about 370 million tonnes come from anthropogenic sources. Based on the climate factor of 24, this corresponds to total greenhouse gas emissions of 14.4 billion tonnes of CO_{2eq} annually, with an anthropogenic share of 8.9 billion tonnes. Methane emissions alone account for 16 % of the global greenhouse gas impact.[170]

In the field of technical methane leakage elimination, the focus is on **minimising emissions arising from the extraction, transport and use of natural gas and liquefied natural gas (LNG)**. Important keywords are pre-chain emissions and flaring. Corresponding measures are relatively easy to implement. Technical details about this are described in chapter 5.6.

In the context of avoiding methane emissions, some initiatives already exist that should be built upon in the Reference Solution.

Of particular note is the **Global Methane Pledge** launched at COP26 in Glasgow in 2021.[171] It aims to trigger global action and provide support for existing international initiatives to reduce methane emissions. On board are 150 countries accounting for nearly 50% of global anthropogenic methane emissions and more than two-thirds of global GDP. The pledge's goal is to prevent more than 8 billion tonnes of carbon dioxide equivalents from entering the atmosphere annually by 2030. In addition to a number of non-governmental organisations, UNEP as a UN agency is involved as a supporter.

The estimated **abatement costs are 600 US dollars per tonne of methane**. This is relatively cheap, as one tonne of methane emissions corresponds to about 24 tonnes of CO_{2eq} emissions. Thus, the CO_{2eq} abatement price is **about 25 US dollars per tonne of CO_{2eq}**. This opportunity for an efficient use of funds should be used.

The measures to avoid methane emissions are not yet bundled worldwide. As a result, regional initiatives are emerging all the time. For example, PETRONAS has launched the ASEAN Energy Sector Methane Leadership Program (MLP) in cooperation with ASEAN energy companies, government agencies and international organisations, and announced methane reduction flagship projects in collaboration with the Japan Organization for Metals and Energy Security (JOGMEC).[172]

The oil and gas industry offers some of the best and most cost-effective ways to reduce methane emissions.[173] The International Energy Agency (IEA) recently criticised the fight against methane emissions for being too slow. It quantified the investment requirements for a consistent reduction of

[170] Cf. IEA (2023a)
[171] Cf. Global Methane Pledge (2023).
[172] Cf. WBCSD (2023b).
[173] Cf. IEA (2023b).

the climate gas by 2030 - and named a sum of 75 billion US dollars. The proportionally (manageable) costs should be borne by the companies in the oil and gas industry and can be passed on to the final price.

In order to deal with the problem of technical methane leaks as quickly as possible, the regulatory environment should be improved and the incentives for private actors to invest effort and resources in corresponding processes should be increased.

At the regulatory level, the aim must be to **create an environment through good governance and international agreements in which private actors bear the costs of eliminating the various methane leaks**.[174] This should be designed in such a way that appropriate measures are taken worldwide and especially in the countries of the Challenge Group. There are oil and gas deposits there as well. In the case of their extraction and use, it should be ensured that the available technologies to ensure greenhouse gas neutrality are applied, regardless of where this takes place.

The countries could also create incentives, e.g. on the tax side, from which those companies benefit that have demonstrably eliminated their methane leaks.

6.3 Programmes for the development and restructuring of the energy system

This sub-chapter describes two approaches to financing the development and restructuring of energy systems in the countries of the Challenge Group. On the one hand, it is about co-financing energy infrastructures and, on the other hand, about assuming differential costs compared to "business as usual", for example in the context of carbon capture.

6.3.1 Co-financing of transnational energy infrastructures

This programme is intended to finance measures in the field of infrastructure development, which are necessary if the goal is an efficient energy system.

In detail, this involves financial support for the countries of the Challenge Group

(a) in the development of transnational electricity grids[175]

(b) in the development of transnational gas pipelines (natural gas and hydrogen)

[174] Cf. IEA (2020).

[175] For example, the Global Energy Interconnection Development and Cooperation Organization (GEIDCO) in Beijing, which was founded in 2016, is dealing with this issue.

(c) in the development of transnational pipeline systems for CO_2

(d) in the development of transnational infrastructure for the transport and storage of CO_2

In other words, it is about the financing of collective inputs that cannot be attributed to any single actor, be it a single state or a single company.

This programme is estimated to cost **150 billion US dollars annually.**

6.3.2 Absorption of differential costs for carbon capture

The differential cost assumption approach goes back to the **Montreal Protocol**, which succeeded in closing the ozone hole in the 1980s. It is a multilateral environmental agreement that has been successfully implemented. Its success was largely due to the fact that the industrialised countries agreed to support the developing countries in fulfilling their contractual obligations and to bear the differential costs compared to remaining in the status quo. In total, 847 million US dollars flowed through a multilateral fund, 20 % of which was spent by the implementing organisations of the donor countries. The World Bank, UNDP, UNIDO and UNEP supported the implementation and enforcement of the protocol. Today, the Protocol is administered by UNIDO.[176]

The Montreal Protocol impressively illustrates how, with good governance and a given willingness on the part of rich countries to provide adequate financial support, it is possible to tackle global challenges that require cooperation and large international flows of money.

In the logic of the Montreal Protocol, this programme is about bearing the additional costs of intercepting CO_2 or other CO_2-avoiding measures in the context of building reliable controllable energy. **In the main programme of the proposal, OECD countries immediately assume all corresponding additional costs when building or expanding the energy systems of the Challenge Group.** The main countries supported include countries on the African continent, Latin America, India and neighbouring countries, Indonesia, etc. This also includes all Least Developed Countries.

It is estimated that the energy demand of these countries will increase by a factor of 2.5 by 2050, whereby a not insignificant part will continue to be covered by fossil energies in the future. It is calculated that the removal of an average of 6 billion tonnes of CO_2 per year will cost an average of 100 US dollars per tonne. This will essentially finance: Carbon capture, but also the increased use of gas instead of coal for power generation, where it makes sense under regional conditions a stronger expansion of nuclear energy or stronger expansion of renewables beyond the 50 % of the energy system usual for GES, but also in the activation of negative emissions via nature-based solutions.

[176] Cf. UNIDO (2023).

Thus, on average, differential costs amounting to an **annual average of 600 billion US dollars** are incurred. This sum is estimated for the programme described.

The average volume of 6 billion tonnes of CO_2 per year is justified as follows, cf. also Chapter 6.1:

Derive the scope for eliminating emissions of 6 billion tonnes of CO_2

The Challenge Group's projected 2025 emissions of 13 billion tonnes of CO_2 are equivalent to a GDP of 20 trillion US dollars.

The target GDP growth of 6 % leads to a GDP of 80 trillion US dollars in 2050. This is a total GDP increase of 60 trillion US dollars. One half of this GDP increase, i.e. 30 trillion US dollars, is covered by efficiency gains and lifestyle changes, which does not require an increase in the amount of energy. For the second half, i.e. again for a GDP growth of 30 trillion US dollars, further, additional energy must be provided.

This growth corresponds to an increase of about 20 billion tonnes of CO_2 , based on the ratio of GDP to resulting emissions in the base year 2025 (20 trillion US dollars with 13 billion tonnes of CO_2).

In total, about 33 billion tonnes of CO_2 need to be eliminated in the Challenge Group in 2050, assuming a structurally unchanged energy mix compared to 2025.

Due to the different net zero points in time, which in parts will not be reached until 2060 or 2070, about 3 billion tonnes of CO_2 will still remain in the Challenge Group in 2050.

In the year 2050, the Challenge Group is thus ultimately aiming to eliminate 30 billion tonnes of CO_2, with a corresponding ramp-up of annual values starting from 2025.

Of the 30 billion tonnes in 2050, 20 % will be covered by a further expansion of the old renewables (hydropower, bioenergy), leaving 24 billion tonnes of CO_2.

Of these, 12 billion tonnes of CO_2 will be covered by new renewables. A further 12 billion tonnes of CO_2 will be generated in the fossil energy sector (insofar as they are not replaced by nuclear energy or reduced by the increased use of gas instead of coal or via nature-based solutions within the framework of the NDCs).

Based on the 12 billion tonnes of CO_2, the average burden of CO_2 per year from fossil fuels over 25 years is about 6 billion tonnes. Of the 12 billion tonnes of CO_2 per year, about 8 billion tonnes are reduced via carbon capture, the remaining 4 billion via the other measures mentioned.

In actual implementation, the funding requirement will increase continuously from year to year. This cost curve can be smoothed over the entire financing period with the help of financing instruments. In economic terms, the above-mentioned financing flows go hand in hand with a massive stimulation of the economies of the respective countries if the value added for the triggered investments takes place in the recipient country and, above all, the additional supply of cheap, reliable energy has a positive influence on economic growth.

A smart approach is needed to ensure that the costs of carbon capture and other measures are proportionally linked to the level of emissions. It must be kept in mind at this point that the green-fossil infrastructure, in interaction with the other components of the energy system, must be able to function as a back-up system during the time when volatile renewables are not generating energy. This must be ensured for each specific case through the design of the available infrastructure, in which an increased expansion of green-fossil capacities, CO2 storage and the possibilities of a smart energy system are combined in such a way that greenhouse gas emissions are avoided for each operating case. Capacity markets or other steering regulations may be required for this purpose.

Some of the costs can be apportioned over the years, e.g. for the one-off technical retrofitting of the carbon capture technology or for the construction of a new gas-fired power plant including carbon capture instead of a coal-fired power plant, whereby differential costs may have to be reimbursed. Other costs will be incurred on an ongoing basis, e.g. in the context of the higher energy consumption for carbon capture, for the operation and maintenance of the carbon capture system itself, and for the transport and injection of the CO2.

The sums accruing in the context of the assumption of differential costs can, if necessary, be allocated to the years via financial policy instruments. Then, for example, savings or investments are made at the beginning, which is appropriate here. In other cases, funds can be made available through Green Funds. The states guarantee the later redemption of the financial payments. Over the years, the costs decrease. Depending on the economic development, the developing and emerging countries can begin to contribute to the costs to a certain extent after perhaps 15 years (2040).

Finally, it should be noted that nuclear solutions will hardly be cheaper in terms of differential costs than carbon capture in green-fossil solutions. Many challenge countries will not be able to safely manage the complexity of the technology for a long time. Many countries in the challenge group are areas of tension with risks of civil wars or armed conflicts with neighbouring states. This will prevent the suppliers of this technology from installing it on the ground. With this in mind, the focus of the Reference Solution is on carbon capture, increased use of gas where possible, and tapping into the nature-based solutions that are not part of the buffer.

6.4 Systemic approaches

This sub-chapter describes two systemic approaches that should lead to a realistic feasibility of the developing countries' NDCs and also allow all actors involved to pursue efficient ways to achieve their climate goals. It is about a revision of the NDCs of developing and emerging countries and a subsequent implementation of a cap-and-trade system based on the NDCs of the participating countries.

6.4.1 Revision of the conditional NDCs to enable their implementation

Chapter 2.2.2 already indicated that the NDCs of developing countries are an Achilles' heel of the Paris Climate Agreement. Not only are they reduction pledges relative to the targeted economic growth, which means that only the CO_2 intensity of economic growth is to be reduced, but not the absolute amount of emissions. In addition, the NDCs are conditional: **Trillions of US dollars must flow from the industrialised countries to the developing countries in order for them to reach their targets.**[177] In the past, such sums of money have never been mobilised. If this remains the case, the NDCs will not be implemented and any climate targets will remain unachieved, because the unconditional shares are not very ambitious for understandable reasons. Developing countries are not the ones causing climate change. Per capita emission levels are often in the range of (only) one tonne per year. In the general discourses on the achievability of the climate goals, hardly any space is given to the great difficulties that exist with the NDCs of the developing countries, which is why many statements in this regard must be assessed as too optimistic.

Moreover, it is not uncommon for the targeted net zero periods to lie in the second half of the century, for example in the cases of China (net zero 2060) or India (net zero 2070). A closer look at the measures described in the NDCs also repeatedly reveals that many of the specifications are imprecise or even unrealistic. For example, there is a very large "land gap": larger areas of land are earmarked for afforestation measures than actually exist. The amount of CO_2 to be sequestered through nature-based solutions is often overestimated.[178] Nevertheless, there is enormous potential in this area.

Against this background, an accurate assessment of the NDCs of the Challenge Group countries and their sustainability is difficult. Apart from the points mentioned above, this is mainly due to the fact that (1) the NDCs are not drawn up according to a uniform scheme, (2) the measures envisaged are only incompletely described and (3) the effort involved is unclear. Since the NDCs also form the core of the Paris Climate Agreement, this is a very unfavourable starting situation.

[177] Cf. Pauw et al. (2020).
[178] Cf. Dooley et al. (2022).

For the reasons mentioned above, a large amount of money is raised under the Reference Solution at **US$250 billion per year to revision developing countries' NDCs - as a precondition for making them achievable.**

It is a matter of reviewing their content, adjusting them if necessary and planning realistic implementation periods. Last but not least, it is necessary to determine the actual financing needs. All of this requires a high level of personnel expense and technical expertise on the "operator side".

The establishment of a common understanding on realistic and feasible NDCs alone will require massive financial support for the Challenge Group countries. The situation should be discussed with all countries of the Challenge Group. Similar to the Just Energy Transition Partnerships, it should be clarified which paths are feasible, when Net Zero can be achieved, and how much money is needed. These are expensive and time-consuming processes of consultation and analysis.

In addition to the implementation costs that will be incurred in the future, **political opportunity and participation costs will be incurred** in the process. It is about enabling the necessary political processes in the developing countries, about compensation payments for economic losers of the process and about capacity building.

Opportunity costs are costs incurred for putting the challenge countries in a situation where they participate in the process of NDC clean-up and subsequent implementation, and carry it year after year. It should be understood here that it is not per se self-evident that a developing country or a country in transition should commit to a binding path to reduce its CO_2 emissions. The right to catch-up development includes the right to increase one's emissions. By committing to Net Zero for 2060, one gives up **options** - including options for further speculation on money and other support. This literally puts a bottom to the bottomless pit, which is better than no bottom at all, even if the pit is relatively large. At least one can estimate its size. For years, the Global North and Global South have been negotiating international climate financing and corresponding transfers without any real results, while the globally still permissible CO2 budget continues to dwindle.

There are signs that the negotiating position of developing and emerging countries is improving. These countries continue to face financial pressures, especially from the West, which only grants financial support if they follow certain paths, e.g. "renewables only". On the other hand, the option of cooperation with China, which can also provide financial support and is less restrictive in the design of energy systems, is becoming more and more available.

Any commitment to a path means giving up options. Certain implementation programmes will have to be pursued, which may bring disadvantages for the domestic economic situation. In such a case, there will have to be trade-offs. There may be enormous difficulties in the political process at home. Unless the advantages of going along clearly outweigh the disadvantages, one will not give up a favourable negotiating position.

Once one has committed oneself, one is a "prisoner" of the accepted obligations and the resulting constraints. If the participation or the commitments are linked to the flow of money, one cannot be sure that the funding will actually be provided reliably year after year and will not be stopped at some point. Ultimately, this is also a question of power relations. There is a path dependency that can lead to the conversion process becoming very expensive as a result of a stop in the flow of money halfway through.

The environment can change. What is cheap today can suddenly become very expensive. All these risks are to be countered with opportunity or participation costs.

The analyses carried out so far show that the **implementation costs are high but bearable**. Major cost components have been described in the previous chapters.

Of great importance are the differential costs for achieving climate neutrality compared to business as usual, which have to be borne by the enlarged OECD year after year over the entire period under consideration. This is in the order of magnitude of the sums demanded by the developing countries in the conditional NDCs. They are thus not unrealistic.

Another important cost block in the context of implementation are the expenses for financing trans-national energy infrastructures. These are, for example, power lines or pipeline systems.

In addition, all countries in which extensive measures in the field of nature-based solutions (affor-estation, soil restoration) are feasible will benefit from the financing of these activities, which at the same time will result in a significant increase in economic activity and thus the creation of jobs and income.

Those countries that have large areas of rainforest benefit from enormous inflows of funds to protect the rainforests. We are talking about a total of 100 billion US dollars per year.

In addition to the restructuring costs incurred anyway, with regard to the conditional NDCs (only) the political opportunity costs for introducing one's own ambitions into the NDC world are incurred, which are then unconditional - apart from the condition that the programmes of the Reference Solution described above are actually implemented.

In the area of **opportunity costs**, we are talking about **50 US dollars per person per year for 25 years,** with the payment being made year by year and apportioned proportionally to the time until Net Zero is reached, based on compliance with the commitments made by the countries. With five billion people and 25 years, we are talking about a total of 2.5 trillion US dollars. So if a country like Kenya with 50 million people plans Net Zero by 2050, 2.5 billion US dollars will flow into the country unconditionally year after year - for 25 years, if the commitments in the NDCs are kept. For India, with 1.4 billion people and Net Zero 2070, it is a matter of a total of 70 billion US dollars per year.

6.4.2 Implementation of a cap-and-trade system

For many reasons, a cap-and-trade system for pricing countries' CO_2 emissions after 2025 would be desirable. Such a global framework - if it can be established - is a much more effective and efficient way than individual agreements between rich countries and developing and emerging countries according to the logic of the Just Energy Transition Partnerships (see Chapter 7). Thus, the bureaucratic burden is much lower. In addition, there are major advantages for all parties involved through the **trading option**. The planned financial transfers can be the lever for such a cap-and-trade system to be established, even if this has not been successful in the past.

In the following, an approach for a cap-and-trade system is described that is based on the NDCs of the world's countries.

From the key data of the NDCs, a cap-and-trade system can be constructed in a canonical manner, as previously proposed by two of the authors of this report.[179] It is based on the fixed pledges of countries for target values for individual years and, in the best case, requires all countries to participate. However, it is known from economics and corresponding models that the desired benefits also arise if less than 100 % of all participants take part.

At this point, the classification of the countries into groups made earlier becomes relevant, cf. chapter 4. There, the countries of the world were first divided into three groups, namely the expanded OECD with a total of 13 billion tonnes of CO2 emissions and a net zero target in 2050, the China Club with 13 billion tonnes of CO2 and a net zero target in 2060, and the Challenge Group with an aggregated total of about 13 billion tonnes of CO2 and net zero targets by 2050, 2060 and 2070. In addition, the countries of the Challenge Group were considered according to the classification of their challenge, the Challenge Index (see Chapter 4.5). In 2030, subgroup 1 will account for about 4 billion tonnes of CO2, subgroup 2 for about 5 billion tonnes of CO2 and subgroup 3 for about 4 billion tonnes of CO2.

The respective reduction paths are made concrete by further base points (in this illustration one or two: 2030 or 2035 or 2050). Between the fixed anchor points of the pledges, emissions and their annual reductions are determined according to linear interpolation. The expanded OECD reduces its emissions by 40 % by 2030. The China Club reduces its emissions by 35% by 2035. In 2050, 2 billion tonnes of CO_2 will still be produced there. For subgroups 2 and 3 of the Challenge Group, 1 and 2 billion tonnes of CO_2 respectively remain in 2050.

The following table provides an overview of the **supporting points** from which the reduction paths of the five groups of countries result, which in turn form the **basis for the cap line** of the cap-and-trade system:

179 Cf. Herlyn, Radermacher (2021).

	2025	2030	2035	2050	2060	2070
Extended OECD	13	7.8		0		
China Club	13		8.45	2.0	0	
Challenge Group – Subgroup 1	4.0		2.5	0		
Challenge Group – Subgroup 2	5.0		3.0	1.0	0	
Challenge Group – Subgroup 3	4.0		2.5	2.0		0
Cap values	**39**	**29.025**	**22.3**	**5.0**	**1.0**	**0**

Table 5: Supporting points of the CO_2 reduction paths of the groups of countries (in billion tonnes CO_2)

For each of the five sub-groups, it is thus determined for each point in time until 2070 how many emissions are still permitted in each year on the total territory of these states. Adding up the emissions still permitted for each point in time yields the cap line for the world. The five groups are weighted with their initial emission volumes, i.e. the expanded OECD with 13 billion tonnes, the China Club with 13 billion and the three sub-groups of the Challenge Group with 4, 5 and 4 billion tonnes of CO_2 emissions per year (see figure).[180, 181] In the implementation, the CO_2 emissions should be broken down individually to all the 185 states of the world under consideration and then all individual reduction trajectories should be used to derive the total annual cap values

Figure 8 below visualises the CO_2 reduction curves of the five groups considered with linear interpolation between the base points. The curves are similar within each of the five groups, i.e. they only differ by a constant factor that is proportional to the total emissions of the respective country in 2025.

[180] The Challenge Group's energy-related CO_2 emissions in 2019 were around 9.4 billion tons of CO_2. To increase the robustness of the cap-and-trade system, this value was increased to 13 billion tons. This can be justified by the fact that further emission increases are expected until 2025, which is the start date of the presented Reference Solution. In addition, the countries of the Challenge Group in particular generate high emissions of other greenhouse gases, such as methane, which are not energy-related but are caused by land-use changes, among other things. The assumption of 13 billion metric tons of CO_2 for the Challenge Group is therefore a plausible and conservative value.

[181] A "challenge index" was developed for the classification of the Challenge Group into the three subgroups, which rates the countries in terms of the magnitude of the challenges to be overcome in order to achieve Net-Zero. The challenge index includes data on the availability of fossil and renewable energy sources, economic strength, potential for nature-based solutions, population growth, and good governance. For more information, see Chapter 4.5 and Appendix A.3.

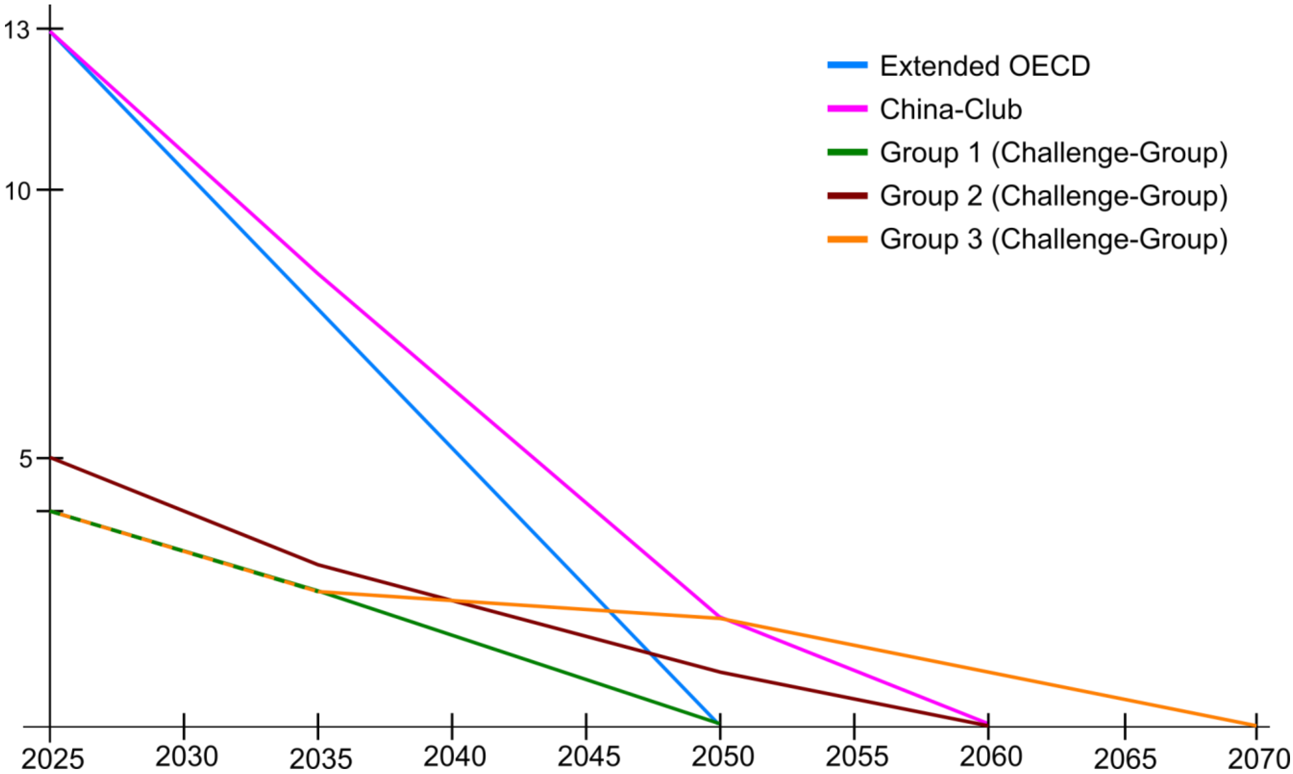

Figure 8: CO_2 reduction trajectories 2025-2070

The following figure shows how the global cap line can be derived from the five CO_2 reduction trajectories, which are added together. The resulting sum is finally the basis for an approximation. Details of the resulting cap line are available for all years up to 2070 and can be found in the appendix.[182] The cap line shown in red in the figure is reflected in the summary figure 9, which summarises the CO_2 effects of the measures taken.

With this approach, each country thus receives as the quantity of emission rights which is permissible on its territory according to its own NDC - and thus exactly its share of total emissions. So the challenge is the same for each individual country, whether they use the trading option under a cap-and-trade system or not.

[182] Cf. appendix A.3.

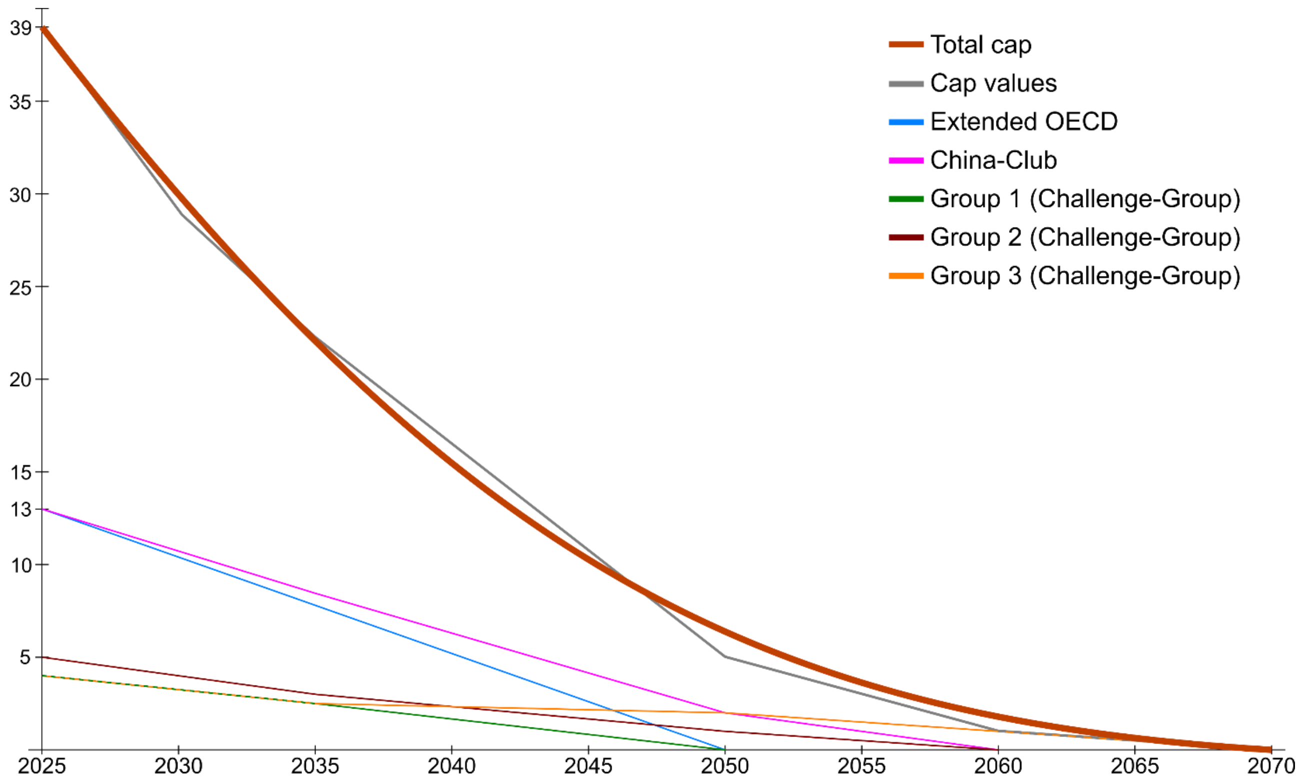

Figure 9: Cap line resulting from the CO_2 reduction curves

In addition, there are two aspects that underpin the advantageousness of the proposed system:

1. the reliability that all countries keep their pledges, because it is economically disadvantageous, especially for developing and emerging countries, not to keep them, because at that moment the money flows from the enlarged OECD (political opportunity costs) completely or partially fail to materialise. Thus, the **free rider problem** is largely eliminated.

2. the possibility of **trading**. This has a general **cost-reducing** effect for all participating countries. They all benefit in economic terms.

It is therefore to be expected that all countries will participate. Once countries have committed to pledges through their own NDCs (without conditionality), there is no economic advantage to not participating in the cap-and-trade system if substantial financial flows from rich countries depend on their own reliability. Given the many advantages for participants, non-participation is not a wise option. This is especially true for the Challenge Group.

The members of the other two groups, after weighing the pros and cons, have chosen a path towards Net Zero anyway. They are powerful enough to achieve these goals and are aware of the other countries' historical claims to them. However, the reductions promised in the NDCs must then also be delivered. There is a lot of money at stake for countries in the Challenge Group in terms of compliance, e.g. the annual unconditional grants described above, which they receive for participating and "committing" to realistic NDCs. This is possible for them because of the considerable financial support in this process provided for in the Reference Solution (especially also politically) and because of the also promised financing of differential costs. In addition, there may be various participation gains by countries from the many special programmes of the Reference Solution. Thus, there are only expensive exit options for the Challenge Group countries once they have opted for NDCs without conditioning (and at the same time with massive financial support). But **if exit is no longer an option, participation** in the cap-and-trade system **is the smartest solution**.

Should the Reference Solution be implemented, participation in the cap-and-trade world based on realistic NDCs is thus designed to be so attractive that non-participation would rather entail disadvantages for countries in the Challenge Group.

As participants in the cap-and-trade system, countries can freely dispose of their CO_2 quotas. They may sell them to other participating countries or buy additional rights there. They are also allowed to make them available to their companies. If they want to emit more on their territory in a year than they have rights to, they have to buy them from others. Otherwise, the task is to ensure each year that no more CO_2 emissions are produced on their own territory than there are rights available.

At this point, it is worth taking **a look back**: Interestingly, a viable agreement for a solution to the climate problem was on the table at the world climate conference COP15 in Copenhagen in 2009 - in the form of a global cap-and-trade system based on the idea of climate justice. The approach followed on from the Kyoto Protocol. Unfortunately, despite many years of intensive preparatory work, the conference failed, due in particular to the USA and China closing ranks against the approach. At that time, the climate problem could have been solved comparatively "gently".[183] Unfortunately, things turned out differently. The idea of a coherent, coordinated solution with mutual obligations and the facilitation of emissions trading was shelved. Six years later, the Paris Climate Agreement came into being, which, when viewed realistically, is not much more than a "half-measure": the countries of the world declared individually what they were prepared to do. The NDCs came into being. These are not ambitious enough and ultimately not legally binding - unless they were translated into national laws or, in the EU, also into binding regulations. In the case of developing and emerging countries, the NDCs are strongly linked to financial flows from other countries. A state can demand such flows in its NDC, but then there is still no partner to pay. The approach of individual NDCs reaches its limits here. In the absence of high financial flows, there are no substantial climate protection measures in many developing and emerging countries. With the approach of a cap-and-trade system based on realistic NDCs described in the framework of the Reference Solution, there

[183] Cf. Radermacher (2020).

is hope of a return to the earlier path, which unfortunately was not pursued further after the Copenhagen Climate Conference.

6.5 Summarizing View

In total, the enlarged OECD has to bear costs amounting to 1.2 trillion US dollars annually. These are made up as follows:

	Annual costs for the enlarged OECD
Preservation of the remaining rainforests Gigaprogramme Nature-based Solutions Short-rotation plantations Avoidance of technical methane leaks	200
Co-financing of energy infrastructures	150
Absorption of differential costs for carbon capture, increased use of gas instead of coal, nature-based solutions outside the gigaprogramme	600
Cleaning up the conditional NDCs and enabling their implementation	250
Implementation of a cap-and-trade system	0
Total	**1.200**

Table 6: Annual costs for the enlarged OECD (in billions of US dollars)

This corresponds to an annual cost of **US$800 per citizen of the enlarged OECD.**

For each person in the Challenge Group, in which about four times as many people live as in the expanded OECD, financial resources amounting to an average of **200 US dollars per year** will be raised, which corresponds to an inexpensive avoidance of CO_2 in comparison to European conditions. The funds to be raised are many times more than what has been discussed for years under the term climate financial compensation in the context of the Green Climate Fund.

In the context of the governance and financing contributions described above, funds that are to flow from the Green Climate Fund to the developing countries were therefore not considered separately, since it is only a matter of promised support amounting to 100 billion US dollars annually from 2020. This amount of support has never been reached so far. Moreover, a large part of the funds are loans and guarantees. The topic of climate financial compensation in the sense described is not explicitly pursued in the Reference Solution. Diverse, targeted and better financed programmes take over the tasks. These often involve direct transfers of a social nature. In total, it is about ten times the amount of what has been discussed so far in this area, namely much more than 1 trillion US dollars. The funds are thus in the range of the amounts demanded by the countries of the Challenge Group in the area of conditional NDCs.

The figure below summarises key elements of governance and funding and places them in the larger context of the imperative cooperation between the three groups of countries:

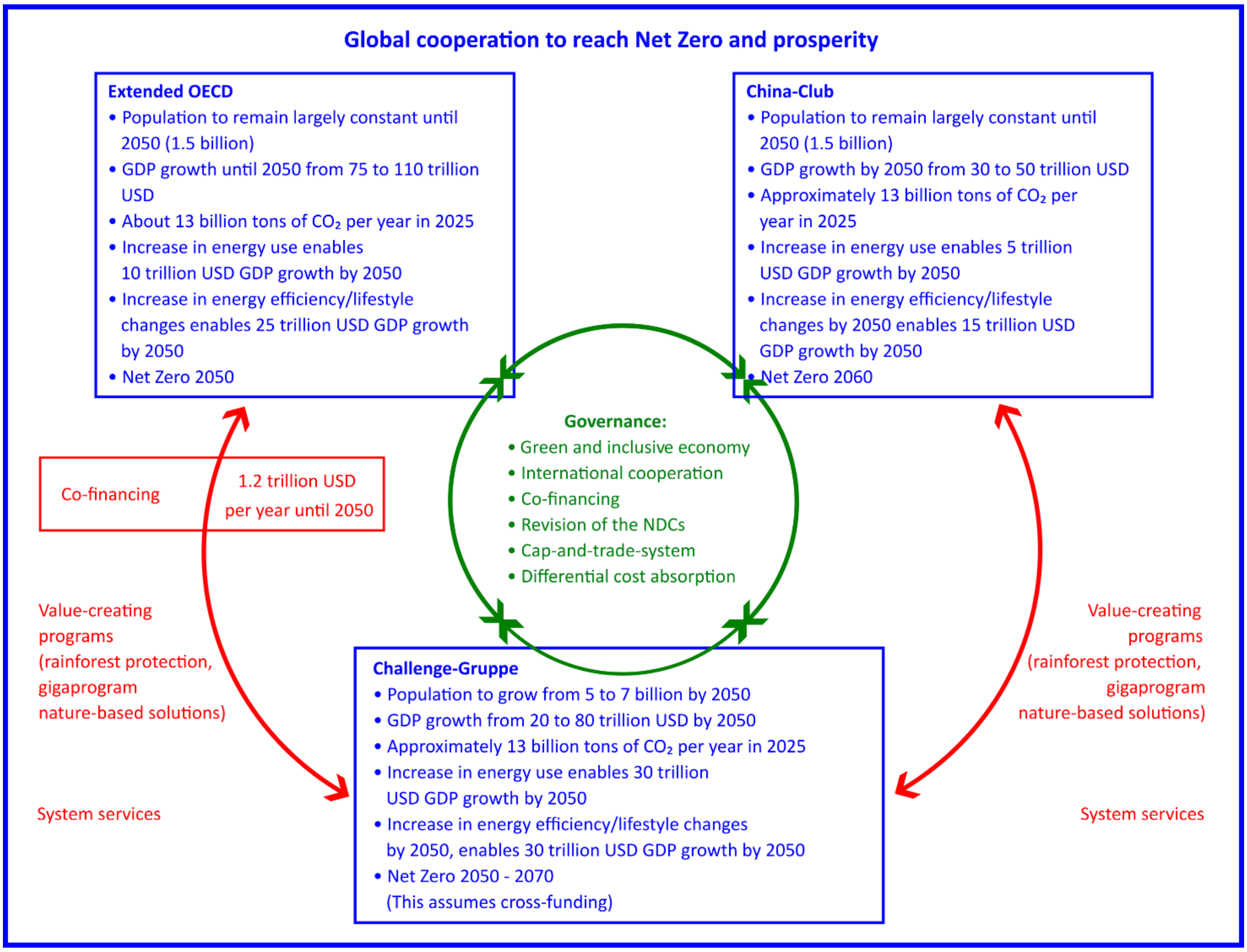

Figure 10: Global cooperation to stabilise the climate system and promote development

Source: Own representation

7 References to other approaches and studies

This chapter describes references to other approaches and studies that aim to transform the energy system towards Net Zero. It is noticeable that a parallel consideration of growth expectations in developing and emerging countries is often not taken into account in the same way as in the GES Reference Solution. In the context of the BMZ, the so-called Just Energy Transition Partnerships are a relevant reference, as they also pursue the goal of supporting individual countries in their transformation towards a climate-neutral energy system.[184] Local grid programmes are also taken into account here, as the aim is to help people who have not yet had access to energy out of this situation - both in terms of content and financially.

7.1 The Just Energy Transition Partnerships

7.1.1 Funding requirements in the South

Tackling energy and climate problems is, in particular, a **global problem** in the view of Global Energy Solutions. The dynamic in the climate sector is linked to countries that are comparatively poor, but where at the same time the population is increasing rapidly, especially in Africa. At the same time, there is a goal of great wealth creation, also in line with the global community's position on Goal 8 of the Sustainable Development Goals. The motivating example is China, whereby the difference to China lies in particular in the fact that the challenge countries worldwide already have a population that is three to four times as large as the current population in China. What does this mean for CO_2 emissions, which today in some of the countries concerned are only 1 tonne per capita and year? Four times the population means - simply put - four times the amount of CO_2 emissions, if everything else remained the same. This is not to be expected. Nevertheless, China's emission volume could be added once again.

In this situation, the policy of some rich countries seems to be to push the poorer countries as far as possible into a **"renewables only" strategy.** This is mainly based on the argument that there is no need to repeat the mistakes made by the rich countries and China. Another argument is that renewable energies are the cheapest energies and that it therefore makes the most sense to move in this direction alone. However, there is more and more resistance to this from the poorer countries, especially those that want to industrialise heavily, e.g. build up a **steel and cement industry.** They know that the volatility of renewable energies practically rules out industrialisation. They therefore speak of the **"hypocrisy of the North**". [185]

[184] Cf. BMZ (2023a).
[185] Cf. Herlyn, Radermacher (2022).

In this situation, the North is using other instruments, such as its influence on the World Bank, on the international development banks and the financial sector, and has thus caused them to decide, in the sense of a moratorium, to generally no longer finance fossil fuel projects in the global South.

7.1.2 Exemplary Just Energy Transition Partnerships

A special form of aid pledges from the North (within the framework of climate financial compensation) are the Just Energy Transition Partnerships (JETPs), with support from Germany. The first existing examples are remotely similar to what we propose at Global Energy Solutions.

Just Energy Transition Partnerships go back to the **G7 summit in Germany** (Elmau 2022), at which the G7 countries agreed on the one hand that (1) coal, in which CO_2 is not captured (non-abated coal), should not be abolished but phased out, that (2) clean and renewable energies should be promoted and (3) that all this should happen in an ecologically and socially just manner. At the same time, (4) issues such as a circular economy should be taken into account.

In these general considerations, it has been agreed that **individual states should be encouraged** within the framework of strong partnerships in the sense of Just Energy Transition Partnerships (JETP). The approach is that various partners from rich countries agree on agreements with developing countries that have two sides. On the one hand, a plan by the poorer country to move out of "non-abated coal", for example, to promote renewable energies and with concrete plans of what is to be achieved by 2030, for example. On the other hand, a group of rich countries should help with the financing.

Provide funding

In addition to direct grants, this involves loans, collaterals and also contributions from the private sector in the sense of support measures. The contributions of the financial sector can consist of granting loans at particularly favourable rates or, for example, seeking intertemporal solutions when money is needed immediately but is not available until later. The first such agreement was concluded with **South Africa.**[186] South Africa has **higher CO_2 emissions than the UK,** with a smaller population and significantly lower GDP per capita than the UK. This is due to the specific structure of the energy sector in South Africa, which is massively coal-based. Because of the previous oil boycotts against South Africa in the context of apartheid, the country produces all its own fuel from coal.

[186] "Multilateral JETPs aim to cushion the social risks of the ecological transition and thus increase social acceptance. With South Africa, which covers most of its energy needs with coal, Germany, the EU, France, the UK and the USA have agreed on a JETP that promotes the expansion of renewable energies and, in cooperation with the private sector, supports workers in the mining sector affected by the coal phase-out." BMZ (2023a).

In the case of South Africa, the partnerships also include green hydrogen. It is hoped to avoid 1 - 1.5 billion tonnes of CO_2 over the next 20 years through the partnership. The initial funding envisaged is that donor countries will provide 8.5 billion US dollars for this first phase until 2030. It is actually a small amount for the ambitions involved. Rather, ten times that amount would be needed. The funds are being raised by the governments of France, Germany, the United Kingdom, the United States of America and the European Union.

The agreement with **Indonesia,** a large country with a population of more than 270 million people, is considered a major success.[187] Indonesia has a **high share of coal** in electricity generation. Despite plans over the last 20 years to reduce this share, exactly the opposite has happened and the use of coal has continued to increase. One of the JETP targets is that Indonesia should not emit more than 290 million tonnes of CO_2 per year in the power generation sector by 2030. From 2030, it aims to move ambitiously towards zero emissions in the power sector by 2050. This includes an accelerated phase-out of coal-fired power plants, again depending on the level of international support. The development of renewable energies is to be accelerated. The aim is for at least 34 % of electricity production to come from renewables by 2030. In this context, Indonesia has brought forward its **2060 net zero target to 2050**. The funding provided is 20 billion US dollars over the next three to five years of the partnership. Half of this (10 billion US dollars) is to be raised by the state members of the partnership. The financial sector, the so-called GFANZ (Glasgow Financial Alliance for Net Zero), is to raise a further 10 billion.

A corresponding partnership has also been established with **Vietnam**.[188] On the funding side, the European Union, Great Britain, Northern Ireland, the United States of America, Japan, Germany, France, Italy, Canada, Denmark and Norway are involved. It could be that the funds made available are not sufficient from Vietnam's point of view. Financially, **15.5 billion US dollars** are under discussion, whereby the financing partner group would activate half of the funds from the public side, with the other half to be raised by partners from the financial sector. In any case, coal-fired power plants without capture of CO_2 should be phased out as quickly as possible. For renewables, the focus is on wind, solar and hydropower.

Another Just Energy Transition Partnership was established in 2023 with **Senegal**.[189]

In the meantime, negotiations have also been held with other countries. Above all with **India**, by far the most interesting country in this context. However, no agreement has yet been reached with India. From India's point of view, the funds offered are far too small.

[187] Cf. Van Reybrouck (2022).
[188] Cf. BMZ (2022).
[189] Cf. BMZ (2023b).

The difference between the Just Energy Transition Partnerships and the **GES Reference Solution** lies primarily in the area of financing. In their current form, JETPs certainly aim in the right direction, but are ultimately only one element among several and have so far been financially undersized. In the Reference Solution, the **use of funds is higher** by a factor of 5 to 10. This is much more realistic if one wants to achieve Net Zero. Moreover, the partnerships usually aim for 2030, so the time horizon is much shorter. This may make sense for individual projects because, for example, there is a chance of political stability over this period. For an overall solution to the energy and climate issues, however, the time until 2030 is too short. It is certainly right to push the expansion of renewable energies until then. However, the questions of how to create a stable energy system in the long term and how to meet the rising energy demand cannot be answered with measures in the field of renewable energies alone. Moreover, the planning, realisation and financing cycles of such large-scale projects usually extend beyond the period up to 2030.

7.2 Local Grid programmes

The local grid programmes - in many cases with German participation - fall within the framework of a multitude of efforts, in particular also of development policy, to bring **renewable energy into** use in **poorer countries**. Such programmes are a significant step forward for poor populations in the South - a first step in the implementation of SDG 7 "Affordable and Clean Energy" for all. As Germany is financially involved, it is also a contribution to international cooperation and co-financing.

This is a low-cost solution, as it has been successfully implemented for two decades in Bangladesh, for example by Muhammad Yunus with the Grameen Family of companies.[190,191] Today, Grameenphone is the pioneer and market leader of mobile telephony in Bangladesh. Grameen Shakti is a pioneer and market leader in the distribution of solar home systems and supplied five million villagers with electricity years ago. The **basis** for the dissemination of the technologies, which also provide an important contribution to protection during the annual floods (via messages on the phone), is **microcredit**, the basic offering of the Grameen Bank. In fact, every access to electrical energy improves people's lives, with the marginal benefit of the first kilowatt hours being the largest.

Local grids address the energy poverty of hundreds of millions of people, for example in sub-Saharan Africa. They relate primarily to SDG Goal 7 "Affordable and clean energy". This is done from the German side, for example, within the framework of the initiative "Green Citizen Energy for Africa". On behalf of the Federal Ministry for Economic Cooperation and Development (BMZ), the Deutsche

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[190] Cf. Yunus (1998).
[191] Radermacher; Solte (2014).

Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and KfW Entwicklungsbank jointly implemented the Green Citizen Energy for Africa initiative, according to the initiative's website.

The former Africa representative of the BMZ, the late politician Josef Göppel, was also involved in the "Local Grids" project. As important as the programmes are, they are only a first step. They fall within the framework of a renewable-only philosophy. From the point of view of the Reference Solution, this is too little.

Local grids are a substantial step forward in terms of the goals of the 2030 Agenda, even if the differences to the GES reference solution are massive, especially in terms of industrialisation and financing concerns. Electricity access for all on a limited scale is the goal here, which is still far from being achieved and has been substantially underfinanced to date.

At the same time, it is clear that **no industrialisation** can be realised **on the basis of local grids**. Large amounts of energy are needed for this - stable and without volatility. From the point of view of the reference solution, a share of fossil energy sources comes into play, which is transformed into a low-carbon energy supply with carbon capture.

It is also worth taking a comparative look at the so-called NDC partnerships. Here, the concerns of international cooperation manifest themselves in the sense of SDG target 17 "Partnerships to achieve the goals". But this is without the use of funding as part of the cooperation - always the same shortcoming in such programmes. In this respect, there are enormous differences between the GES Reference Solution and the NDC partnerships. For the latter, a lot of support is provided, especially through advisory services - which is important. But there is a lack of material contributions.

7.3 Differences to other Net Zero studies

In the following, the results of the data model used by Global Energy Solutions in the development of its Reference Solutions are compared with the statements of essential Net Zero studies of the past two years:

Considered were:

- IEA (2021): Net Zero by 2050 - A Roadmap for the Global Energy Sector[192]
- IRENA (2021): World Energy Transitions Outlook: 1.5°C Pathway[193]
- bp (2022): bp Energy Outlook - 2022 Edition[194]
- Shell (2021): The Energy Transformation Scenarios[195]

It is interesting to look at the authors of the four studies. The **International Energy Agency** (IEA) was founded out of the experience of the oil crisis in 1974, it has 31 member countries (including Germany, USA, France, Japan), a further eleven countries are associated (including China and Brazil), three of which are candidates for membership (including Israel). Neither Russia nor countries of the Middle East nor members of OPEC belong to it. **International Renewable Energy Agency** (IRENA) is an organisation based in Abu Dhabi whose aim is to promote renewable energies. It currently has 168 countries as members and a further 16 countries as candidates for membership.

It therefore represents the broad spectrum of opinion in very many countries with regard to the expansion of renewable energies. Finally, we have selected the studies of the two large listed **oil companies BP and Shell**, in each of which BlackRock is a major individual shareholder. Wherever possible, the data contained in these studies have been converted to the energy unit terawatt hour and are commented on in this text in PWh (one petawatt hour (10 to the power of 15) equals 1,000 terawatt hours, TWh) for the sake of clarity.

[192] Cf. IEA (2021b).
[193] Cf. IRENA (2021).
[194] Cf. bp (2022).
[195] Cf. Shell (2021).

	Total energy supply 2019 / PWh	Total final energy consumption 2019 / PWh	Total energy supply 2050 (Net Zero) / PWh	Total final energy consumption 2050 (Net Zero) / PWh	GDP 2019 / trillion US-$	GDP 2050 (Net Zero) / trillion US-$	CO2 emissions 2050 (reference) / Gt CO2	CO 2 emissions 2050 (Net Zero) / Gt CO2
IEA	170	121	151	96	134,7	316,4	36	0
IRENA	167	105	167	97	N.N.		36,5	0
BP	174	133	181	98	127	283	31,1	2,4
Shell	169	116	230	153	134,1	292,6	/	14,2 Net zero: 2058
GES	164	110	210	172	93,3	240	51,1	5 Net zero: 2070

Table 7: Overview of key energy data

Source: Own representation

First of all, it can be seen in Table 7 that the **primary energy** use that GES used as a starting point in 2019 based on data from the IEA is in the same order of magnitude as the data used by the other studies. The primary energy use in 2050 does not quite reach the level of Shell's study, but is overall significantly higher than the values in the other three studies. In final energy consumption, the GES forecast is above Shell and accordingly has fewer conversion losses.

Not surprisingly, the GES programme, which focuses on prosperity and growth, yields a higher **GDP** growth rate over the period than the other studies: GES achieves a growth rate by a factor of 2.6 over the period, while all other studies are only at 2.2 - 2.3. Moreover, the GES study is the only one that places a special focus on the growth impulses for the challenge countries and thus builds a bridge to the Sustainable Development Goals.

Similar to Shell, GES concludes that climate neutrality will not yet be achieved in 2050; our perspective is 2070.

With regard to the possible levers of impact of the additional programmes of measures required to achieve Net Zero, the studies partly use comparable approaches, but arrive at different weightings of the requirements. **Moreover, the GES work is the only one that explicitly describes and considers the important role of nature-based solutions.** The approaches presented in the studies are compared with the GES considerations in the following.

	Global electricity demand 2019 / PWh	Share of total final energy consumption 2019 / %	Global electricity demand 2050 / PWh (net zero)	Share of total final energy consumption 2050 / % (net zero)
IEA	22,8	ca. 20	46,9	49
IRENA			50,0	51
BP			49,6	51
Shell			65,6	43
GES			73 (59 + 14 for electrolysis)	38 (electrons only)

Table 8: Projected share of electrification in final energy consumption.

Source: Own representation

While only around 20 % of final energy demand was consumed in the form of electricity in 2019, the studies expect a **significant increase in the share of electricity in final energy consumption**. The work of GES has some special features here: The potential of electrolysis technology is fully exploited according to our findings on the possible expansion rates, and requires 14 PWh of electricity generation. However, the hydrogen produced with electrolysis is in our model fully used as a molecule and is not converted back into electricity. To represent the electricity demand, a higher use of fossil energy sources is required, similar to Shell.

Nevertheless, the share of electrification in final energy consumption is comparatively lowest in GES: we consider the high electrification percentages of the other studies to be practically unachievable in the period up to 2050, especially in the mobility sector.

<table>
<tr><th colspan="2">Renewable Energy Forecast 2050</th><th>Solar / PWh</th><th>Wind / PWh</th><th>Hydro / PWh</th><th>Bioenergy / PWh</th><th>Other / PWh</th><th>Total share of Total energy supply / %</th><th>Total share of electricity generation / %</th></tr>
<tr><td rowspan="2">IEA</td><td>Energy supply</td><td>30,3</td><td>24,8</td><td>8,5</td><td>28,3</td><td>8,8</td><td>68</td><td></td></tr>
<tr><td>Electricity generation</td><td>24,9</td><td>24,8</td><td>8,5</td><td>3,3</td><td>0,9</td><td></td><td>88</td></tr>
<tr><td rowspan="2">IRENA</td><td>Energy supply</td><td colspan="5">N.N.</td><td>74</td><td></td></tr>
<tr><td>Electricity generation</td><td colspan="2">51,0</td><td colspan="3">21,9</td><td></td><td>90</td></tr>
<tr><td rowspan="2">BP</td><td>Energy supply</td><td colspan="2">116,1</td><td>17,9</td><td>inkludiert in 116,1</td><td>/</td><td>74</td><td></td></tr>
<tr><td>Electricity generation</td><td colspan="2">43,3</td><td colspan="3">„low carbon“ (incl. nuclear): 16</td><td></td><td>94</td></tr>
<tr><td rowspan="2">Shell</td><td>Energy supply</td><td>35,3</td><td>24,4</td><td>5,3</td><td>30,3</td><td>8,1</td><td>44</td><td></td></tr>
<tr><td>Electricity generation</td><td>20,6</td><td>22,8</td><td>4,7</td><td colspan="2">22,2</td><td></td><td>60</td></tr>
<tr><td rowspan="2">GES</td><td>Energy Supply</td><td>34</td><td>11</td><td>6</td><td colspan="2">36
(Bioenergy + Geothermal)</td><td>42</td><td></td></tr>
<tr><td>Electricity Generation</td><td>34</td><td>11</td><td>6</td><td colspan="2">6</td><td></td><td>56</td></tr>
</table>

Table 9: The projected importance of renewable energies in comparison.

Source: Own representation

With regard to the projected **importance of renewable energies**, Shell and GES on the one hand and the studies by IEA, IRENA and BP on the other hand are in agreement: In terms of the importance of renewable electricity generation, GES and Shell are similar with 56 and 60 % of electricity generated based on renewable energy, respectively, while the three studies by IEA, IRENA and BP, expect about 90 % of electrical energy to be produced based on renewables. GES and Shell expect renewables to account for 42 and 44 % of primary energy, respectively, while the other three studies see these shares closer to 70 %.

Role of Hydrogen	Global hydrogen demand 2019 / Mt	Global hydrogen demand 2050 / Mt	Energy content / PWh	Share of final energy consumption 2050 / %
IEA	91	530	20,9	21
IRENA		613	24,2	12
BP		446	17,6	15
Shell		138	5,6	3
GES		631 (40% green & 60% blue)	25	14,5

Table 10: The projected expansion of hydrogen production.

Source: Own representation

In terms of **hydrogen** production, GES expects the largest growth among the comparative studies, but we assume that a good 60 % of the hydrogen will be produced on natural gas basis with CCS, so-called blue hydrogen.

Hydrogen & Biofuels	Global hydrogen demand 2019 / Mt	Global Hydrogen demand 2050 / Mt	Energy / PWh	Share of final energy consumption 2050 / %	Biofuels / PWh	Share of final energy consumption 2050 / %
IEA	91	530	20,9	21	13,3	14
Shell		138	5,6	3	17,8	11
GES		631	25	14,5	30	7

Table 11: Projections for hydrogen and biofuels in comparison.

Source: Own representation

With regard to the importance of **bioenergy**, different assessments emerge. While the IEA sees hydrogen and its derivatives as more important than bioenergy, this is reversed for Shell: Here, the role of bioenergy in 2050 is seen as three times as high as that of hydrogen - the highest value of all studies. IRENA and BP do not make any explicit statements with regard to the expected importance of biofuels. GES is also rather cautious about the final energy potential of biofuels: the yields per area are comparatively low and the losses during conversion are high, even if the potential from short-rotation plantations certainly shows an approach that can be sensibly tapped. In addition, agricultural and forestry waste should be used for second-generation biofuel plants.

Role of Carbon Capture	CO2 captured per year / Mt (2019)	CO2 captured per year / Mt (2050)	CO2 captured from fossil fuels and processes / Mt (2050)	CO2 captured from bioenergy (BECCS) / Mt (2050)	Direct air capture / Mt (2050)
IEA	40	7.602	5.245	1.380	985
IRENA		8.100	3.400	4.700	N.N.
BP		6.000	4.700	1.300	N.N.
Shell		5.200	5.200	N.N.	N.N.
GES		14.200	N.N.	N.N.	N.N.

Table 12: Expected development of the use of carbon capture.

Source: Own representation

In all studies, carbon capture is of considerable importance for achieving climate neutrality. Compared to the base year 2019, the amount of carbon dioxide captured worldwide will increase more than a hundredfold (!). GES goes one step further: in order to be able to achieve the targets for the Sustainable Development Goals (SDG) in a world with justified growth aspirations of the Challenge Group and in view of significant reserves of fossil fuels, carbon capture is the decisive technology alongside the expansion of renewable energies. GES therefore makes an even higher growth forecast than the four comparative studies. The stated value of 14,200 million tonnes of CO_2 (14.2 billion tonnes of CO_2) could even be exceeded.

Role of fossil fuels and nuclear 2050		Oil / PWh	Natural Gas / PWh	Coal / PWh	Nuclear / PWh	Share of total energy supply / %	Share of electricity generation / %
IEA	Energy supply	11,7	16,7	4,8	16,9	34	
	Electricity generation	0,006	0,7	0,7	5,5		10
IRENA	Energy supply	N.N.				26 (excl. nuclear)	
	Electricity generation	0	4,9	0	3,2		10
BP	Energy supply	12,2	16.9	4,7	13,6	24	
	Electricity generation	0	2,2	0,5	16		29
Shell	Energy supply	44,4	31,9	27,8	22,2	54	
	Electricity generation	0,6	16,1	7,5	21,9		39
GES	Energy Supply	22	70	11	15	56	
	Electricity Generation	0	24	6	15		44

Table 13: Remaining role of fossil energy sources and importance of nuclear energy.

Source: Own representation

The share of remaining **use of fossil energy sources** decreases significantly in all studies compared to the starting point of over 80 % in 2019. BP still expects the use of approx. 34 PWh, 17 % proportionally, and is thus clearly below IRENA, which indicates 26 % of primary energy production, without further differentiation of the individual energy sources. Shell publishes a remaining share of 45 % of primary energy based on fossil fuels, with oil (19 %) continuing to play the largest role, followed by natural gas (14 %) and coal (12 %). Similarly, Shell's absolute decline relative to 2019 is the smallest: oil by five PWh (-10%), natural gas by nine PWh (-22%) and coal by 16 PWh (-39%). GES' forecast is similar in approach to Shell's; we see a significant decline in oil, remaining primarily for mobile applications, and a sharp decline in coal, which we believe should be replaced by natural gas wherever possible, also to avoid having to expand the logistics requirements for CO_2 captured via carbon capture too much. In this respect, we see a significant increase in the use of natural gas with a decline in the use of fossil fuels overall.

Without being explicitly argued as an effective lever for achieving climate neutrality, **nuclear energy** plays a weighty role in the 2050 forecasts. Compared to 2019 (2.7 PWh), all studies expect an increase in nuclear-based electricity generation, IEA and BP by a multiple, Shell even by a factor of 8 to 22 PWh, probably also to meet the significantly increasing energy demand. GES also sees nuclear energy as an important contribution, especially to help balance the fluctuations of new renewables in the more developed countries.

Conclusion of the comparison of the Reference Solution with the four studies

An important issue is the question of the further use of fossil energy sources. Oil, natural gas and coal deposits are essentially concentrated in 25 countries that have more than 80 % of the known reserves. How is the use of renewable energy sources promoted there? What alternative business models might secure national budgets and economic development? The use of **carbon capture**, as presented by all studies, is a strategically significant solution element of the Net Zero challenge as a direct compensation option for future fossil CO_2 emissions and is thus **of utmost relevance**.

The extensive use of renewable energy sources is significantly influenced not only by the questions of availability of raw materials and affordability, but also by a cost-efficient manageability of volatility issues in the generation of electricity. A high share of solar and wind energy seems possible wherever large-scale cost-effective strategies against dark periods can be used, e.g. via fossil-fuelled (gas) power plants with carbon capture or cost-effective storage strategies.

Obviously, the expansion of hydrogen-based energy sources also plays a significant role. However, this presupposes that the numerous scaling obstacles for the comprehensive development of corresponding capacities can be overcome promptly at economically justifiable costs.[196]

Efficiency gains and behavioural changes will also be able to contribute significantly in the future, but their predictability is associated with great uncertainty. Technical progress is also a significant source of hope. On the one hand, all major conceivable solutions (nuclear fusion, tidal power plants, etc.) are known, but on the other hand, their practical application is still mostly too uncertain to be priced into a concrete outlook.

[196] Cf. Berks (2022).

8 Implications

This chapter explains which previously formulated objectives can be achieved with the Reference Solution.

It describes the goals in the climate sector, i.e. the achievement of Net Zero, as well as the path to achieving the 2°C goal. In addition, implementation perspectives for the 17 Sustainable Development Goals are outlined in their social, economic and ecological dimensions. It also outlines the development impacts of the Reference Solution with reference to the China model. Finally, it will be shown how the system services approach can hopefully succeed in meeting the long-standing demand of the developing countries "From Billions to Trillions" in the area of financing. The work on the Reference Solution is based on years of preliminary work in the field of "Development and Climate". [197]

All the goals formulated at the beginning in the areas of climate, energy and prosperity ultimately prove to be achievable in principle because the Reference Solution is agreeable to all three groups of countries - the expanded OECD, the China Club and the Challenge Group - and makes cooperation possible. A decisive reason is that it proves to be compatible with prosperity for all. In addition, conflicts of principle over the use of fossil energy sources are eliminated. Industrialisation of the developing and emerging countries, essentially the Challenge Group, thus becomes possible.

The chapter concludes with sensitivity analyses, on the basis of which it is possible to make statements about the robustness of the Reference Solution. The question is how influential changes in decisive solution parameters are on the overall result.

8.1 Net Zero and the achievement of the 2°C target

The Reference Solution makes it possible to achieve Net Zero worldwide by 2070. Net Zero can already be largely achieved by 2050, and after a temporary overshoot, the 2°C target could also be achieved retroactively in 2070. The year 2070 is in line with the formulation in the Paris Climate Agreement that Net Zero should be achieved in the second half of the 21st century. One reason why the target will not be reached until 2070 is that many important emerging economies, such as India, have pledged Net Zero in their NDCs only for this point in time.

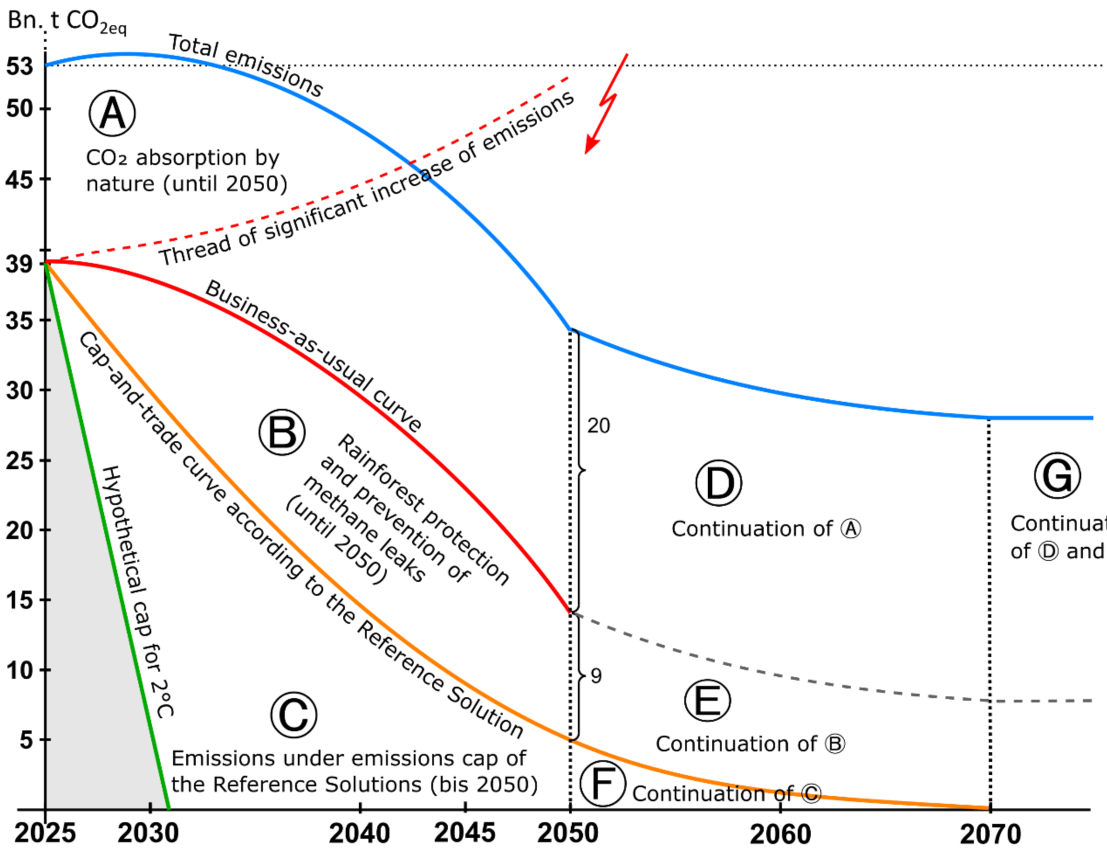
It should be emphasised at this point that the objectives as formulated in the **Paris Agreement** have **not** yet been **backed up with measures**. An important added value of the Reference Solution is that the ambitious objectives are backed by a package of measures that can be implemented in principle.

[197] Cf. e.g. E.g. Radermacher (2011, 2018, 2020)

In developing the Reference Solution, global emissions are considered as net CO2 equivalents. The approach looks at the goal of achieving Net Zero globally between 2050 - 2070 from the side of the solution elements. In this sense, no reduction options are explicitly developed for individual sectors, e.g. agriculture or the steel industry. Instead, it analyses which measures exist to reduce net emissions and how high their respective contribution can be. This supports opportunities for cross-sectoral net reductions because it does not prescribe how large a share of new renewables or the use of carbon capture technologies should be in individual sectors to reduce emissions. The easiest to implement and cheapest solutions are thus favoured in those sectors where it makes sense.

Of course, it is often easy to establish a link between the measures of the Reference Solution and the emitting sectors. For example, the nature-based solutions have an impact on agriculture when it comes to soil improvement. But the proposed short-rotation plantations and climate neutral fuels also affect the agricultural sector as well as mobility and thus have a cross-sectoral impact. How large the share of emissions is that is absorbed by the solution components in the individual causative sectors is, in the sense of the logic described, not part of the statements that are developed within the framework of the Reference Solution.

Figure 11 below illustrates key elements for achieving Net Zero, as explained in the previous chapters, and their interplay, which together lead to the significant CO_2 reductions required for Net Zero.



Explanation

Ⓐ **CO_2 sequestration by nature (by 2050):** 480 billion metric tons of CO_2 uptake by nature (increasingly also oceans, 130 billion metric tons of CO_2).

Ⓑ: Rainforest protection and methane leakage elimination (by 2050): Saving 200 billion metric tons of CO_2 to supplement the cap-and-trade system through special programs (720 = 520 + 200).

Ⓒ/Ⓕ: Emissions under cap-and-trade of the Reference Solution (by 2050): Still about 520 billion metric tons of CO_2 emissions below the cap-and-trade line by 2050, Net Zero will be reached in 2070. In 2050-2070, 33 billion metric tons of CO_2 still permitted under cap-and-trade Ⓕ (orange line). In 2050, the 2 °C target is estimated to be exceeded by 290 billion metric tons of CO_2 (520 instead of 230 billion metric tons of CO_2). Ⓕ: Consequence of NDCs that envisage Net Zero only for 2060/2070.

Ⓓ **Continuation of Ⓐ:** 384 billion metric tons of CO_2 savings as a result of absorption of CO_2 by nature, including oceans. This includes 104 billion metric tons of CO_2 relief by oceans.

Ⓔ: **Continuation of Ⓑ:** Continuation of complementary special programs with 160 billion metric tons of CO_2 savings. Of which 33 billion metric tons by 2070 for expiring cap-and-trade system. In addition, relief of 104 billion metric tons of CO_2 negative emissions by considering absorption by the oceans.Thus, negative emissions of about 230 billion metric tons CO_2. 2 °C target can be achieved in 2070 by 230 billion tons of negative emissions in Ⓔ and non-utilization of 60 billion tons of CO_2 allowed from an appropriate gigaprogram nature-based solutions (total 230 + 60 = 290 billion tons of CO_2). Remark: The gigaprogram i s designed as a buffer and is not otherwise included in the figure.

Ⓖ: Continuation of Ⓓ and Ⓔ.

Total emissions

Threat of a significant increase of emissions: DEspecially as a consequence of significant economic growth in developing and emerging economies (Challenge-Group).

Business-as-usual curve: The figure assumes 720 billion metric tons of CO2 in the business-as-usual scenario.

Cap-and-trade curve according to the GES Reference Solution

Hypothetical cap for 2°C: unrealistic, only shown for making the case plausible.

Figure 11: Elements to achieve Net Zero

Source: Own representation

In the sequel, we describe how to achieve Net Zero except for 5 billion tonnes of CO_{2eq} in 2050 and fully by 2070.

In **2025**, **39 billion tonnes of CO_{2eq}** are produced mainly in the energy production sector (about 34 billion tonnes of CO_{2eq}) and in the forestry and land use change sector (about 5 billion tonnes of CO_{2eq}), cf. Chapters 2.2, 2.3 and 5.1. In the reference solution, it is assumed that this figure will increase by a further 20 billion tonnes by **2050** due to the considerable growth in the energy sector of the developing and newly industrialising countries (challenge group), cf. Chapter 5.1. In total, we are then talking about **59 billion tonnes of CO_{2eq}.**

Of these, 54 billion tonnes of CO_{2eq} can be eliminated by 2050. The remaining 5 billion tonnes of CO2eq, which will only be eliminated by 2070, result on the one hand from the NDCs of China and Russia, and on the other hand from the adjusted NDCs of the countries in the Challenge Group. The values for the developing and emerging countries result from the assumptions made in the context of the adjustment of the conditional NDCs of these countries. For this purpose, the Challenge Index was developed in Chapter 4.5 for the subdivision of the countries in the Challenge Group. Achieving the goals here is only conceivable through enormous financial transfers, as envisaged in the centre of the Reference Solution, cf. chapter 6. The practical implementation of the diverse requirements in a total of almost 200 countries is efficiently done through the envisaged cap-and-trade system, which was canonically derived from the NDCs that are no longer conditional, cf. chapter 6.4.2.

The **elimination of the 54 billion tonnes of CO_{2eq} by 2050** will be achieved through measures that in part require considerable cross-financing.

According to Chapter 5.3, the restructuring and build-up of the energy systems will follow the logic of the two pillars. The significant **expansion of new renewables** reduces CO_{2eq} **emissions by 24 billion tonnes of CO_{2eq}** per year by 2050 (the new renewables capacities installed in 2020 save about 1 billion tonnes of CO_{2eq} per year).

The use of fossil fuels with carbon capture will result in **15 billion tonnes of CO_2** savings by 2050. For old renewables, little change from the current status quo is to be expected (for the Challenge Group we calculate 6 billion tonnes of CO_2), nuclear energy will be expanded comparably to other approaches.

We calculate the protection and conservation of tropical rainforests at around **3 billion tonnes of CO_2** emissions avoidance, cf. Chapter 5.7.1. In the context of eliminating technical methane leaks, we assume **5 billion tonnes of CO_{2eq}** savings (with a total potential of around 8 billion tonnes of CO_{2eq} , cf. Chapter 5.6).

As a contribution from the **revised NDCs** of the Challenge Group, we expect in the order of about **5 billion tonnes of CO_2** relief through a combination of nature-based solutions, cf. chapter 5.7.4, and an increased use of gas instead of coal, especially in power generation.

As a further element for negative emissions, the Reference Solution sees the short-rotation plantation programme with a potential of **3 billion tonnes of CO_2** per year by 2050 based on the UN calculations, cf. chapter 5.7.5.

In total, the above measures will eliminate (even) **55 billion tonnes of CO_{2eq}** in the ramp-up from 2025 - 2050. Depending on the success of the implementation of the individual elements, there is thus a good chance of completely reducing the 54 billion tonnes of CO_{2eq} arising from the energy-related sectors by 2050. The share of emissions reduced by carbon capture should not have to exceed 15 billion tonnes of **CO_2** if possible through increased use of gas instead of coal, since (similar to the necessary ramp-up of electrolysers for the production of green hydrogen, cf. chapter 5.3.3) limits are to be expected in the ramp-up of carbon capture technologies. The more capacities are used by the countries of the expanded OECD and the China Club, the less capacity remains for the less solvent countries of the Challenge Group. Here, attention should be paid to a smartly organised global distribution of capacities.

If there is a need for further negative emissions, the gigaprogram nature-based solutions can also be used, which acts as a buffer in the Reference Solution, cf. chapters 5.7.2 and 5.7.3. This gigaprogramme, if successfully implemented as described, includes further negative emissions totalling 10 billion tonnes of CO_2 (5 billion tonnes of CO_2 each from afforestation on 1 billion hectares and humus formation on a further 1 billion hectares of land).

It is striking that, contrary to popular expectation, low carbon hydrogen does not make an explicit contribution to achieving Net Zero. This is because hydrogen has (only) a transformation function. A contribution to Net Zero must be made by the energy carriers through which the low carbon hydrogen is produced, i.e. new renewables, gas with carbon capture or nuclear energy.

Finally, with regard to the 2°C target, it should be noted that this can only be achieved with a certain probability. The IPCC put this at around 67% with a budget of residual emissions of 1,150 billion tonnes of CO_{2eq} starting from 2020.[198] A decisive factor for its achievement is the generation of massive negative emissions from 2050 - 2070. Their effect on the greenhouse gas content will be greater the fewer new emissions have to be "offset". However, the delayed achievement of the target can result in considerable further costs in the area of "loss and damage". Furthermore, self-reinforcing effects can also occur in the meantime that lead to further climate burdens, e.g. through the tipping elements of the climate system. In that case, retroactive achievement of the 2°C target is no longer

[198] Cf. IPCC (2021).

possible. The question also remains to what extent the reduction in CO_2 concentrations will actually take place as expected. This applies above all to the time dimension of the effectiveness of CO_2 avoidance and pollution in the atmosphere.

8.2 Development effects of the Reference Solution

Development is an ambitious programme that aims to ensure that the living situation of people in developing and emerging countries improves significantly. It falls within the framework of discussions on sustainable development. As a rule, the goal pursued worldwide is development in the direction of the prosperity of industrialised countries.

In history, there have been a number of impressive development processes of countries since the Second World War, such as the resurgence of Europe, especially Germany, the resurgence of Japan, the reconstruction processes in Korea and Taiwan, the situation in Singapore or, for example, the industrial rise of China.

For the development of Europe after the Second World War, the Marshall Plan stands as a central metaphor of possibility. However, one must point out essential differences to the development needs discussed today. In 1944, Germany - despite the war - was at the peak of its possibilities in terms of its industrial production capacity, and in doing so - in terms of population sizes - was at the top of the world; this was similar for Japan. Other countries such as Korea or Taiwan had long been integrated into the Japanese sphere of influence and had already experienced many developmental steps. What they lacked after the war was above all capital. The experience with industrial processes was there, as was a rudimentary infrastructure; it was relatively clear what expansion processes were necessary.

In this respect, the **great successes after the Second World War** are not as surprising as they sometimes seem. On the other hand, they are not so easily transferable to other countries where many elementary prerequisites are lacking, e.g. a high level of education of the population or a functioning legal system, effective governance, etc.

In a contribution by one of the authors on the question "**What makes a country rich?**", eight dimensions relevant in this context are listed: [199]

1. A well-functioning, efficient governance system
2. Excellently educated and suitably oriented and motivated people (in particular: education, health and age as a core social issue)

[199] Cf. Radermacher (2014).

3. Outstanding infrastructures at international level
4. An excellent capital stock
5. Access to required resources
6. High-performance research and internationally competitive innovation processes
7. An efficient monetary and financial system
8. A close embedding of companies and people in global value networks

In addition, as mentioned above, there is an **efficient/ balanced income situation**, described by a Gini index between 0.25 - 0.35. However, empirically, there is currently no country that fulfils the above-mentioned eight factors and whose Gini index lies outside the above-mentioned range. If we look at the situation of many developing countries today, they face enormous difficulties with regard to practically all of the above eight dimensions - and this against the background of a rapidly growing population. Therefore, it is not possible to build on the successes mentioned after the Second World War. What remains is possibly the study of China's success. However, it should also be noted that the country has been able to play a special role, namely as the factory of the world, which others cannot do now in this form, because China already has this role. China has a very large population and can exert an effective (dictatorial) influence on it. Much more effectively than, for example, India (as a democracy) can or Africa as a continent with 54 countries, some of which act more against each other than with each other. Moreover, **China has a long historical tradition of efficient social organisation, as a unit.** China was for a long time the richest and most successful country in the world and had an education system that brought the country's brightest minds (from all classes) into administrative positions.

Ethnically, China is relatively homogeneous. There is a common (written) language, a Confucian tradition. In particular, the grip of the communist party was and is massive. Therefore, a central will could be enforced within the framework of China's industrialisation, e.g. in the development of the country via special zones - coming from the coast and slowly moving into the interior.

Property issues were quickly resolved by expropriation if necessary. The general interest formulated by the party took precedence and was enforced. Planning processes were rigorously implemented, economic success was and is above all - of course always under the primacy of securing the power of the Communist Party. In the process, the communist system endeavoured to bring the most successful companies, especially from the industrialised countries, into the country, while also ensuring that they could profit substantially from their involvement in China.

For example, China brought European and American car companies into the country. They knew how to do business and brought modern production to the country. **Substantial investments were made in the education of the Chinese workforce**, infrastructure was built and ultimately a massive increase in prosperity was achieved in China, while at the same time large profits were transferred abroad. All this was also possible because although wage growth in China was part of the programme, it was also controlled; trade unions were not allowed. In return, China used its market power to secure access to intellectual property rights of foreign companies.

So what does all this mean for the GES Reference Solution? First of all, it should be noted that one of the **most important indicators of development** is **the gross domestic product per capita.** Looking at GDP makes it possible to derive over the years how much growth is added to people's lives on average. Incidentally, this also applies when GDP, as a measure of a country's prosperity, shows deficits. When comparing the annual values, this balances out. It is then important to observe that poor countries have a great potential to grow very fast in percentage terms year after year. This makes them attractive for capital and foreign investors. In absolute terms, the high growth rates are perhaps a smaller absolute increase compared to (more modest) growth rates in rich countries. According to the theme "much of little can be less than little of much". On the other hand, if such a process runs over years and decades, as in China, then at some point the prosperity in the poorer part becomes substantially greater, also in an absolute sense: a middle class emerges. China has been able to lift almost a billion people out of poverty in recent decades (after the Communist Party had previously led many people into unimaginable poverty and hardship during the failed "Great Leap Forward" and the "Cultural Revolution" under Mao), probably the greatest development achievement of recent decades - in which the industrialised countries of course played a major role.

A kind of communist equal distribution is not a good solution for development. **For development and wealth creation, you need capital.** Capital concentration is necessary for high investment and risk-taking. Moreover, **performance must be visibly rewarded**. This leads to a differentiated distribution of income. However, it is clear that a two-class society is also no way to achieve general prosperity. The consensus today is that one should strive for an "**efficient inequality**" **state**.

Worldwide, the decisive differences in prosperity still lie between countries - and less within countries. It is interesting to note, however, that the gap between countries has been decreasing over the last decades. Partly in parallel, however, the gap within countries has increased again - especially in some rich countries. Typical examples are the USA (with the Rust Belt problem probably resulting from this) and also Great Britain (with the Brexit probably resulting from this). These are examples where globalisation generated enormous globalisation gains in countries like China, which of course benefited the rich in China as well as the rich all over the world, but precisely the industrial workers of the rich countries lost part of their wealth because their jobs "emigrated" and no sufficient compensation was organised in the respective countries.

It is important to note that we are talking about GDP here and not other measures of well-being, although there are many arguments against GDP. Many attempts have therefore been made, including after the great financial crisis of 2008/2009, to examine whether a different concept of wealth should not be introduced. Nobel Prize winners in economics, such as Professor Joseph E. Stiglitz, were involved - but they did not get very far. An alternative to GDP is, for example, the **Human Development Index,** which, in addition to GDP, also takes into account the educational level of countries and health care on an equal footing. It should be noted, however, that - not surprisingly - there is a close correlation between GDP and the Human Development Index. This is of course because a rich country must have a well-educated population, and a broad one at that. Whereby investment in this education almost economically forces investment in a good health system. The Human Development Index consists of these variables.

If we look more deeply into the necessary preconditions, one point is particularly important in the context of the eight points mentioned above, namely the **co-financing of poorer parts of the overall system by the richer parts**. This is urgently needed to avoid cannibalisation of various kinds. There are variants of a fiscal equalisation system in all rich countries. This is already the case, for example, when the richer parts take on larger shares of financing, just as much larger as relative to the size of the population. This then affects the financing of general state tasks such as the state apparatus, the military apparatus, the country's central research programmes, etc. But mechanisms of transfer are also necessary. In Germany this is the **Länder financial equalisation,** in Europe it is the so-called **structural funds**. This is generally an expenditure in the order of a few per mille to a few percent of the total tax revenue. And this prerequisite must be fulfilled if one wants to have a chance of parallel development of the sub-sectors.

It is also important to observe **certain standards**, for example in the situation of workers, including for strikes and co-determination. In particular, the material and legal situation of women, training opportunities, opportunities to have a say, etc. are important. One also has to think a lot about the relationship between the centres and the periphery. The more prosperous families are, the more they invest in the education of their children, especially in the education of girls, the more likely it is that there will be a stabilisation in the reproductive sphere, in addition to the generally desired equitable relationship between the sexes.

The proposed measures in their entirety lead to a considerable increase in prosperity in the countries of the Global South - very much in the spirit of a **Marshall Plan with Africa.**[200]

For Africa alone, for example, it is possible to triple its own food production in the next 30 years. Africa should be able to feed itself and export food. The proposals include a wide range of

[200] Cf. CoR & Senate of the Economy (2016).

considerations on water management, the development of the food industry, the role of cold chains and, in particular, the processing of its own resources, as well as a strong timber industry. Again, the growth programme is linked to an industrialisation process. In Africa, at least a doubling of the real estate stock as well as the existing infrastructures of all kinds is on the agenda over the next 30 years. All in such a way that the climate is protected at the same time.

Renewable energy production will become big business in parts of Africa. By means of infrastructures, electricity can be distributed across the continent, perhaps also to Europe. The production of green hydrogen and synthetic fuels will be a big issue. Many innovations are still possible here.

8.3 "From Billions to Trillions" through system services

The Reference Solution focuses on an approach beyond classical ODA funds: The funds of international development cooperation could increase from today's 200 to 300 billion US dollars by 2050. In the end, the increase to over 200 billion US dollars in ODA funds "succeeded" due to the Ukraine war. ODA funds are an important instrument of North-South cooperation, but they cannot be increased at will. The populations of rich countries often find it difficult. Populists always find an agitational environment here.

A central element of the Reference Solution is therefore the **system services** approach. They are a decisive financing lever and complement the idea of classical development financing. They open up an opportunity to finally succeed in making the Global South's demand "From Billions to Trillions", which has been in the air since 2015 in the context of the 2030 Agenda, a reality. In essence, it is about the realisation that the global ecological and social systems can only be stabilised for the benefit of all if corresponding sums are raised for cross-financing the Global South.

Moreover, the funds for system services flow according to an ex post logic, i.e. only after projects have been implemented, measures have been delivered and goals have been achieved. This counteracts the phenomenon of "dying projects" that is often encountered in traditional development cooperation, because financial incentives are set to ensure their continuation. Negotiations are based on the logic of "I will, if you will", which in economic theory is expected to bring the most benefits for both negotiating parties.

The system services approach is not about helping other countries, which is to be understood as charity. Nor are unresolved questions of justice the argument for the flow of money to the Global South. It is not even about development in the classical sense. **The systems services approach feeds solely on the motivation of insightful egoism,** which leads to taking the necessary measures to keep ecological and social systems stable in one's own interest. Even the rich of this world can only profit from the global economic system to the extent that it is supported by existing functioning systems, even if they need to be expanded. If the system destabilises, prosperity declines. And if the population increases, this also means that the ecosystems would not be saved. Rather, they would be destroyed more quickly because, for example, the clearing of the rainforest means quick profits. Therefore, the global system must be further expanded through the services described and supported where it is currently threatening to erode.

So far, this is not succeeding and this fact is increasingly bringing the world into a state of instability in many respects, which more and more people are beginning to perceive.

Successes in climate protection fail to materialise. The current approach to the energy transition is increasingly proving to be very expensive. The threat of a loss of prosperity is being talked about more and more openly.

Despite this interim balance, climate policy remains almost exclusively focused on measures at home. Politicians and citizens must take note of the fact that emissions are nevertheless continuing to increase worldwide, and that as a result the climate threats are becoming even more acute. The negative consequences of this intensification affect everyone. On the one hand, there are the direct consequences of climate change on the ground, such as extreme weather events and droughts. But the indirect consequences will be even more threatening if parts of the world become uninhabitable. There is a threat of refugee flows of unprecedented magnitude. Little is currently being done to prevent or at least alleviate these developments.

There is also currently an increase in armed conflicts and a new division in the world, which threatens to be further exacerbated by disagreement on how to proceed with climate protection ("phasing out fossil energies" vs. "phasing out fossil emissions"). These are also elements of destabilisation that threaten the future. At a time when geopolitics is becoming very important, military spending is growing massively worldwide. As a result of the conflicts, many markets are faltering and the resulting shortages are driving up costs - with particularly tragic consequences for the global food situation.

The uncertainty that exists at home, combined with the global turmoil, is increasingly leading to a loss of confidence in politics. As a result, right-wing parties are gaining more and more support in many countries of the enlarged OECD, which threatens to destabilise the political situation.

Against the background of the situation described above, which is characterised by multiple destabilising developments, **it is to be expected that the OECD countries will realise that they should use the few options that could succeed in bringing about a stabilisation of the ecological and social systems**. If there is a way to eliminate the worst threats with an average of 800 US dollars per capita and year per OECD citizen, a turnaround in the design of international financing is not without chance. If in this context - albeit belatedly - the SDGs and climate neutrality can be achieved and peace secured, these should be further motivating arguments.

As with the successful implementation of the Montreal Protocol, the system services approach focuses on its own benefits. The Global South pays for valuable contributions to the stabilisation of ecological and social systems. A strict coupling between the Global South's service provision and the Global North's cash transfers guarantees consistency and reliability of the measures over long periods of time.

Within the framework of the Reference Solution, the approach was deliberately chosen that **cash transfers are only granted year after year for system services rendered**. For example, in the case of rainforest protection, the money for one hectare of rainforest will only flow for another year if the forest is still maintained in the same quality after one year. The funds for the implementation of the NDCs should also be paid out annually and based on the fact that the promises made have been kept. In this way, compliance can be strengthened, which in turn should improve the Global North's willingness to provide funding.

Realising this approach is a great opportunity for the future. **The time for new dimensions in co-financing the Global South is pressing**. With the approach of system services that the Global South provides for the world, an idea is at hand that will hopefully succeed in massively increasing the willingness of the actors of the enlarged OECD to make financial contributions in the Global South. It is important to note that the Reference Solution opens up good chances of keeping the CO_2 avoidance price below 100 US dollars per tonne of CO_2 internationally through decisive efforts in the challenge countries. The proposed cap-and-trade system is helpful here.

8.4 Implementation perspectives for the SDGs

The Sustainable Development Goals (SDGs) are an ambitious system of goals set by the world of countries at UN level to implement sustainability ideas for the globe. They are also referred to as the **2030 Agenda,** which was adopted in 2015 in parallel with the Paris Agreement on climate. The ambitious programme has virtually no prospects of being implemented by 2030. However, this is the norm at the United Nations level. Former UN Secretary-General Kofi Annan once said: *"What is needed now is not more declarations or promises, but action to fulfil the promises already made"*.[201] An interesting reference is the Millennium Development Goals, the precursor of the Sustainable Development Goals. They were supposed to be implemented in the period 2000 - 2015, but this was far from successful.[202]

[201] Annan (2005).
[202] Cf. Radermacher (2015).

At that time, the **Millennium Development Goals** had a focus on developing countries. The rich countries were involved to promote and especially co-finance the development of the poorer countries. In the end, this has led to little. There is a fundamental lack of willingness to finance substantial transfers at this point. With the SDGs, things have been made even easier in a certain sense. Primarily, each country is asked to implement the goals individually, as the Paris Agreement does with the climate. This leads to a lot of approval on the ground, because the country's own money stays in the country. It also leads to a great deal of approval among the relevant NGOs, which, with this philosophy, can implement their own agenda in their own country, with their own country's money. So the money does not flow to the Global South. Therefore, the chances for the SDGs are bad from the outset, especially for sustainability in poorer countries - even worse than the chances for the Millennium Development Goals. In addition, with regard to such important issues as hunger (SDG 2), there is the sad situation that the food situation worldwide has even dramatically deteriorated again due to the Covid pandemic and subsequently the distortions resulting from the Ukraine conflict. We are further away from achieving Goal 2 than we were in 2015.

In the following, we discuss the chances of achieving the SDG targets in the context of the Reference Solution. From the outset, our aim is not to implement the SDGs by 2030, which in our view is unrealistic, but to achieve the goals between 2050 and 2070. This seems possible to us. Here, the Reference Solution as an approach with substantial international co-financing ("**From Billions to Trillions**") is of course much more suitable for achieving these goals than the initial situation with classic development cooperation and modest international climate financing, which is the basis today. We describe these circumstances in detail for the 17 goals below. It should be noted that these 17 goals are differentiated into 169 sub-goals. However, we will not deal with these sub-goals here, but (only) take a summary look at the individual goals.

Goal 1: No poverty

Achieving this goal means a significant improvement in the welfare situation for a very large number of people all over the world. Poverty is the reality for hundreds of millions of people today. Depending on the specific wealth situation of a country, every person should **at least** have **the minimum** that is to be achieved according to international principles in order to no longer be considered poor. The aspiration of a quadrupling of GDP growth in the Challenge Group is an essential precondition for a minimum wage to be paid worldwide. In fact, the target of the Reference Solution goes well beyond this minimum.

Goal 2: Zero hunger

Currently, hunger in the world is on the rise again. This is a consequence of Covid and the war in Ukraine, but droughts due to climate change are also exacerbating the situation. Hunger always has two sides: On the one hand it is about how much food is available, on the other hand it is about purchasing power. **Does everyone have enough purchasing power to** buy the food they need to **avoid starvation**?

As already described for Goal 1, the eco-social approach on which the Reference Solution is based aims to overcome poverty by guaranteeing minimum standards, such as a minimum wage. In this way, purchasing power is created, which is often the cause of hunger - not the scarcity of food. This is achieved in particular through the massive economic development envisaged, which is "fuelled" by substantial inflows of funds from rich countries. In addition, the solution allows food production to be increased on a large scale, especially because the yield capacity of agricultural land is increased through large-scale restoration of soils. In this way, countries in the Challenge Group could increasingly supply themselves with food, whereas currently a large proportion must be imported, e.g. from Ukraine, Russia or the USA.

Goal 3: Good health and well-being

It is part of the ecological-social paradigm that the promotion of prosperity must essentially also rely on populations being well educated, being able to keep themselves healthy and therefore also tending to grow old. This is what distinguishes countries with prosperity. Prosperity is a central theme of the Reference Solution, with the use of digital approaches playing a major role in enabling the **adequate provision** of modern medical options to an ever-growing human population without driving resource consumption and costs into unsustainable dimensions. By simultaneously combating climate change, bringing about a situation for a stable climate and making enormous efforts to ensure biodiversity and resilience important parts of the programme, the conditions for health and well-being continue to improve.

Goal 4: Quality education

As already mentioned under 3, high-quality education is an essential prerequisite for making societies capable of creating value. It is part of a global eco-social programme that prosperity grows everywhere in the world, most rapidly in the poorer countries, i.e. that the **balance** in the world also increases **in terms of the Gini coefficient**, within the poorer countries as well as between the countries. High-quality education is an essential element for this process.

Goal 5: Gender equality

Among other things, it is about how families are set up, what the division of labour within the family looks like, what the legal situation is, for example with regard to property or land titles. In any case, it is important to create **comparable situations and options for both genders**. This is an essential element of the ecosocial programme. This also applies to value creation aspects. Corresponding capacities of people's abilities are needed. These can only be fully developed if they are developed in men *and* women.

One aspiration of the solution is that population growth should stabilise by 2050. This also depends significantly on the situation of women's rights, especially in education and health. Property issues also play a major role, e.g. inheritance or other tenure.

Goal 6: Clean water and sanitation

The Reference Solution programme means a significant improvement in living standards for all people. It includes major efforts to **stabilise the water balance**. This applies in particular to the rainforests, but also - through the promotion of humus formation - to agricultural soils, e.g. by increasing the water-binding capacity by means of biochar in agricultural soils. In general, growing prosperity is always associated with improved access to clean water and sanitation.

Goal 7: Affordable and clean energy

This issue is at the centre of the Reference Solution. Compared to other futures being discussed today, it includes substantial economic growth in the developing and emerging countries as an explicit goal. Corresponding to this is substantial growth in energy supply. It is about **energy prosperity for all**. It is a clearly different strategy than, for example, "renewables only" for developing and emerging countries. The central element of the solution is extensive co-financing to provide affordable and clean energy for all, including - as a second pillar - fossil energy with carbon capture.

The Reference Solution includes the assumption of differential costs for all measures in the energy sector of developing and emerging countries that strive to protect the climate. By assuming the costs for the conditional NDCs, decisive contributions from the rich world are made for affordable and clean energy in the developing countries and emerging economies. This also applies to the planned transcontinental infrastructure development in the energy sector and in the context of the cap-and-trade system described above.

Goal 8: Decent work and economic growth

The reference model aims at a significant **increase in the social balance worldwide**. This is achieved in particular through high economic growth in developing and emerging countries, for which, among other things, the necessary energy is provided. The approaches to make all this possible include the expansion and restructuring of energy systems, the construction of intercontinental (energy) infrastructures, programmes to bind CO_2 in the area of nature-based solutions and large special programmes, for example to prevent methane leaks in oil and gas production. At the same time, this creates many new jobs: e.g. as a result of the Nature-based Solutions gigaprogramme, in consistent rainforest protection, but also in the production and incorporation of biochar into agricultural soils. The creation of attractive jobs ultimately leads to high economic growth in developing and emerging countries.

Goal 9: Industry, innovation and infrastructure

The proposed solution is intended to create the conditions for developing and emerging countries to have a good chance of industrialising. China serves as an example here. Large industrialisation programmes are co-financed. This also applies to many activities in the field of agriculture and forestry. These are all thematic areas in which innovations play a central role, but also existing innovations find their implementation - worldwide. The GES Reference Solution is thus also a global programme for **technology transfer**. The Reference Solution is strongly aligned with **UNIDO's mission**.

Goal 10: Reduced inequalities

The Reference Solution was developed against the background of many years of academic work on the topic of inequality.[203] On the one hand, it deals with inequalities between countries and, on the other hand, with inequalities within countries. In the latter case, **income distribution** plays an essential role. Here, there are deep insights into the significance of the Gini coefficient.[204] It is a key indicator that manifests the extent to which people are supported across the board, especially in education, health, pensions, etc.

A central concern addressed by the Reference Solution is the reduction of disproportionate inequalities, both within and between countries. This does not mean that the world is moving towards a utopian communist or socialist model of society. Rather, it is an orientation towards the economic

[203] Cf. Herlyn (2012); Radermacher, Kämpke (2015).
[204] Cf. Herlyn, Radermacher (2018).

theory of so-called efficient/balanced inequality, the core of which is the achievement of the so-called efficient inequality range, according to which the Gini coefficient should be between 0.25 and 0.35. Empirically, the world is currently rich and poor. Empirically, rich countries are currently in this range. Therefore, it corresponds roughly to the level of equalisation that exists today between and within European countries. As multiple studies by Wilkinson and Pickett in this area show, a balanced equilibrium level has many other advantages for other indicators of a functioning society and healthy people living in it. From this, it can be deduced what is intended to achieve with the Reference Solution worldwide.

Goal 11: Sustainable cities and communities

The issue of population development, such as the parallel further increase in **urbanisation**, is a central theme of the Reference Solution. The fact that two billion more people will be added to the world by 2050 - especially in the Challenge Group - is a central concern. In particular, it is about the doubling of the population in Africa by 2050, but also about the further population growth in India. The Reference Solution aims to break these growth processes and thus reach the peak of the world population at ten billion in 2050. The expansion of cities and municipalities, especially in view of these enormous growth processes, is a central concern of the Reference Solution. Many cities will grow gigantically, and as much **sustainability compatibility** as possible must be ensured in the process. The world will see that more and more of the largest cities will be in Africa, but also in India. The Reference Solution is designed to give precisely these countries a chance to secure a good future for their cities and communities. This concerns energy availability, mobility, etc.

Goal 12: Responsible consumption and production

The entire programme of the Reference Solution is designed so that the world actually achieves Net Zero - after temporarily exceeding the 2°C target - by 2070. Combined with co-financing on the social side, this is a programme for sustainability that encompasses consumption and production. All these processes will ultimately become climate neutral. Where they are transitionally not, the Nature-Based Solutions gigaprogramme provides a biological buffer. It opens up an opportunity of 10 billion tonnes of CO_2 emissions for humanity per year. The bottom line is that **climate neutrality** will be achieved this way, albeit **not until 2070**. This path to the future leads to jobs and more prosperity everywhere. It is designed for sustainable consumption and production. This is also because it moves towards the full implementation of the SDGs.

Goal 13: Climate action

This is the central theme of the Reference Solution with Net Zero by 2070, by which time the implementation of the 2°C target should also succeed retroactively.

Goal 14: Life below water

The situation will be such that the pressure for more CO_2 absorption in the water will decrease, i.e. the acidification of the oceans will be mitigated. At the same time, the pressure on coastal regions, mangrove forests, coral reefs will also be reduced. Sewage treatment plants are becoming a matter of course. In addition, the oceans, especially in the coastal regions, will be activated to generate more wealth. This applies, for example, to the afforestation of mangrove forests or the large-scale planting of algae farms ("maritime afforestation") in order to bind CO_2 on the one hand, but to generate added value through the accompanying cultivation, whether for synthetic fuels or vegetable carbon from algae up to processing into algae-based food.

Goal 15: Life on land

The reference programme includes numerous programmes that lead to positive development in this area. This is especially true for **rainforest protection**. Of course, this also applies to the **gigaprogramme** in the area of **nature-based solutions**, which refers to both forestry (especially on degraded soils in the tropics) and food production (especially on semi-arid soils with poor humus balance). Other nature-based solutions are an important part of the Reference Solution to reduce global emissions to only 5 billion tonnes by 2050. Mangroves, boreal forests, humus formation on agricultural land in general, algae etc. were addressed.

Goal 16: Peace, justice and strong institutions

At last, the concern of Indira Gandhi, Stockholm 1972, is being implemented. In it, prosperity all over the world is the goal. By promoting **more social balance between countries in developing countries**, the **starting point for peace is improved**. The eco-social character means a strengthening of the WTO, which fairly links North and South with regard to trade issues, whereby the rich countries increasingly no longer feel bound by WTO logic, especially with regard to energy and climate, and apparently rely on being able to assert themselves, if necessary, with their economic strength against positions of the developing and emerging countries. The philosophy of the Reference Solution is different. With a corresponding approach, an **ecological-social framework** of the world economy can be established - in coupling with the ILO standards - which can be designed **in conformity with**

the WTO. The application of the WTO's "same product" rule, which is important in the context of free trade, remains the "anchor" of the system. In the future, however, it will be assumed that a state will operate within the framework of the proposed cap-and-trade system (cf. Chapter 5.3) and observe the other requirements of the proposed programmes as well as the ILO standards.

Goal 17: Partnerships for the goals

Within the framework of the Reference Solution, a global partnership for the implementation of the SDG goals is established, to which all three groups of countries belong. In particular, **the proposal of the Reference Solution is peaceable** because it takes into account the economic interests of all countries in the logic of the three groups of countries. This is important because presumably each country will defend its economic interests by force in case of doubt instead of "sacrificing" them to international climate protection. The Reference Solution bridges the contradictions that often exist between the three pillars of sustainability - economic, ecological and social.

8.5 Sensitivity analyses

In model studies such as those undertaken in this text, it is important to carry out sensitivity analyses. It is about examining what happens if assumptions are not exactly correct. The goal of the reference model is to ensure prosperous climate neutrality for ten billion people by the second half of this century. In this context, it is essential for the prosperity compatibility of the solution that a growth rate of 6 % per year on average is ensured in the group of challenge countries over the next 25 years. This means that this group of countries will contribute one-third of the world's GDP in 2050, compared to only about 10% in 2020. However, due to the large number of countries included in this group, the GDP share rises to well over 20 % of world GDP even with only half the growth. This shows the robustness of the model with regard to the importance of the countries in the Challenge Group.

With regard to the goal of reducing emissions to net zero worldwide, the consistency of the **"extended OECD"** and **"China Club"** groups of countries in the implementation of their NDCs, which are not examined here, will of course have a **decisive influence** on whether the goal is achieved for the global community. How these country groups implement their Net Zero pledges will also determine to what extent and how far requested technical solutions are available for the Challenge Group. This is because, even for the future, the expanded OECD and, for many years to come, the China Club will have greater purchasing power than the Challenge Group. In the worst case, these groups of countries simply buy up a large part of the available options in the field of electrolysers for hydrogen production, but especially a large part of the available capacities for carbon capture. This leaves less capacity for the Challenge group, which would have to rely more on other building blocks to achieve Net Zero. In such a scenario, it is to be expected that costs would increase and Net Zero would be reached much later.

Among the technical measures, first of all the assumed **disproportionate growth of renewable energies** and the associated significant increase in the role of electricity as a final energy source are of major importance: both are a major lever for reducing climate gas emissions. However, since fossil energy sources will retain their high share of primary energy supply, the **degree of introduction of carbon capture technologies**, in addition to increasing the share of renewable energies, will be of decisive importance for approaching climate neutrality. Fossil energies will not be ousted from mobility applications in the coming decades due to the difficulty of extensive electrification and will also remain the only source of molecules in many applications due to the clearly limited growth potential of electrolysers. This is why the degree of introduction of carbon capture is, along with the growth of new renewables, the decisive variable for approaching Net Zero.

Among the technical topics, the special programme to **reduce methane leakage** continues to play an essential role: due to the high negative climate impact of this gas, the targeted avoidance of leakage in connection with development and transport as well as measures to prevent methane losses at flares are essential.

The next part of the programme, whose growth rates are crucial in shaping the achievement of Net Zero, is the scale and success of the implementation of **afforestation**. More than 40 million hectares per year over a period of 25 years is a very demanding path. This also applies to the extensive measures for humus formation and **soil improvement**.

In summary, looking at the essential parameters, accompanied by the challenging work of transforming today's conditional NDCs into implementable programmes and co-financing them and creating a cap-and-trade solution, shows how difficult and demanding the proposed path is for the global community.

The reference model addresses the decisive parameters and also shows a way how climate neutrality can be achieved in the period 2050 to 2070. Most of the relevant relationships are of a linear type, i.e. the corresponding **modelling** is **very robust**. Smaller changes - e.g. in the growth rate - only marginally influence the resulting results. The large influence of the parameters summarised here and the robustness of their influence strengthens the validity of the conclusions drawn. In reality, therefore, the considerations are more likely to fail because of the power of particular interests to prevent viable solutions than because of inherent instabilities in the proposed programmes.

The sooner the key decision-makers are willing to face the essential elements of the model presented here in unison, the higher the likelihood of achieving the goal.

9 Obstacles and limitations

Even if an implementation of the Reference Solution is possible in principle, a possible implementation in practice will face many challenges to be solved, perhaps even insurmountable obstacles. It would be a miracle if this were not the case, since the promise of simultaneous realisation of catch-up development and energy prosperity AND environmental and climate protection that goes hand in hand with sustainable development has not been fulfilled to date. Due to the tight timeframe alone, the Reference Solution will encounter many problems in its practical implementation.

The following section describes the basic restrictions that can impair or even prevent the successful realisation of the solution. To this end, fundamental restrictions are first described. This is followed by a description of existing specific issues that could prevent the successful implementation of the Reference Solution.

An **exemplary analysis of the effectiveness of regulatory restrictions** was carried out for the client. On the one hand, a scenario was considered in which regulation prohibits the capture of CO2 at coal-fired power plants on the one hand and no synthetic fuels may be used for passenger cars on the other. On the other hand, a scenario was examined in which a complete phase-out of fossil energies (and not fossil emissions) is prescribed by regulation. Both scenarios are described **in a separate document.**[205]

9.1 Restrictions on the path to a climate-neutral energy system

If we look at the energy supply of countries, but also at their possibilities to achieve Net Zero, both are influenced by a variety of factors. These factors can be very different in different countries, and they can be different factors that promote or hinder the process. This applies in the same way to the development and transformation of energy systems. This quickly becomes clear when one realises that the country of Bhutan is so far the only country in the world that has achieved Net Zero. It is even climate positive: crucial prerequisites for this are the high share of hydropower in energy generation and the country's very large forest areas.[206] The relatively low level of prosperity also contributes to this.

The path a country takes or can take to build or transform its energy system and achieve Net Zero depends on a variety of conditions and circumstances. In the following, some of the relevant points

[205] Cf. Global Energy Solutions (2023b)
[206] Cf. Mayer (2023).

that have restrictions for the design of the energy system and the achievement of Net Zero are discussed. These restrictions are further differentiated for developing and emerging countries. [207]

9.1.1 Geography

The geography and the geographical conditions of a country represent variables that cannot be influenced, or can hardly be influenced, and have always been a strong determinant for the development of peoples and regions. It is about climate, vegetation and fauna, landscape type and ecology, surface forms, water and biosphere.

For example, the question of which forms of energy production are possible and sensible in a particular region is strongly dependent on the geographical conditions. The same applies to the question of what role nature-based solutions can play.

In terms of energy supply, the situation is different for countries with mountains than for countries without mountains. Take, for example, the pumped-storage power plants in Switzerland. You can produce electricity with hydropower. So can those who have favourable geological possibilities - such as Iceland with its volcanism. Natural storage possibilities for gas and hydrogen also play a role, as do possibilities for injecting CO_2 in old oil and gas production sites.

In the context of geography, it is also important how many people live in a country relative to what is available in terms of biological resources. For example, Austria, with its enormous biomass capacities, is a very mountainous country with a lot of forest and has a comparatively small population. It is then relatively easy to create a climate-neutral energy system. This is similarly true for Norway, Sweden and Finland.

Of course, geography is also a decisive factor in how costly and complicated it is to build overland power lines. For example, it took Austria about 30 years to realise a high-capacity power connection across the Alps.

In the current approaches to the energy transition, offshore wind power is a big topic. This in turn requires access to the seas, preferably to sites with shallow water depths and a lot of wind that blows reliably. If there is a lot of wind, as in southern Chile, onshore sites are also interesting. The efficiency of solar energy generation is strongly dependent on solar radiation. Thus, the location factors for the use of renewable energy in the world are obviously very different.

[207] Cf. Stappen (2023).

9.1.2 Technological development status

The level of technological development of countries is of great importance for their ability to act in general. But it is also relevant in terms of their attractiveness for companies, managers and employees in general. In many respects, there is a big difference between being in a developing country and being in a high-tech country. The technological status quo has a decisive influence on what a path towards a climate-neutral energy system might look like and which technologies that come into question will ultimately be used, taking all influencing factors into account.

Of course, it makes a big difference whether there is a developed electricity infrastructure in the status quo or not, whether there is a functioning electricity system to fall back on. In developing countries, where half the population still cooks with charcoal, the introduction of electromobility will be under completely different circumstances than in an industrialised country.

The technological status quo essentially determines the realistic possibilities for further development. In this context, **technology transfer** takes on an important significance. In each individual case, it must be analysed how further technological development can be shaped from a given status quo. One question is how it can best succeed in skipping technological development stages (leap frogging). This seems easier in the context of local grid applications than in the case of technologies that are tied to high and widely distributed technological prerequisites, e.g. smart grids.

The **level of education of the population** is always very influential, for example in implementing technologies and subsequently operating them independently. However, knowledge in the field of economics and management is also central in order to establish efficient entrepreneurial processes.

9.1.3 Infrastructure

The existence of infrastructure has always been a decisive basis for the emergence of prosperity. The term infrastructure covers all facilities, institutions, structures, systems and non-material conditions that serve the provision of public services and the economic structure of a state or its regions. In the context of the Reference Solution, the focus of the discussion on infrastructure is on the technological side, which becomes relevant in the context of energy supply. Areas of application include electric power, gas supply, district heating and the petrol station network. They are usually closely linked to a country's level of technological development, but also to its financial and economic performance. Increasingly, digital infrastructure is becoming important, especially with regard to opportunities for leap frogging.

Individual questions that become relevant in the context of a transformation of the energy system concern the status quo of the infrastructure in the field of renewable energy, the electricity infrastructure in general or also the water and pipeline infrastructure. The time frame in which changes to the energy supply are realistically possible depends on this status quo. From the status quo, it is important to consider, for example, what the situation is with regard to pipelines, whether a country has its own refineries, what the port and shipping infrastructure looks like, or even what the infrastructural conditions are for transporting and compressing CO_2.

9.1.4 Financial and economic circumstances

The financial resources of a country and the strength of its economy are always central issues. They are significant factors influencing its ability to act and assert itself in the international competition for capital, investors and access to markets and raw materials. All of this is of crucial relevance to the question of how vigorously a country can pursue a Net Zero path.

In this context, country ratings play an important role. They are assigned by various credit rating agencies and provide information on the creditworthiness of countries. This in turn has a major influence on the financing conditions prevailing in the country.

For developing countries, a **dilemma situation** often arises: due to poor ratings, if only because of the unfavourable world region, they can only offer low collateral when they need a lot of money. They only receive money from creditors if they can promise high returns. Public debt is rising to ever greater heights. The IMF recently warned of an ever increasing "debt wall".[208] The debt that developing countries will have to refinance in 2024 alone amounts to 30 billion dollars.

The financing conditions thus play a central role. While promising projects can be well financed in the home countries of the major international currencies, poorer countries have to pay **risk premiums** when they borrow money - meanwhile even risk premiums for climate risks that they did not cause but of which they are victims. This is a deeply unfair situation.

It is self-evident that a conversion or even the establishment of a climate-neutral energy system is massively impeded under such conditions.

In addition, there is another phenomenon: it can increasingly be observed that rich European countries, in the context of the **supply chain duty of care**, impose their own, often very expensive ideas on poorer countries, which are subsidised on a large scale by the state at home, e.g. the production of green hydrogen. There are also repeated cases of rich countries using their influence on the World Bank, the European Investment Bank, etc. to withhold loans from poorer countries when they want to develop their own gas infrastructure, for example.

The situation becomes very critical when the large energy companies belong to the public, as in India and South Africa. Partly they belong to the state, partly to the region. In a situation where there

[208] Cf. Winkelhahn (2023).

is high indebtedness and the state has liability responsibility, it is to be expected that costly conversion measures have little chance of being implemented.

9.1.5 Regulation

Regulation, i.e. the "rules of the game" under which the transformation to climate neutrality takes place, is of decisive influence on what ultimately happens. **What is forbidden? What is required? What is subsidised with public money? What will be made more expensive?** The answers to these questions can vary from country to country and thus lead to different approaches. An impressive example at this point is the massive use of nuclear power in France and the rejection of such use in Germany. Both countries are neighbours, similar in many relevant dimensions, furthermore friends and part of a common electricity grid. Such differences in regulation mean that internationally active companies pursue completely different technology paths in different markets. An example of this is RWE, which in Germany relies solely on renewable energies, while in the Netherlands it has converted a coal-fired power plant into a biomass power plant at which it captures CO_2 using carbon capture. [209]

Policymakers have various regulatory instruments at their disposal with which they can influence the actions of actors in the markets. So-called regulatory instruments conceal requirements and bans, non-compliance with which is accompanied by sanctions. One example is the ban on passenger cars with internal combustion engines, which has been under discussion at EU level for a long time. With market-based instruments, politics sets financial incentives to steer the behaviour of actors in a certain direction. Solutions that politicians want to promote are subsidised. Other things are made more expensive in order to make them less economically attractive. One example is the extensive state support for electromobility in Germany in recent years.[210]

As a rule, the **nation state** is the level of regulation. An exception is the European Union, which is creating regulations for the 27 member countries in an increasing number of policy areas. An example relevant in the energy sector is the (highly controversial) EU **taxonomy**. The fact that the scope of regulation is limited has consequences for its actual effectiveness, especially when it comes to subject areas that have a global dimension. Climate protection is one such issue. When, as a result of strict national regulation, economic actors who naturally operate according to the economic principle leave the country and relocate, the problem of **carbon leakage** often arises: Emissions are not eliminated, but merely shifted out of the country. So far, far too little attention has been paid to this phenomenon. Because of the difficulties in principle that exist in creating global framework conditions

[209] Cf. Industry & Energy (2023).
[210] Cf. Dyckhoff, Souren (2008).

("trilemma of globalisation"), this challenge can be expected to continue for a long time, if not forever.[211]

The issue of regulation is always a **tightrope walk**. With too little regulation, ecological and social concerns risk falling by the wayside, which corresponds to the status quo in a global perspective. Markets with too much regulation are static and inhibit innovation. Without smart regulation, the proposed Reference Solution will remain a pipe dream.

To see the power of regulation, it is enough to look at the difference between Germany and France on nuclear energy, as mentioned earlier. Finland is a country where the Green Party votes in favour of nuclear energy. Norway, which is considered particularly environmentally friendly, has taken the lead on carbon capture and storage.

Political regulation is also a big issue when it comes to the question of whether CO_2 can be injected into the ground. It is still not allowed in Germany. Export is also still banned, even though the policy currently seems to be changing. Economic actors can be thwarted and driven into other markets if technologies are not wanted. Whether fracked gas can be extracted is also a regulatory issue. Whether you are allowed to import fracked gas is another question. In Germany, we are not allowed to do the former, but we are allowed to do the latter - and we do it on a large scale.

It is interesting that the **USA** is very generous with the **Inflation Reduction Act** when it comes to what falls under the term low carbon hydrogen. This includes blue hydrogen that is produced from gas, whereby the CO_2 is captured in the reforming process from gas to hydrogen. A central question is then carbon capture. This is another issue that often divides opinion. After all, in February 2023 the EU adopted two delegated acts that define what renewable hydrogen means and what it does not mean according to the **EU's Renewable Energy Directive**. It is intended to ensure that corresponding fuels (e.g. hydrogen or ammonia) can be considered renewable fuels of non-biological origin (RFNBO).

The issue of regulation is central, including the question of **which CO_2 may be used for the production of climate neutral fuels**, which has not yet been conclusively answered. If one produces a synthetic fuel from a low carbon hydrogen, according to German procedure the CO_2 must come from direct air capture - as is done in the Haru Oni project in Chile. Capturing the CO_2 at a coal-fired power plant, where it is produced anyway, on the other hand, is prohibited, even though the process would cost significantly less.

Finally, the handling of biomass and CO_2 produced in this context should be addressed. There are questions here about how to evaluate CO_2, which is produced during the combustion of biomass, captured and used as biogenic CO_2. This CO_2 may find acceptance, as does CO_2 from direct air

[211] Cf. Rodrik (2011).

capture. The many unanswered questions ultimately lead to a massive delay in the ramp-up of technology. One of the consequences of the debates on the origin of CO_2 is that the market is now very much focused on **ammonia.** The CO_2 problem described does not arise there. In addition, ammonia can be transported better than hydrogen, although much more difficult than methanol, for example.

9.1.6 Political system and society

The political system and social conditions all over the world play an important role in the success of transformation and the achievement of Net Zero.

Thus, the form of government has a decisive influence on the "how" of change. Do majorities have to be won in the democratic process? Does a centralised system have the possibility to enforce change? Is there a political authority that is able to bring about the needed changes?

Quite a few voices do not trust democracy to be able to solve global problems such as climate change in time, partly because of lengthy processes of majority formation. At the same time, they emphasise the much greater capacity for action of authoritarian systems.[212] In many Western democracies, the phenomenon can also be observed that voters weary of change strengthen nationalist parties of the right or left fringe, which do not rely on international cooperation to tackle existing challenges and strictly reject international money transfers.

Thus, the state of society also has a great influence on the success of change processes. Of great importance are the widespread narratives that guide people in times of an increasingly opaque reality. If these are not in the spirit of an international and cooperative approach, but convey simple solutions, it is difficult to change them and convince society of the need for holistic solutions.

9.1.7 Raw material availability

Every form of energy production requires raw materials. It is obvious that an increasing demand for energy entails an increasing demand for raw materials. For example, if the energy mix changes in the direction of an expansion of renewable energies, the demand for raw materials needed in the field of renewable energies will increase. If the demand for battery storage increases, the demand for raw materials used in battery production also increases.

Not only the globally increasing demand for energy, but also the worldwide GDP growth of the last decades has led to a steady increase in the demand for raw materials, all of which are non-renewable resources. The long-established term "rare earths", which include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium,

[212] Cf. Stehr, Machin (2019).

erbium, thulium, ytterbium, lutetium and yttrium, suggests that raw material shortages are not a new phenomenon.

Manufacturing companies know that the absence of just one component can bring the entire production to a standstill. Similarly, an unavailability of raw materials that are absolutely necessary for energy production can bring the transformation of the energy system to a standstill.

The unavailability of raw materials can have various causes:

- an actual worldwide unavailability
- a local unavailability (due to proprietary use in the mining countries)
- (geo-)political conflicts that prevent procurement
- High raw material prices that prevent procurement

The facts mentioned below make it clear that the phenomenon of raw material scarcity is indeed a serious restriction on the global energy transformation:[213]

1. A large and ever-growing number of minerals and chemical elements can be classified as critical raw materials.
2. In the case of lithium, cobalt and rare earths, the world's three largest producers, led by China, control three quarters of the global market.

   Lithium in particular represents a key resource in the field of renewable energies and the production of green hydrogen, because the element is irreplaceable in the field of battery storage and PEM electrolysis. [214]
3. The increasing demand for raw materials needed for the energy transformation is faced with problems in the supply of raw materials, caused on the one hand by the Corona pandemic and on the other hand also by the necessary lead time for exploration and the development of production and logistics capacities.
4. The procurement costs of raw materials are exploding due to the mismatch between supply and demand on the one hand and the increased production costs of raw materials with deposits in low concentrations, such as in the case of rare earths, on the other.
5. The industrialised nations' dependence on critical raw materials can be used to blackmail them politically in conflicts.

[213] Cf. IEA (2021c).
[214] Cf. Palitza et al. (2023).

6. Even if global problems can only be solved through cooperation between the producers and users of critical raw materials, the ability to control critical raw materials will be used in some countries to strengthen their own position as a production and trading power to the detriment of others.
7. Unless dependence on critical raw materials can be reduced, e.g. by developing substitutes or improving recycling and extending it to urban mining, the achievement of Net Zero is in serious jeopardy.

Finally, it should be noted that the economically and politically weaker developing countries will be far more affected by commodity shortages than others, because they will be left out in times of rising prices and rich countries will deprive them of scarce goods. The same phenomenon was seen in 2022 as a result of rising LNG demand from European countries: Developing countries like Pakistan and Bangladesh were forced to rely more on coal again because they could no longer afford the expensive LNG.[215]

9.2 Current obstacles

This subchapter describes previous behavioural patterns and current developments that represent obstacles to the successful realisation of the described Reference Solution. They are all closely related to the basic restrictions described above, which influence the implementation of the Reference Solution in practice.

9.2.1 Lack of willingness to co-finance on the part of the enlarged OECD

The issue of co-financing the countries of the Challenge Group, i.e. the developing and emerging countries, by the enlarged OECD is a key issue of the Reference Solution. We are talking about trillions of US dollars to be transferred from the Global North to the Global South. Corresponding sums have never been raised in history. A **paradigm shift** is necessary here. If it does not succeed, the Reference Solution will not be implemented. The past shows that classical public funds for development cooperation cannot be raised in the necessary amount. They are not politically enforceable.

In the following, previous experiences with Official Development Assistance (ODA) are described, from which lessons need to be learned if the Reference Solution is to have a chance of implementation.

[215] Cf. Peer et al. (2022).

It is easy to argue against development cooperation funds - with reference to corrupt potentates in developing countries or with arguments that there is enough to do at home, which also requires public funding. The political environment is objectively difficult.

Not surprisingly, the question of financing development cooperation has preoccupied the world community for decades. For years, contributions amounting to 0.7 % of a (rich) country's GDP have been on the table. However, the average value achieved to date is only about half of that. Scandinavian countries have reached values of over 1 % in some cases.

If we look at the situation from the perspective of the main donors, i.e. the OECD countries, with a total GDP of about 75 trillion US dollars, we are talking about a good 200 billion US dollars per year. Germany accounts for a good 35 billion US dollars of this. In relation to the GDP of the recipient countries, it is about 1 %. The most recent growth in ODA funds results from extensive aid to Ukraine, which is counted as ODA funds.

It should be noted that most of these are not free funds. It often involves contributions to UN programmes, e.g. famine relief or other disasters. It is about promoting health or education programmes. Each country keeps a very close eye on what happens to the funds it provides. Often there are obligations to spend part of the funds in the donor country itself. The financing of advisors from the donor country, including extensive travel by its very nature, requires large sums of money. In developing countries, money is sometimes spent on establishing so-called safe zones, especially in and around important airports, which in turn are a prerequisite for extensive political travel and the holding of conferences. The donor countries send many observer missions to the supported countries. This is how parliaments exercise their control function.

27 EU countries are pursuing 27 national programmes, each according to a specific logic. High-level visitors want to see the responsible ministers of the developing countries. They invest a substantial part of their working time in such visitor programmes. All in all, it is clear that the ODA funds appear to be much higher than they actually are, because a not insignificant part does not benefit the actual topic of development, but flows into accompanying measures of various kinds.

In addition, many countries want to use part of their aid to help their own economy and, for example, open up new sales or procurement markets for them. Many projects motivated in this way "die" as soon as the funding ends, e.g. because the priorities of development policy in a country change. There is a lack of consistency.

Political and social conditions are difficult in many developing and emerging countries. Power is often held by clans and potentates who are keen to provide for their surroundings. Insurgencies and armed conflicts repeatedly lead to unclear power relations. Sometimes ideological crusades are waged and proxy wars fought. Recently, countries have seceded. China and Russia are active in several countries, Russia also with military aid. Bases are being established, e.g. on the coasts. The countries' resources, which have always been gold and diamonds, arouse desires. With the raw materials run as a result of the energy transition, metals and rare earths such as cobalt, iridium, indium and germanium are increasingly coming into play.

Political conditions are often unstable, especially in poor countries. They are confronted with major political problems. Poverty meets a growing population and great expectations of prosperity. Parts of the countries are hit hard by climate change. There is a lack of infrastructure. For one billion people in sub-Saharan Africa, there is only electricity production the size of that of Belgium. Hundreds of millions of people have no access to electricity and cook with charcoal.

It should not surprise anyone that with such conditions in the recipient countries, it is difficult to find majorities in the donor countries for the much needed increase in development cooperation funds. Politicians in the industrialised countries will hardly be able to communicate this to their own populations. This becomes particularly clear when one realises that they are already struggling within Germany with the Länder fiscal equalisation system and within the EU with cohesion and structural policy. In addition, the Ukraine conflict, the previous pandemic and the energy transition are currently placing great financial burdens. The funds are not enough even in a country as rich as Germany. Inflation is further exacerbating the situation. In addition, Germany must also be prepared for large transfers within Europe if the euro should come under pressure again.

If in this situation larger sums were demanded for classical development cooperation, it would be easy for populist parties to massively oppose it and cause shifts in votes. No one is going to go for that.

Thus, **unless fundamental changes can be brought about in the area of international money flows from the Global North to the Global South** and **new approaches** can be developed that hold the chance of moving large sums of money, it is illusory to assume that the required funds will flow in the trillions.

The central idea of **system services** within the framework of the Reference Solution represents a substantially new approach.

9.2.2 Unsuccessful involvement of private donors

If there is to be a solution to the current energy and climate challenges, a **significant financial commitment from non-state actors is absolutely necessary**. The GES Reference Solution also relies on private sector contributions at various points, especially in the context of nature-based solutions. If it is to succeed in making the necessary leap "from billions to trillions", companies, foundations, private individuals, etc. must contribute on a much larger scale than is the case today. Otherwise, this solution also has no chance of implementation.

So far, one possibility for generating corresponding funds is the **voluntary CO_2 market**, which has grown strongly in recent years, but not nearly to the necessary extent. In 2021, its size developed worldwide towards 2 billion US dollars.[216]

In Germany, the **Alliance for Development and Climate** was launched in 2018 with the participation of two authors of this report. The multi-actor partnership aims to mobilise non-state actors to financially support projects in developing and emerging countries that simultaneously promote development and international climate protection. By mid-2023, the alliance has a good 1,400 supporters. In 2021, these partners supported projects with a climate impact of just under 10 million tonnes of CO_2, which corresponds to about half the volume of the German voluntary CO_2 market.

The dominant frame of thought in this context so far is **CO_2 compensation**. Emissions that cannot be avoided or reduced at home are offset in international projects. The overall result is (balance sheet) climate neutrality. This "frame" repeatedly leads to criticism - allegations of a "free buy", accusations of "indulgence trading" and "greenwashing" and even "misleading consumers". In early 2023, "REDD+" projects certified with the VCS standard were criticised with great international publicity for their methodology of measuring the CO_2 impact of the projects.[217, 218] The fact that such incidents are detrimental to scaling up the absolutely necessary measures for rainforest conservation needs no explanation.

So unless new pragmatic approaches to private sector involvement can be developed and put in a positive light, it seems illusory to achieve the quantum leaps that are urgently needed in this area.

Politics, and especially international politics, should **protect** corresponding **non-governmental measures and funding from any discrediting** and **offer security of reputation**. On the contrary, the commitment should be actively publicised and appreciated by the political side.

It is obvious that the notion of CO_2 compensation is not very helpful in such a context. The future requires a better framework of thinking and a new framework in which non-state actors receive the recognition they deserve for their essential contributions.

The fact that the GES Reference Solution represents a consistent and coherent framework that describes a realistic path to achieving a Net Zero and the 2°C target (again) at least by 2070 should also relieve non-state actors of the feeling that they are being asked to fill a "bottomless pit" with no prospect of achieving the target.

216 Cf. Ecosystem Marketplace (2022).
217 Cf. Fischer, Knuth (2023).
218 Cf. The Guardian (2023).

9.2.3 Disagreement and discontinuity in regulation

In many places today, it is apparent that there is great **disagreement** at the regulatory level about what is to be considered "sustainable" and what is not. In this context, it happens time and again that companies are accused of greenwashing. It is obvious that such an environment unsettles actors and they ultimately **withdraw for fear of reputational damage** and stop their commitment to sustainable development out of caution. At the same time, it is understandable that different interests collide in the context of shaping regulation, since it is a matter of determining where the extensive public funding for the green transformation flows and where it does not.

As an example, consider the dispute within the European Union about what is and what is not to be considered "sustainable" in the context of the EU taxonomy. In particular, there was the question of how to deal with natural gas and nuclear energy. With regard to nuclear energy, there was a great deal of controversy because, on the one hand, the known risks of the energy were in the room, but on the other hand, it was difficult to argue against it being climate neutral. With the argument of climate protection, it was finally agreed to regard nuclear energy as green. In the meantime, there is a dispute about whether the electricity from nuclear energy, which is now recognised as sustainable, is permissible to produce green hydrogen in the sense of European regulation. One can certainly have doubts about whether it makes sense to produce green hydrogen in this way. However, if this path is taken, it is hard to see why electricity generated from nuclear energy should not be suitable, since we are now talking about "low carbon" and not about a fundamental dispute about the use of nuclear energy.

Such disagreements quickly take on an even wider geographical scope when one considers that legal requirements that exist in the procuring company's country of domicile are transferred to the entire value chain via supply chain laws. This often means that developing countries that want to supply green hydrogen to the EU, for example, must also meet the requirements that apply within the EU.

In addition, the current period is characterised by uncertainty in the political arena. Changes in government and the strengthening of parties on the political fringes mean that the regulatory environment is not very reliable, especially in the medium and long term. This **unsteadiness** is highly problematic, especially in the context of restructuring and building energy systems, because it requires many long-term investments. However, if the investment conditions are as uncertain as they currently are, this will discourage many private actors from making the urgently needed long-term investments.

Another fundamental difficulty is in the area of **carbon or CO_2 accounting**, a central issue when it comes to verifiably achieving climate neutrality or net zero. There are many differences in terms of content and methodology regarding the design of accounting and the communication of the climate protection measures implemented. For example, the EU is currently working on a directive to prevent (allegedly) misleading environmental claims (green claims), in which the use of the term "climate neutrality" is also a key issue. The differences and recurring uncertainties result from the objectively complex subject matter, which, for example, deals with questions of permanence (of CO_2 binding) and double counting. In this context, too, there is understandable uncertainty among actors who are actually prepared to make contributions to climate protection, but who withdraw from the issue because of its complexity and the threat of damage to their reputation and cease their involvement.[219]

It should not be overlooked in this context that countless experts in the political field, but also in research, foundations and NGOs, for example, are financed in this environment. There are many vested interests at play here. It is obvious that a simplification of accounting would reduce the workload. However, in the spirit of the Decade of Action announced in the context of the 2030 Agenda, it would be welcome if more resources were finally channelled into actual climate protection and less into the accompanying bureaucratic processes.

The innovative approach to the protection of the remaining rainforest proposed in the framework of the Reference Solution also fits into this logic. No permanence is required, but funding is provided ex post at the end of a year if it is proven that the rainforest was preserved in unchanged quality in the course of the past year. This is based on the assumption that, with sufficient payment per hectare, there is sufficient motivation to preserve the rainforest. It should also be possible to strengthen the indigenous population in their function as guardians of the forest.

9.2.4 Rejection of compliance requirements

The proposed **Reference Solution** is nothing more than a **self-contained approach to the energy and climate challenges**. It requires that work is done jointly on the formulated goals and that all actors involved stick to the commitments made. This is particularly true in the context of the cap-and-trade system, which in turn is based on the countries' adjusted NDCs.

The issue of **compliance is very important in this context**, as it is a matter of all countries acting in accordance or "in compliance" with their commitments over a long period of time and having this verified by third parties.

Until now, it has generally been the case that countries do not want to enter into any commitments with regard to climate protection that could make them liable in any way. Such an endeavour is both understandable and problematic. In this context, one often finds that it is not even possible to agree on measurement methods for determining CO_2 balances. How are system boundaries defined? To whom are emissions to be attributed? What level of detail is required? Are third-party verifications

[219] Cf. n-tv (2023).

permissible? Since one is in a voluntary and legally non-binding environment in both the governmental and non-governmental sectors in the broadest sense, such questions are difficult to answer.

The situation is **simplified** in the framework of the Reference Solution by the fact that **very substantial financial resources flow ex post, i.e. only after the delivery of a measure or the achievement of a set target**. This time sequence, which provides for cash inflows only after compliance requirements have been met, should be used as leverage and serve as motivation for countries to behave in a compliance-compatible manner.

Here, too, it should not be forgotten that it is a matter of a fundamental change in previous behaviour, which must be promoted with convincing arguments. It is to be hoped that the argument that meeting compliance requirements will bring financial benefits will prove strong enough.

9.2.5 Unclear international jurisdiction issues

The issues of energy and climate affect many areas of life and society. As a result, it is not clear per se who is responsible. In the political sphere, this translates into distributed responsibilities that exist at all political levels. **If responsibilities are unclear and disputed, there is always the danger that the struggle for responsibility will prevent effective action and that incoherent measures and programmes will be developed in different places**. Furthermore, in such an environment it can be observed time and again that individual issues are ultimately not dealt with by anyone and "fall through the cracks".

Corresponding phenomena can be found at the ministerial level. An example is the topic of climate protection in the field of agriculture in developing countries. Here, one finds oneself in the "Bermuda Triangle" between the three ministries of development, agriculture and environmental protection, in which there is always friction.[220]

For the Reference Solution, the international level is of central importance and thus the world of the United Nations with its numerous sub-organisations.[221] Here, too, there is very often an overlapping of areas of responsibility, through which it is not clear who is in charge and who is justifiably entitled to be involved.

One example of this is nature-based solutions as a building block for combating climate change that can hardly be overestimated. This thematic field can be assigned to several UN organisations with good arguments: In addition to the UN Framework Convention on Climate Change (UNFCCC), the UN Environment Programme (UNEP) should be mentioned. At the interface with nutrition is the Food

[220] The "Bermuda Triangle" goes back to an unnamed person with many years of experience in the subject area described.
[221] Cf. UN (2023b).

and Agriculture Organization of the United Nations (FAO). With regard to the in this context important role of soils, there is the United Nations Convention to Combat Desertification (UNCCD). In addition, there is the United Nations World Food Programme (WFP) in the context of combating hunger, and the United Nations Industrial Development Organization (UNIDO) in the area of industrial development.

Despite its incompleteness, this list of involved UN organisations stands as an example for the existing problems. In addition, the United Nations is repeatedly and rightly described as a "toothless tiger", which can be justified with the trilemma of globalisation.[222] In the dispute with the nation countries, which are by far the predominant level of jurisdiction, the United Nations' hands are repeatedly tied, despite good intentions, in getting legally binding things off the ground.

However, if a central challenge is to involve private actors and guarantee them a stable and reputation-safe environment with reliable framework conditions, the situation described is not very hopeful when viewed realistically. This applies to questions of responsibility within the United Nations, but also to the situation between the United Nations and the nation countries. **If these two levels do not succeed in cooperating, regulating responsibilities amicably and creating coherent regulations and incentives, the absolutely necessary goal-oriented and coordinated action of all necessary actors will hardly be achieved**.

9.2.6 Lack of willingness to cooperate

The world is in a situation where it urgently needs coordinated and cooperative action. At the same time, however, no entity has the power to force the others to cooperate. In particular, the West cannot force nuclear powers like China and Russia to abandon their own position and follow the West's strategy. Unfortunately, there is little to suggest that the current situation, characterised by wars and emerging new bloc formations, will change in the foreseeable future.

If you want to promote cooperation, consensual solutions that benefit all parties are a must.[223] Of course, everyone wants to avoid a climate catastrophe, but at the same time there are always (short-term) economic interests and business models at play. In this situation, it is important to find clever solutions.

This is currently not the case. The Petersberg Dialogue brought to light in all clarity what the central global dispute in the field of climate protection is, which will determine the approaching climate conference COP28: It is about a **phase-out of fossil energies vs. a phase-out of fossil emissions**.[224]

[222] Cf. Rodrik (2011).
[223] Cf. Radermacher (2023).
[224] Cf. AA (2023).

The oil countries, but also China and Russia, are arguing for the latter, whereas Europe and Germany are in favour of a complete phase-out of fossil energies and want to see this path followed in the developing countries as well.

In such a situation, it is more than unlikely that the urgently needed global cooperation will succeed. Rather, the emerging new bloc formation threatens to intensify further and to find a further crystallisation point in the different approaches to the issues of energy and climate.

The **"two pillar" proposal** described in the Reference Solution, which is nothing more than a phase-out of fossil emissions but not of fossil energies, was developed with the aim, among others, of presenting a **globally consensual approach** that would bring economic benefits to all countries.

Of course, renewable energies play a major role in this. Many have their business in this area, and many measures are promoted by the countries. The expansion will rightly continue. At the same time, however, with the logic of the "second pillar", the fossil potential also retains its value, in any case for this century. This means that the picture is one of **conversion,** not **demolition**. Given the magnitude of the tasks and given the large material volumes and high costs of demolition, the focus will be on conversion and a slow, gradual shift towards alternative solutions whenever possible. Industrially, there is a lot to do in the "two-pillar" path, for instance in that carbon capture needs to be established. There are many infrastructural requirements and earning opportunities associated with this. Business models do not have to be abandoned. Moreover, this is a path that leads to stable energy systems. The volatility of renewable energies can be brought under control in this way, which massively reduces costs. It is not necessary, for example, to expand the entire energy system with a nationwide metering infrastructure for responsiveness with regard to solar power and/or wind availability. This saves multi-billion sums. It also has the great advantage that not so much data and information has to be collected. For despite all the support for IT solutions and AI, it should also be clear that much of the data to be collected is close to people's lives. It can open up enormous opportunities for control, for example for the state. **The trends that can currently be observed ultimately prove to be a threat to freedom.**

10 Policy recommendations

This chapter policy recommendations are finally formulated. The first part contains recommendations that are formulated in abstract terms and do not refer to individual political issues that are currently under discussion. Against this background, these are also not recipient-specific, for example for the BMZ, the German government or the European Union, but are cross-cutting. If the Reference Solution is to be implemented, the aim must be to establish coherent policies at the various political levels - national and global - and in the various policy areas, which support the most efficient achievement of goals. A second part contains recommendations formulated for German development policy, but also for broader German policy. It deals with cooperation with developing countries and emerging economies.

10.1 General recommendations

The following recommendations are formulated in the abstract and do not refer to individual policy issues. Nor are they recipient-specific, but are directed across the board towards different policy areas and levels.

1. **Change the framework of thinking, narratives and communication**

   There is a lot of confusion around the concept of sustainability today. A far too small part of society is really aware what is at stake and what is at the core of the 2030 Agenda and sustainable development.[225] But if people lack the understanding that beyond all individual issues, it is a matter of global catch-up economic development with simultaneous environmental and climate protection, it cannot be assumed that corresponding political programmes will find majorities and that the right measures will be taken. Ultimately, **the state of sustainability can only be achieved globally**.

   Even in the context of climate protection, one encounters, alarmingly, in many places a purely national perspective, even in politics. Actors who also campaign internationally for climate protection are repeatedly accused of greenwashing and neglecting domestic responsibility. Another shortcoming of the current framework of thinking is the far too frequent ignoring of the close link between climate, energy and thus prosperity.

   If the challenges in these areas are to be overcome, **a change in the framework of thinking, narratives and communication is urgently needed**. Of course, this does not only apply to political communication. But political communication is of central importance.

[225] Cf. Fröndhoff (2021).

Climate protection - like the implementation of the entire 2030 Agenda - should be positioned as a **global challenge** that can only be successfully met through global cooperation. The contributions already made by private actors to international climate protection should finally meet with a positive response from policymakers and be promoted through appropriate communication.

2. **Technology openness and pragmatism**

Germany and Europe are now the parts of the world where only very narrow technological paths are allowed in the context of the energy transition (e.g. "Renewables Only"). Such an approach is unique in the world. For a neutral observer, it is hard to understand why, in such a challenging situation, the space of possible solutions is made smaller than it could be. The negative consequences are considerable: billions are being spent on an overpriced energy turnaround, energy costs are the highest in the world, the effect on the CO_2 content of the atmosphere is small and domestic industry is threatened with considerable disadvantages in international competition. The narrowness in the selection of applicable technologies, enforced by regulation, prevents cost-efficient and rapidly effective solutions.

Against this background, policy-makers should urgently demonstrate more technology openness, especially in the context of further use of fossil fuels with carbon capture. In addition, they should be **more pragmatic about the urgency to act**. Bureaucratic hurdles in the context of the transformation of the energy system should be removed wherever possible.

3. **More Realpolitik**

Politics should be much more oriented towards the objectively given conditions and possibilities of reality. It should be geared towards making quick, impact-oriented decisions and not, for reasons of the history of ideas, remain stuck in thought and solution structures that obviously do not lead to an improvement of the conditions.

This also applies in particular to the area of energy policy: currently, more than 80 % of global primary energy comes from fossil fuels. Only 5 % comes from new renewables. Coal, gas and oil are deeply integrated into a multitude of value chains, for example in cement and steel. Mankind will therefore continue to depend on fossil fuels for decades to come. Developing the new renewables is an important step towards an energy system of the future, but it will not be realised overnight. Fossil fuel producing countries like Saudi Arabia, Russia, Iran, Venezuela or the USA will defend their business models, in case of doubt militarily.

For the foreseeable future, a policy of **"decabonisation" is therefore not only illusionary, but also a threat to peace**. The development of a realpolitik and peace-capable policy is recommended, which is oriented towards the global conditions and the different interests of the countries. Climate neutrality can also be achieved by using fossil energy sources - **carbon capture is the game changer**.

4. **CO_2 -Avoidance costs as a key decision variable**

In Germany in particular, the impression is repeatedly created that the costs of climate protection play a subordinate role, perhaps even no role at all. It still seems possible to set up ever new subsidy programmes worth billions. The continuing inflation, however, suggests that the possibilities of creating more and more new money will soon come to an end. In times of tight budgets, CO_2 abatement costs should become a central decision-making parameter when deciding on investments for climate protection. This applies to Germany, Europe and, of course, the whole world. Even if a cost-optimal path is taken for global energy transformation and climate protection, the costs will be considerable ("trillions"). Considering that it will be a challenge to bear them, every effort should be made to ensure that the funds to be raised remain as manageable as possible.

5. Impact orientation with regard to development and climate

The question of a stronger impact orientation arises in many places in the context of sustainability. It should be given much more attention, not only in the context of energy and climate. The fact that in many places the "Decade of Action" gives the impression of a "Decade of Reporting and Certification" and that parallel to this there have been no noteworthy successes, if not regressions, in relation to all the goals of the 2030 Agenda, should give pause for thought.

It is a widespread phenomenon that reporting and certification requirements are steadily increasing, especially in the sustainability sector. This is a consequence of regulation, which is hitting numerous actors with all its force, and diminishing their commitment. The amount of time, human and financial resources that flow into non-impact-oriented processes is considerable. Especially for the issue of sustainability, where it is time to act, this is a fatal development. The fact that consultancies are currently conquering a new field of business that will devour billions shows that current developments are not going in the right direction.[226]

[226] Cf. Kewes (2022).

Nothing is gained for the cause or the "Decade of Action" in this way. Politicians are **urgently** called upon to **create framework conditions that enable** companies and others **to act** in an impact-oriented manner that is **not smothered in bureaucracy**.

6. Greenhouse gas content of the atmosphere as key control variable

The decisive variable for mitigating climate change is the climate gas content of the atmosphere. National reduction targets are not. It is a misconception to link the achievement of a certain temperature target to the achievement of a national climate target. Nevertheless, this is how it is handled in many places and communicated accordingly.

The **effect of a measure on the climate gas content of the atmosphere should become a central control variable in climate protection**. The moment this happens, international climate protection contributions, for example, will be seen in a much more positive light, as they also have a direct positive influence on the climate gas content of the atmosphere - and often at much lower cost than is the case with domestic measures. It is obvious that CO_2 captured in large quantities at point sources helps to prevent the amount of CO_2 in the atmosphere from increasing further. Accordingly, a corresponding measure should be evaluated. That it is of great value is shown in particular by a look at the - in accordance with the Paris Climate Agreement - further increasing CO_2 emissions worldwide. Preventing this by means of efficient carbon capture processes would make a substantial contribution to stabilising the climate system.

7. Rapid implementation of carbon capture and corresponding infrastructure

Against the backdrop of the "climate emergency"[227] , framework conditions should be created quickly to prevent further CO_2 from entering the atmosphere. The handling of CO_2 should urgently be simplified and accelerated. The aim must be to flank both CCU (Carbon Capture and Usage) and CCS (Carbon Capture and Storage) with regulatory measures that **promote the ramp-up of these technologies**. The necessary transport infrastructure should be considered from the outset. It will rarely be the case that the place where CO_2 is captured is identical with the place where it is used or stored. It is to be expected that the CO_2 infrastructure will reach in industrialised countries similar dimensions as the current gas infrastructure.

[227] Cf. WBCSD (2021).

8. Blending rates for climate-neutral fuels

Another necessity to become active in the sense of the given "Climate Emergency" is the **regulatory anchoring of blending quotas for climate-neutral fuels**. This opens up the opportunity to quickly achieve considerable CO_2 emission reductions in the transport sector. In this way, an opportunity is created to **improve** the situation of the **existing fleet**, which will remain on the roads for years to come. Of course, this will not lead to emission-free combustion engines. Nevertheless, due to the dimensions of transport and the predicted further growth of the sector, the effects are considerable. In addition, admixtures can be used immediately worldwide. In a global perspective, we are talking about more than a billion vehicles with combustion engines.

9. Focus on nature-based solutions

A topic that is still far too little present in public discourse is nature-based solutions, which must be an essential component of any path to Net Zero. Nature is a significant CO_2 sink that must be preserved, expanded and relieved. Many billions of tonnes of CO_2 are at stake. It is not only a question of dealing wisely with the given "Climate Emergency". In addition, "Nature in Crisis" is another urgency that should be addressed.[228]

It is obvious that the preservation of the remaining rainforests - and of course also the boreal forests - is the fastest climate protection that can be implemented, since it is about a negative obligation, i.e. about refraining from doing something. The fact that this has not been achieved to date is crucially related to the fact that the necessary financial resources have not been raised. This, in turn, is partly a consequence of the fact that non-state actors have not yet found the regulatory environment that would enable them to contribute in an uncomplicated and reputation-securing way. In the meantime, many companies have understood that they can and must make decisive contributions here. It is to be hoped that politicians will finally succeed in providing suitable regulatory support for this willingness.

For other nature-based solutions such as reforestation and soil restoration, the same applies: the willingness of the private sector should be taken up and increased through smart communication. Another argument should be helpful here: projects in the field of agriculture and forestry contribute in a significant way to value creation and improve the lives of local people. Development is promoted. In the sense of the 2030 Agenda, the projects can be described as effective with regard to many goals. Policymakers should use communication to promote positive

[228] Cf. WBCSD (2021).

storytelling and at the same time create a regulatory environment that promotes non-governmental engagement.

10.2 Recommendations for cooperation with developing countries and emerging economies

The following points are addressed to the German development policy, but also to the broader German politics. They are primarily aimed at future cooperation with developing and emerging countries, which should be given much greater importance than it has been so far, as this is a key issue for a good future for the planet.

1. The development concerns of developing countries and emerging economies should be a **central policy concern**, even if, realistically speaking, the 2030 Agenda can at best be implemented by 2050. Development must be given priority over climate protection contributions by these countries. The climate protection contributions must be cross-financed by rich countries.
2. The central climate protection concerns such as the 2°C target or Net Zero require **international cooperation** - first between the expanded OECD and the China Club, but also between these and the developing and emerging countries. The 1.5°C target has no chance. Net Zero can at best be achieved after 2070, if only because of the NDCs of important countries (China 2060, India 2070). These truths should be the subject of honest political communication.
3. The current, mostly conditional, NDCs of most developing and emerging countries are of little help because they are hardly resilient and realistic. It will not be possible to implement them in this way. Moreover, the packages of measures they contain are often inadequate in terms of content. In their current quality, the NDCs do not provide a basis for high financial support from the Global North. Nevertheless, it is right that the developing and emerging countries make corresponding demands for money. In the short term, the aim must be to create the conditions for funds to flow. Policymakers should initiate a process to **revise the conditional NDCs**.
4. After revisioning the NDCs of developing and emerging countries, a lot of money has to flow into the implementation of the same. Winning the political consent of these countries requires significant financing contributions to the design of the necessary **political processes**. Cross-financing contributions, especially the **assumption of differential costs** for measures towards CO_2 neutrality in line with the Montreal Protocol, must be made. Germany should make a strong case for this - in the EU, but also beyond.
5. According to UN logic, developing and emerging countries have the right for a **catch-up economic development** and are allowed to further increase their CO_2 emissions. High GDP growth

is also necessary in view of the 2030 Agenda (SDG 8), among other things because of the expected growth of the populations of these countries from a total of five to seven billion people by 2050. This development must be enabled and supported.

6. For the developing and emerging countries, average growth rates of around 6 % should be targeted for the next decades. For the world, this should result in a (climate-neutral) global **economic miracle.** Germany should contribute a lot in terms of regulatory policy, technology and economy for the benefit of the world and for its own benefit.

7. As for other countries, the recommendation with regard to **electricity supply** in developing and emerging countries is that it should be reliably built **on two pillars** - at least for the next few decades - so that industrial development becomes possible. The two pillars are:

   - Old and new renewables that are climate neutral but mostly volatile.
   - Reliably controllable energy, especially fossil energy with carbon capture, alternatively nuclear energy, which are also climate neutral but not volatile.

8. Carbon capture should be treated as a key issue: **Fossil emissions** should be **phased out, not fossil fuels**. Carbon capture can be a **peace-building issue**. Germany should take a leading role, also because its domestic industry can contribute a lot worldwide. If we try to prevent carbon capture, we risk conflicts with China and many other countries in the Arab world as well as the OPEC countries. Many developing and emerging countries will also want to use their own fossil fuels for good reasons.

9. Integrating the developing and emerging countries into the necessary global transformation process is the great challenge. Again, Germany can contribute a lot. Above all, large financial transfers from the OECD world are needed. These are not to be understood as charity or "good will for development". Instead, it is about **system services** of the South for a good future of the world, especially also of the rich countries. The required funds (more than 1 trillion US dollars per year) should be raised by the rich countries out of self-interest. If they do not, the resulting costs of dealing with damage are much higher. This also needs to be communicated.

10. It is recommended that **Germany** participate, or better still **take a global leadership role, in international processes that contribute to the implementation of the proposed Reference Solution for a better future**. These include consistent rainforest protection, large global projects to reforest degraded soils in the tropics and to improve degraded soils for improved agricultural use, further development of nature-based solutions, for example in mangroves, agricultural land in general or maritime reforestation with algae, the creation of reputation-safe framework conditions for short-rotation plantations, the fight against (technical) methane leaks and the establishment of a global cap-and-trade system to implement the NDCs. This will become

much easier as soon as feasible NDCs (with target dates of 2050 or 2060 or 2070) are worked out for developing and emerging countries, which, if successfully implemented, will be linked to high annual subsidies from the rich world. Such a cap-and-trade system is beneficial for all participating countries.

11 Conclusion and outlook

The presentation of the Reference Solution described opens up considerably improved opportunities in the areas of development and climate, because it was not clear a priori that a **Reference Solution existed** that would actually allow ten billion people to live a life in freedom with adequate prosperity in social balance, an intact environment and a stable climate system in the long term. Now, however, there is a holistic approach that can be pursued in global cooperation and, of course, further optimised.

The **simultaneous achievement of the SDGs** - even if this process will only be completed from 2050 onwards - and the safeguarding of multiple biodiversity conservation and environmental protection concerns, in particular the path towards a stable climate system by 2070, are extremely ambitious. So far, this has never been achieved internationally. The situation is further complicated in the coming years by population growth of another two billion people by 2050 and justifiably high expectations of prosperity in the Global South - a seemingly insurmountable task.

However, a clever **combination of solution building blocks** opens up a hopeful path into the future. There are many new opportunities and possibilities - through a new view of the whole, namely of the world as a place of cooperative interaction for the joint solution of existing challenges. This requires the broadening of intellectual and political horizons. Tolerance and openness for different approaches and technologies are important - and in this sense, for example, a rejection of generalisations such as "renewables good, fossils bad".

A major task for the future for all social actors lies in the field of **communication**. In many respects, it is a matter of changing the current narrative in the energy and climate sector, which is firmly anchored in large parts of society. Its core elements are a national framework of thinking, a focus on renewable energies and an extensive electrification of all economic sectors. Renewable energies are presented as the exclusive solution for establishing a climate-neutral energy system. A change in this framework of thinking could succeed, as more and more people are realising that the current path is not leading to the goal, and a purely national focus on climate protection is obviously not appropriate for the global problem of climate change.

Instead, it is important to understand that measures are needed all over the world to master the challenge of climate change. In this sense, the rich countries need gigantic "**system services**" from the developing countries and emerging economies, with which it is possible to jointly stabilise the climate system. These services must be financed by the rich countries for their own good.

The Reference Solution described comprises a variety of building blocks, ranging from consistent rainforest protection to extensive reforestation measures in the tropics, massive soil improvement efforts and methane leakage prevention activities, in addition to various elements from the field of energy production and conversion, and is linked to diverse governance and financing efforts.

In order to guarantee stable **electricity systems**, which is an absolute prerequisite for economic development, they should be based **on two pillars**: **Volatile renewables** should be **combined with reliably controllable energy**. This can be fossil with carbon capture or nuclear energy. Green hydrogen plays a role in the context of renewable energy, but it is not the game changer it is often thought to be. The reasons are the very high costs, but also the limited electrolyser capacities in the future.

Carbon capture is seen as a wild card for the next decades. By 2050, up to 15, and with a lot of engineering success and ramp-up, possibly up to 20 billion tonnes of CO_2, could be captured annually. It is thus moving towards a "fossil emissions phase-out" that replaces a "fossil energy phase-out". **This approach is consensus-building and thus peace-building from a global perspective**. On the one hand, it is about the economic interests of central actors such as China, Russia as well as numerous countries of the Arab world, OPEC, etc., and on the other hand, it is about creating the energy prerequisites for building prosperity in the developing and emerging countries. All the aforementioned countries can only meet the challenges in the areas of development and climate together and will only do so if advantages can be seen from their respective perspectives.

Of central importance is finally a **serious engagement with the legitimate development concerns of the Global South**. For 50 years, there has been a lack of strong will on the part of the industrialised countries. The Reference Solution aims at an annual GDP growth of 6 % for the next 25 years as a target for the developing and emerging countries (with 7 % for the Least Developed Countries). The GDP of these countries could thus grow from 20 trillion US dollars today to 80 trillion US dollars in 2050. The result would be a **world economic miracle**. Participation in the implementation opens up economic advantages.

The big challenge is to cope with the resulting growth in energy demand in developing and emerging countries, which will increase from about 20 PWh today to 50 PWh in this process - despite considerable efforts in energy efficiency and lifestyles.

In order to create a solid foundation for jointly tackling the necessary measures, today's **conditional NDCs** of developing and emerging countries **must be put on a realistic footing**. Today, they form the Achilles heel of the Paris Climate Agreement. This revision is a gigantic intellectual, technical and financial task that is imperative if the NDCs are to become the basis for a global cap-and-trade system, as proposed under the Reference Solution.

In addition to the costs incurred to manage the necessary political processes, the actual construction or restructuring of the energy system must be financed and the measures in the area of nature-based solutions must be flanked. All of this requires massive investments from the OECD countries, e.g. for the development of transnational energy infrastructures and in the context of the differential costs incurred for achieving climate neutrality (see Montreal Protocol).

Politically, the transfer volumes from the OECD to the developing and emerging countries will be a key issue: It is about **1,200 billion US dollars per year for the implementation of a multitude of programmes, thus finally moving in the direction of the "From Billions to Trillions" demand that has been in place since 2015**. It should be noted that the support per capita in the Global South is nevertheless only 200 US dollars per year, which is just about the cost of avoiding about 2 tonnes of CO_2 - if these are low. In many places, not only in Germany, far higher sums are raised to avoid 1 tonne of CO_2.

If a historical debt has to be paid off in the climate sector, the Reference Solution shows a way how this can be achieved. From the point of view of the industrialised countries, the consideration received in the form of stabilising "system services", which work to the advantage of all, can be had for very manageable sums. This needs to be recognised, understood and communicated.

This is not the only reason why the concerns of the developing and emerging countries should now finally be taken up - in the interest of us all. Climate protection is precisely not an argument for breaking welfare promises once again, but for tackling the great common challenge that can only be overcome in cooperation. To keep costs manageable, smart cost-effective solutions must be pursued. Generalisations such as "all electric" are not helpful here. No technical solutions should be prescribed; rather, there should be openness to technology. The forces of the markets should become effective and global diversity based on local knowledge should be allowed. Realism, pragmatism, speed and a fair distribution of the burden should determine the next decades, because time is running out.

Last but not least, people all over the world must be won over to participate - in a situation in which frustration and resignation can be observed in some places in the commitment to sustainable development. It is to be expected that some actors will be more motivated to make their contribution again when they lose the feeling of having to fill a "bottomless pit". This will be replaced by the realisation that one can make a contribution to a consistent overall approach, which in sum will lead to achieving Net Zero - even if only after 2050 - and implementing the 2030 Agenda. This opens up a path that can ultimately succeed in ensuring that all people can live well within the limits of the planet.[229]

It is hopeful that there is a prosperity-compatible solution to the global energy and climate challenges that can be described in a coherent way, and for which there are at least no principled reasons why it cannot be implemented.

[229] Cf. WBCSD (2021).

Bibliography

AA - Auswärtiges Amt (2023). Petersberg Climate Dialogue - Co Chairs Summary. Im Internet unter: https://www.auswaertiges-amt.de/blob/2595566/5324a0a6dcaa4c989e13eb3618560c09/230504-pcd-co-chairs-summary-data.pdf. Retrieved on: 11 May 2023.

Annan, A. (2005). Kofi Annan's statement to the General Assembly. On the Internet at: https://www.un.org/sg/en/content/sg/speeches/2005-03-21/kofi-annans-statement-general-assembly. Retrieved on: 1 July 2023.

Aurora Energy Research (2021). Hydrogen Market Attractiveness Report. On the Internet at: https://auroraer.com/wp-content/uploads/2021/11/Aurora_Oct21_HydrogenMarketAttractivenessReport-freeREPORT-1.pdf. Retrieved on: 19 November 2022.

Berks, L. (2022). Electrolysis: Status quo: technology, costs and challenges. On the Internet at: https://global-energy-solutions.org/wp-content/uploads/2022/04/220224_LB_Elektrolyse_Status-Quo.pdf. Retrieved on: 10 July 2023.

Betzwieser, M. (2016). El Hierro: Disappointing results of the Gorona energy project. La Palma News. On the Internet at: https://lapalma1.net/2016/01/09/el-hierro-regenerative-energie-bilanz/. Retrieved on: 30 July 2023.

BMWK - Federal Ministry of Economics and Climate Protection (2023). The German electricity distribution grid. On the Internet at: https://www.bmwk.de/Redaktion/DE/Infografiken/Energie/verteilernetz.html. Retrieved on: 30 July 2023.

BMZ - Federal Ministry for Economic Cooperation and Development (2017). EINEWELT braucht Wald - Das Waldaktionsplan der deutschen Entwicklungszusammenarbeit. On the Internet at: https://www.bmz.de/resource/blob/23396/0f74ec8afbb9fdbc19a4ef374925b3a7/materialie317-waldaktionsplan-data.pdf. Retrieved on: 1 May 2023.

BMZ - German Federal Ministry for Economic Cooperation and Development (2022). Energy Transition Partnership (JETP) with Vietnam. On the Internet at: https://www.bmz.de/de/aktuelles/aktuelle-meldungen/energiewende-partnerschaft-mit-vietnam-135468. Accessed on: 4 August 2023.

BMZ - Federal Ministry for Economic Cooperation and Development (2023a). SHAPING THE FUTURE TOGETHER WITH AFRICA. The Africa Strategy of the BMZ. On the Internet at: https://www.bmz.de/resource/blob/137600/bmz-afrika-strategie-de.pdf. Retrieved on: 13 July 2023.

BMZ - German Federal Ministry for Economic Cooperation and Development (2023b). New energy transition partnership with Senegal agreed. On the Internet at: https://www.bmz.de/de/aktuelles/aktuelle-meldungen/neue-energiewende-partnerschaft-mit-senegal-beschlossen-157496. Accessed on: 13 July 2023.

Borenstein, S. (2022). Cement carbon dioxide emissions quietly double in 20 years. On the Internet at: https://apnews.com/article/climate-science-china-pollution-3d97642acbb07fca7540edca38448266. Accessed on: 10.10.2022.

bp (2022). bp Energy Outlook - 2022 Edition. On the Internet at: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2022.pdf . Retrieved on: 3 July 2023.

Brandes, J.; Haun, M.; Wrede, D.; Jürgens, P.; Kost, C. & Henning, H.-M. (2021). Pathways to a climate-neutral energy system - The German energy transition in the context of societal behaviour. Fraunhofer Institute for Solar Energy Systems ISE. On the Internet at: https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/Fraunhofer-ISE-Studie-Wege-zueinem-klimaneutralen-Energiesystem-Update-Klimaneutralitaet-2045.pdf. Accessed on: 30 July 2023.

Castellum.AI (2023). Russia Sanctions Dashboard. On the Internet at: https://www.castellum.ai/russia-sanctions-dashboard. Retrieved on: 14 April 2023.

Climate Action Tracker (2023): Climate Target Update Tracker. On the Internet at: https://climateactiontracker.org/climate-target-update-tracker-2022/. Retrieved on: 4 May 2023.

Climate Transparency (2020). G20 - Need for urgent climate action. On the Internet at: https://www.climate-transparency.org/g20-summit-need-for-urgent-climate-action. Accessed on: 11 May 2023.

Climate Watch (2023). Historical GHG Emissions. On the Internet at: https://www.climatewatchdata.org/ghg-emissions?source=Climate%20Watch. Accessed on: 23 May 2023.

Copernicus Climate Change Service (C3S, 2022). Globally, the seven hottest years on record were the last seven; carbon dioxide and methane concentrations continue to rise. European Union, Press Release, 10 January 2022.

COP26 (2021). UN Climate Change Conference in Glasgow, 2 November 2021.

CoR - Club of Rome (2022). Earth for all - A survival guide for our planet, the new report to the Club of Rome, 50 years after "The Limits to Growth". oekom Verlag.

CoR - Club of Rome, Senate of the Economy (2016). Migration, Sustainability and a Marshall Plan with Africa - A Memorandum for the Federal Government. On the Internet at: https://www.fawn-ulm.de/wp-content/uploads/2018/07/Denkschrift_EN_MP_Afrika.pdf. Accessed on: 1 July 2023.

Cornia, G. A., Court, J. (2001). Inequality, Growth and Poverty in the Era of Liberalization and Globalization. On the Internet at: https://www.wider.unu.edu/publication/inequality-growth-and-poverty-era-liberalization-and-globalization. Accessed on: 4 May 2023.

DENA - Deutsche Energie-Agentur GmbH (ed.) (2021). dena-Leitstudie Aufbruch Klimaneutralität. On the Internet at: https://www.dena.de/newsroom/publikationsdetailansicht/pub/abschlussbericht-dena-leitstudie-aufbruch-klimaneutralitaet/. Retrieved on: 27 July 2023.

Dooley, K., Keith, H., Larson, A. et al. (2022). The Land Gap Report 2022. On the Internet at: https://www.landgap.org/. Retrieved on: 1 July 2023.

Dyckhoff, H., Souren, R. (2008). Nachhaltige Unternehmensführung - Grundzüge eines industriellen Umweltmanagements. Berlin: Springer.

Earth Ranger (2023). Protecting wildlife with real-time data. On the Internet at: https://www.earthranger.com/. Retrieved on: 13 July 2023.

Ecosystem Marketplace (2022). State of the Voluntary Carbon Markets 2022 Q3. On the Internet at: https://www.ecosystemmarketplace.com/publications/state-of-the-voluntary-carbon-markets-2022/. Accessed on: 22 January 2023.

European Federation for Transport and Environment (2022). Addressing the heavy-duty climate problem. On the Internet at: https://www.transportenvironment.org/wp-content/uploads/2022/09/2022_09_Addres-sing_heavy-duty_climate_problem_final.pdf. Retrieved on: 27 July 2023.

FAO - Food and Agriculture Organization of the United Nations (2022a). The State of World's Forests - Forest pathways for green recovery and building inclusive, resilient and sustainable economies. On the Internet at: https://doi.org/10.4060/cb9360en. Accessed: 28 February 2023.

FAO - Food and Agriculture Organization of the United Nations (2022b). Global Soil Organic Carbon Sequestration Potential Map - GSOCseq v.1.1 - Technical Report. On the Internet at: https://www.fao.org/documents/card/en/c/cb9002en. Retrieved on: 21 May 2023.

Fischer, T., Knuth, H. (2023). CO_2 -Zertifikate: Grün camouflaged. *DIE ZEIT* 04/2023. On the Internet at: https://www.zeit.de/2023/04/co2-zertifikate-betrug-emissionshandel-klimaschutz. Retrieved on: 22 January 2023.

FÖS - Forum Ökologisch-Soziale Marktwirtschaft (2023). Positions of the Forum Ökologisch-Soziale Marktwirtschaft. On the Internet at: https://foes.de/de-de/unsere-aufgaben/unsere-positionen. Retrieved on: 5 May 2023

Friedlingstein, P., Jones, M. W., O'Sullivan, M., et al. (2022). Global Carbon Budget 2021. Earth System Scientific Data, 14, 1917-2005, 2022. On the Internet at: https://essd.copernicus.org/articles/14/1917/2022/. Accessed on: 27 April 2023.

Fraunhofer IEE (2023). Global PtX Atlas. On the Internet at: https://maps.iee.fraunhofer.de/ptx-atlas/ Retrieved on: 3 July 2023.

Fröndhoff, B. (2021). Ignorance about UN goals: Managers' sustainable knowledge gaps. Handelsblatt 8 September 2021. On the Internet at: https://amp2.handelsblatt.com/unternehmen/industrie/studie-der-wertekommission-unkenntnis-ueber-un-ziele-die-nachhaltigen-wissensluecken-der-manager/27592560.html. Accessed on: 1 August 2023.

Fuest, C. (2023). The Energy Efficiency Act Threatens Economic Growth. *Handelsblatt* 11 May 2023. On the Internet at: https://www.handelsblatt.com/meinung/gastbeitraege/gastkommentar-das-energieeffizienzgesetz-bedroht-das-wirtschaftswachstum-/29142748.html. Retrieved on: 23 May 2023.

Garcin, Y. (2022). Hydroclimatic vulnerability of peat carbon in the central Congo Basin. *Nature 612,* 277-282. https://doi.org/10.1038/s41586-022-05389-3.

Gates, M. (2023). Melinda Gates calls for three reforms for a fairer world. *Handelsblatt* 21 June 2023. On the Internet at: https://www.handelsblatt.com/meinung/gastbeitraege/gastkommentar-melinda-gates-fordert-drei-reformen-fuer-eine-gerechtere-welt/29218542.html. Retrieved on: 30 June 2023.

GCCA - Global Cement and Concrete Associaton (2021). Global Cement and Concrete Industry announces Roadmap to achieve ground-braking 'Net Zero' CO_2 emissions by 2050. On the Internet at: https://gccassociation.org/news/global-cement-and-concrete-industry-announces-roadmap-to-achieve-groundbreaking-net-zero-co2-emissions-by-2050/. Accessed on: 5 May 2023.

GCCA - Global Cement and Concrete Associaton (2022). Key Facts. Global Cement and Concrete Association.

Gelinsky, K. (2022). Corporate responsibility. A price tag for nature. *FAZ* 30.11.2022. On the Internet at: https://www.faz.net/aktuell/wirtschaft/unternehmen/verantwortung-der-unternehmen-ein-preisschild-fuer-die-natur-18497365.html. Retrieved on: 21 May 2023.

Ghosh, I. (2020). How China Overtook the U.S. as the World's Major Trading Partner. *Visual Capitalist*. On the Internet at: https://www.visualcapitalist.com/china-u-s-worlds-trading-partner/. Accessed on: 28 April 2023.

Girardin, C., Jenkins, S., Seddon, N. et al. (2021). Nature-based solutions can help cool the planet - if we act now. *Nature 593*, 191-194.

Global Energy Solutions (2022). *Sustainable Construction and Wood.* [Internal publication].

Global Energy Solutions (2023a). *Consideration of different forms of propulsion for heavy trucks.* [Internal publication].

Global Energy Solutions (2023b). *Restriktionsanliegen des BMZ*. [Internal Publication].

Global Methane Pledge (2023). Fast action on methane to keep a 1.5°C future within reach. On the Internet at: https://www.globalmethanepledge.org/. Accessed on: 3 August 2023.

Global Solar Atlas (2018). Global Photovoltaic Power Potential by Country. Available online at: https://globalsolaratlas.info/global-pv-potential-study. Accessed on: 3 March 2023.

Griscom, B. W., Adams, J., Ellis, P. W. et al. (2017). Natural climate solutions. *Proc. Natl. Acad. Sci.* 201710465. https://doi.org/10.1073/PNAS.1710465114.

Grunwald, A. (2022). Technology Assessment - Introduction. 3rd ed. Baden-Baden: Nomos.

Grytz, M. (2021). Does Transmutation Solve the Nuclear Waste Problem? On the Internet at: https://www.tagesschau.de/wissen/forschung/belgien-forschungsreaktor-myrrha-101.html. Retrieved on: 23 March 2023.

H2Accelerate (2022). Analysis of cost of ownership and the policy support required to enable industrialisation of fuel cell trucks. On the Internet at: https://h2accelerate.eu/wp-content/uploads/2022/09/H2A-Truck-TCO-and-Policy-Support-Analysis-VFinal.pdf. Accessed on: 27 July 2023.

Herlyn, E. (2019). The 2030 Agenda as a systemic challenge - conflicting goals and further implementation challenges, in: Herlyn, E., Lévy-Tödter, M. (eds.): *The 2030 Agenda as a Magic Polygon of Sustainability: Systemic Perspectives*. Wiesbaden: Springer Gabler, pp. 43-58.

Herlyn, E., Lévy-Tödter, M., Fischer, K. et al. (eds.) (2023): *Multi-actor networks: cooperation as an opportunity for implementing the 2030 Agenda.* Wiesbaden: Springer Gabler.

Herlyn, E., Radermacher, F. J. (2014). Nachhaltig wirtschaften - Eine weltweite Ökosoziale Marktwirtschaft als Zukunftsstrategie. *Schriftenreihe der Schwäbischen Gesellschaft 75*, Stuttgart.

Herlyn, E., Radermacher, F. J. (2018). A 1-1-1 relationship for World Bank Income Data and the Gini. In: ECINEQ Working Paper 2018 - 473. Available online at: http://www.ecineq.org/milano/WP/ECINEQ2018-473.pdf. Accessed on: 1 July 2023.

Herlyn, E., Radermacher, F. J. (2021). A club model for a cap-and-trade system based on NDCs, FAW/n Report. On the Internet at: https://www.fawn-ulm.de/publikationen. Retrieved on: 26 June 2023.

Herlyn, E., Radermacher, F. J. (2022). The "hypocrisy" of rich countries. Insights into the current international debate on the right way to transform the global energy system. On the Internet at: https://global-energy-solutions.org/wp-content/uploads/2022/08/heuchelei.pdf. Retrieved on: 1 July 2023.

Hydrogen Council/McKinsey & Company (2021). Hydrogen Insights Brussels. On the Internet at: https://hydrogencouncil.com/en/hydrogen-insights-2021/. Retrieved on: 03 March 2023.

IEA - International Energy Agency (2020): Methane Tracker. On the Internet at: https://www.iea.org/reports/methane-tracker-2020 . Retrieved on: 23 May 2023

IEA (2020a). Share of government/SOE ownership in global energy investment by sector, 2015 compared to 2019. On the Internet at: https://www.iea.org/data-and-statistics/charts/share-of-government-soe-ownership-in-global-energy-investment-by-sector-2015-compared-to-2019. Retrieved on: 3 March 2023.

IEA - International Energy Agency (2020). World Energy Outlook 2020. On the Internet at: https://www.iea.org/reports/world-energy-outlook-2020. Accessed on: 23 May 2023

IEA - International Energy Agency (2021b). Net Zero by 2050 - A Roadmap for the Global Energy Sector. On the Internet at: https://www.iea.org/reports/net-zero-by-2050 Accessed on: 3 July 2023.

IEA - International Energy Agency (2021c). The Role of Critcal Minerals in the Energy Transition. On the Internet at: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions. Accessed on: 3 March 2023.

IEA - International Energy Agency (2021d). Hydrogen: More efforts needed. https://www.iea.org/reports/hydrogen. Accessed on: 25 November 2021.

IEA - International Energy Agency (2021e). Hydrogen Projects Database. https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database. Accessed on: 19 November 2021.

IEA - International Energy Agency (2021f). World Energy Outlook 2021: IEA Publications. https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf. Accessed on: 3 March 2023.

IEA - International Energy Agency (2022a). World Energy Outlook 2022. On the Internet at: https://www.iea.org/reports/world-energy-outlook-2022. Accessed on: 23 May 2023

IEA - International Energy Agency (2022b). Cement: tracking report. On the Internet at: https://www.iea.org/reports/cement. Retrieved on: 10 October 2022.

IEA - International Energy Agency (2023a). Global Methane Tracker 2023. On the Internet at: https://www.iea.org/reports/global-methane-tracker-2023. Accessed on: 3 August 2023.

IEA - International Energy Agency (2023b). Financing reductions in oil and gas methane emissions. On the Internet at: https://www.iea.org/reports/financing-reductions-in-oil-and-gas-methane-emissions. Retrieved on: 15 July 2023

IEA and Cement Sustainability Initiative (2018). Technology Roadmap - Low-Carbon Transition in the Cement Industry. https://iea.blob.core.windows.net/assets/cbaa3da1-fd61-4c2a-8719-31538f59b54f/TechnologyRoadmapLowCarbonTransitionintheCementIndustry.pdf. Accessed on: 3 March 2023.

ILO - International Labour Organization, UNEP - United Nations Environment Programme, IUCN - International Union for Conservation of Nature (2022). Decent Work in Nature-based Solutions 2022. On the Internet at: https://www.ilo.org/wcmsp5/groups/public/---ed_emp/documents/publication/wcms_863035.pdf. Retrieved on: 12 May 2023.

Industry & Energy (2023). RWE's BECCUS project to drive negative CO_2 emissions. On the Internet at: https://www.industryandenergy.eu/ccus/rwes-beccus-project-to-drive-negative-co2-emissions/. Retrieved on: 2 July 2023.

International Transport Forum (2022). Decarbonising Europe's Trucks: How to Minimise Cost Uncertainty", International Transport Forum Policy Papers, No. 107, OECD Publishing. On the Internet at: https://www.itf-oecd.org/sites/default/files/docs/decarbonising-europes-trucks-minimise-cost-uncertainty.pdf. Accessed on: 15 May 2023.

IPBES - Intergovernmental Platform on Biodiversity and Ecosystem Services (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://ipbes.net/global-assessment. Retrieved on: 14 May 2023

IPCC - Intergovernmental Panel on Climate Change (2014). *AR5 Climate Change 2014: Mitigation of Climate Change* - updated Feb 15, 2023.

IPCC - Intergovernmental Panel on Climate Change (2021). Climate Change 2021 - The Physical Science Basis. On the Internet at: https://report.ipcc.ch/ar6/wg1/IPCC_AR6_WGI_FullReport.pdf. Retrieved on: 23 May 2023

IPCC - Intergovernmental Panel on Climate Change (2023). AR6 Synthesis Report - Climate Change 2023. On the Internet at: https://www.ipcc.ch/report/ar6/syr/. Retrieved on: 23 May 2023

IRENA - International Renewable Energy Agency (2021). World Energy Transitions Outlook: 1.5°C Pathway. On the Internet at: https://www.irena.org/publications/2021/Jun/World-Energy-Transitions-Outlook . Retrieved on: 3 July 2023.

IRENA - International Renewable Energy Agency (2022b). Geopolitics of the Energy Transformation - The Hydrogen Factor. On the Internet at: https://www.irena.org/publications/2022/Jan/Geopolitics-of-the-Energy-Transformation-Hydrogen. Retrieved on: 10 March 2023.

Kapitza, S. (2014). The divine engineer: The evolution of technology. 8th ed. Tübingen: expert.

Kewes, T. (2023). The consultants' new billion-dollar business: decarbonising the German economy. Handelsblatt 31 October 2022. On the Internet at: https://www.handelsblatt.com/unternehmen/management/mckinsey-boston-consulting-bain-das-neue-milliardengeschaeft-der-berater-die-dekarbonisierung-der-deutschen-wirtschaft/28768532.html. Retrieved on: 1 August 2023.

Lazard (2021). Lazard's Levelised Cost of Storage Analysis - Version 7.0. On the Internet at: https://www.lazard.com/media/451882/lazards-levelized-cost-of-storage-version-70-vf.pdf. Retrieved on: 3 March 2023.

LDES Council/ McKinsey & Company (2021). Net-zero power: Long duration energy storage for a renewable grid.

Lenton, T. (2014). The Global Potential for Carbon Dioxide Removal. In: Environmental Science and Technology, 38, pp. 52 - 79. On the Internet at: https://www.rifs-potsdam.de/sites/default/files/2018-04/The%20Global%20Potential%20for%20Carbon%20Dioxide%20Removal.pdf. Retrieved on: 15 July 2023

Luick, R. (2021). Primeval forests, natural and commercial forests in the context of biodiversity and climate protection. *Naturschutz und Landschaftsplanung - Zeitschrift für angewandte Ökologie 12/2021*, DOI: 10.1399/NuL.2021.12.01.

Mahnke, E. (2015). CO_2 injection: Problems from the depths. Heinrich Böll Foundation. On the Internet at: https://www.boell.de/de/2015/06/02/co2-verpressung-probleme-aus-der-tiefe. Retrieved on: 3 March 2023.

Massey, J. (2021). Carbon Capture, Utilisation & Storage (CCUS). A Green power Global event Dec 7th-9th.

Mattingly, D., Incerti, T., Ju, C. et al. (2022). Chinese State Media Persuades a Global Audience That the "China Model" Is Superior: Evidence from A 19-country Experiment. On the Internet at: https://doi.org/10.31219/osf.io/5cafd. Retrieved on: 27 July 2023.

Max Planck Society for the Advancement of Science (2022). An interview with Max Planck Director Robert Schlögl on the gas crisis and the energy turnaround. On the Internet at: https://www.mpg.de/19042600/energiewende-gaskrise-schloegl Retrieved on: 27 July 2023.

Mayer, O. (2023). Himalayan small state of Bhutan - Where more carbon dioxide is captured than produced. *tagesschau* 23 June 2023. On the Internet at: https://www.tagesschau.de/wirtschaft/bhutan-klimaschutz-100.html. Retrieved on: 1 July 2023.

McKinsey (2020). Laying the foundation for zero-carbon cement. On the Internet at: https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement. Retrieved on: 3 March 2023.

Mills, M., Malhi, Y., Ewers, R. et al. (2023). Tropical forests post-logging are a persistent net carbon source to the atmosphere- *PNAS 120*(3). Online at: https://www.pnas.org/doi/10.1073/pnas.2214462120. Accessed on: 12 January 2023.

Model Ökoregion Kaindorf (2023). Advantages of humus build-up. On the Internet at: https://www.humusplus.at/humus-wissen/vorteile-von-humusaufbau. Retrieved on: 21 May 2023.

Mongird, K., Viswanathan, V., Alam, J., et al. (2020). 2020 Grid Energy Storage Technology Cost and Performance Assessment. On the Internet at: https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf. Accessed on: 3 March 2023.

Nagler, A., Gerace, S. (2020). First and Second Generation Biofuels. On the Internet at: https://waferx.montana.edu/documents/fact_sheets/1st%20v%202nd.pdf. Retrieved on: 3 March 2023.

Nasa (2019). Technology Readiness Level. On the Internet at: https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level. Retrieved on: 3 March 2023.

NDC Partnership Support Unit (2022). Powering Collective Action. On the Internet at: https://ndcpartnership.org/sites/default/files/NDC%20Partnership%20Empowering%20Collective%20Action.pdf. Retrieved on: 14 April 2023.

NETL National Energy Techn. Lab (2021). Carbon Capture and Storage Database. On the Internet at: http://netl.doe.gov. Accessed on: 3 March 2023.

n-tv (2023). CO_2 certificates worthless? Rossmann stops its "climate neutral" advertising. On the Internet at: https://www.n-tv.de/wirtschaft/Rossmann-stoppt-seine-Klimaneutral-Werbung-article23870274.html. Retrieved on: 30 July 2023

OBRIST Group (2023). On the Internet at: https://www.obrist.at/powertrain/. Retrieved on: 7 April 2023.

OECD - Organization for Economic Cooperation and Development. Official Development Assistance (ODA) in 2022. On the Internet at: https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/official-development-assistance.htm. Accessed on: 25 April 2023.

Ocko, I. (2022). Climate consequences of hydrogen emissions. *Atmos.Che.Phys. 22*, 9349. accessed on: 25.3.2023.

Our World in Data (2022a). Sector by Sector: Where do global greenhouse gas emissions come from? On the Internet at: htpps://ourworldindata.org/ghg-emissions-by-sector, Accessed on: 01.06.2023.

Our World in Data (2022b). Nuclear Energy. On the Internet at: https://ourworldindata.org/nuclear-energy#citation. Accessed on: 3 March 2023.

OXFAM (2023). G7 owes huge $13 trillion debt to Global South. On the Internet at: https://www.oxfam.org/en/press-releases/g7-owes-huge-13-trillion-debt-global-south. Accessed on: 30 June 2023.

Palitza, K., Düttmann, D., Landwehr, A. (2023). China secures global control over the battery raw material lithium - Germany's dependence grows. On the Internet at: https://www.businessinsider.de/wirtschaft/china-sichert-sich-weltweit-kontrolle-ueber-batterie-rohstoff-lithium/. Retrieved on: 3 July 2023.

Pauw, W. P., Castro, P., Pickering, J. et al. (2020). Conditional nationally determined contributions in the Paris Agreement: foothold for equity or Achilles heel? *Climate Policy 20*(4), 468-484. online at: https://doi.org/10.1080/14693062.2019.1635874. accessed on: 30 June 2023.

Peer, M., Ehringfeld, K., Drechsler, W. (2022). Europe buys gigantic quantities of liquefied gas - "This plunges millions of people into darkness. *Handelsblatt* 30.7.2022. On the Internet at: https://www.handelsblatt.com/politik/international/energiekrise-europa-kauft-gigantische-mengen-fluessiggas-das-stuerzt-millionen-menschen-in-die-dunkelheit/28556708.html. Retrieved on: 3 July 2023.

Prognos (2020). *Costs and transformation pathways for electricity-based energy sources Final report on the project "Transformation pathways and regulatory framework for synthetic fuels".*

Radermacher, F. J., Beyers, B. (2011). *World with a Future - The Ecosocial Perspective*. Hamburg: Murmann.

Radermacher, F. J., Riegler, J., Weiger, H. (2011). *Ecosocial Market Economy - History, Programme and Perspective of a Sustainable Global Economic System*. Munich: oekom.

Radermacher, F. J.; Solte, D. (2014). Microcredit - Addressing an Ongoing Debate. FAW/n Report. On the Internet at: https://www.fawn-ulm.de/publikationen. Retrieved on: 3 August 2023.

Radermacher, F. J. (2014). What makes societies rich? - A systemic view, FAW/n Report. On the Internet at: https://www.fawn-ulm.de/publikationen. Retrieved on: 1 July 2023.

Radermacher, F. J. (2015). Global Development Agendas, Sustainability, Future - Navigating Difficult Terrain, in: Bruns, P. (ed.): *The Post 2015 Agenda for Sustainable Development - A Critical-Rational Reflection on its Implications for Development Policy, Series World Economy and International Cooperation 17*. Baden-Baden: Nomos, pp. 71-107.

Radermacher, F. J. (2018). *Der Milliarden-Joker - Wie Deutschland und Europa den globalen Klimaschutz revolutionieren können*. Hamburg: Murmann.

Radermacher, F. J. (2020). The Rio/Kyoto/Paris Dilemma - A Climate Policy Reconstruction of Missed Opportunities, in: *Coursebook 202 Donner. Weather. Klima,* Kursbuch Kulturstiftung gGmbH.

Radermacher, F. J. (2023). On the Importance of Cooperation in Human Groups and Societies - From the Beginnings to the Question of Climate Justice in a Globalized World, in: Herlyn, E., Lévy-Tödter, M., Fischer, K. et al. (eds.) (2023): *Multi-actor networks: cooperation as an opportunity for implementing the 2030 Agenda*. Wiesbaden: Springer Gabler, pp. 15-45.

Righetti, T. (2017). Siting Carbon Dioxide Pipelines. *Oil and Gas, Natural Resources, and Energy Journal 3*(4). Online at: https://digitalcommons.law.ou.edu/onej/vol3/iss4/3 Accessed on: 5 July 2023.

Rhodium Group (2021). China's Greenhouse Gas Emissions Exceeded the Developed World for the First Time in 2019. On the Internet at: https://rhg.com/research/chinas-emissions-surpass-developed-countries/. Retrieved on: 9 July 2023.

RNE - Council for Sustainable Development (2023). Financing Transformation and Sustainable Development - Reforming the International Financial Architecture. On the Internet at: https://www.nachhaltigkeitsrat.de/wp-content/uploads/2023/06/2023_06_21_RNE_Stellungnahme_Finanzierung_Transformation_und_nachhaltige_Entwicklung.pdf. Retrieved on: 1 June 2023.

Rodrik, D. (2011). *The globalisation paradox - Democracy and the future of the world economy*. Munich: C.H.Beck.

Schneider, C. et al. (2019). *Climate-neutral industry: Detailed presentation of key technologies for the steel, chemical and cement sectors. Analysis commissioned by Agora Energiewende*. Berlin.

Science Media Center (2021). In Search of Power Dips and Power Valleys - Prepping for the Dark Slack I. Fact Sheet. On the Internet at: https://www.sciencemediacenter.de/alle-angebote/fact-sheet/details/news/auf-der-suche-nach-stromdellen-und-stromtaelern-preppen-fuer-die-dunkelflaute-i/. Retrieved on: 21 March 2023.

Shell (2021). The Energy Transformation Scenarios. On the Internet at: https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/what-are-the-previous-shell-scenarios/the-energy-transformation-scenarios/_jcr_content/root/main/section_524990089/simple/promo_copy/links/item0.stream/1652119830834/fba2959d9759c5ae806a03acfb187f1c33409a91/energy-transformation-scenarios.pdf. Retrieved on: 23 May 2023.

Skea, J., Shukla, P., Reisinger, A. (2022). Climate Change - Impacts, Adaptation and Vulnerability - Summary for Policymakers released. On the Internet at: https://doi.org/doi: 10.1017/9781009157926.001. Retrieved on: 27 July 2023.

Smil, V. (2023). *How the world really works - The fossil foundations of our civilisation and the future of humanity*. Munich: C.H.Beck.

Smith, P., Adams, J., Beerling, D. et al. (2019). Impacts of Land-Based Greenhouse Gas Removal Options on Ecoystem Services and the United Nations Sustainable Development Goals. *Annual Review of Environment and Resources.* https://doi.org/10.1146/annurev-environ-101718-033129 Retrieved on: 14 October 2022

Snoebjörnsdottir, S. O., Sigfusson, B., Marieni, C. et al. (2020). Carbon dioxide storage through mineral carbonization. *Nature Reviews 1,* 90?102. https://doi.org/10.1038/s43017-019-0011-8.

Stappen, R. K. (2023). Analysis of restrictions and constraints of developing and emerging countries on the path to climate neutrality. GES and FAW/n Report.

statista (2022). Loss of global tropical rainforest area from 2002 to 2021. On the Internet at: https://de.statista.com/statistik/daten/studie/1184901/umfrage/verlust-der-globalen-regenwald-flaeche/. Retrieved on: 28 April 2023.

statista (2023a). China: Real gross domestic product (GDP) growth from 1981 to 2022 and forecasts to 2028. On the Internet at: https://de.statista.com/statistik/daten/studie/14560/umfrage/wachstum-des-bruttoinlandsprodukts-in-china/. Retrieved on: 5 May 2023.

statista (2023b). Net profit of Saudi Aramco worldwide in fiscal years 2017 to 2022. On the Internet at: https://de.statista.com/statistik/daten/studie/990694/umfrage/nettogewinn-von-saudi-aramco-weltweit/. Retrieved on: 11 May 2023.

Stehr, N., Machin, A. (2019). *Gesellschaft und Klima - Entwicklungen, Umbrüche, Herausforderugen*. Weilerswist-Metternich: Velbrück Wissenschaft.

Stelter, D. (2023). The absolute economic war. *Handelsblatt* 2 April 2023. On the Internet at: https://www.handelsblatt.com/audio/bto/bto-2-0-der-oekonomie-podcast-mit-dr-daniel-stelter-der-absolute-wirtschaftskrieg/29073842.html. Retrieved on: 28 April 2023.

Stölzel, T., Martin, S. (2022): Battery is not enough. *Wirtschaftswoche* 04.11.2022.

The Economist (2023a). Hard truths about green growth. On the Internet at: https://www.economist.com/leaders/2023/06/29/how-misfiring-environmentalism-risks-harming-the-worlds-poor. Accessed on 8 August 2023.

The Economist (2023b). Development v Climate. On the Internet at: https://www.economist.com/finance-and-economics/2023/06/27/the-choice-between-a-poorer-today-and-a-hotter-tomorrow. Accessed on: 8 August 2023.

The Guardian (2023). Revealed: more than 90% of rainforest carbon offsets by biggest provider are worthless, analysis shows. On the Internet at: https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe. Retrieved on: 22 January 2023.

UN - United Nations (2023a). The Sustainable Development Goals. Department of Economic and Social Affairs. On the Internet at: https://sdgs.un.org/goals. Retrieved on: 28 April 2023.

UN - United Nations (2023b). The United Nations System. On the Internet at: https://www.un.org/depts/german/orgastruktur/vn-organigramm_oktober2011.pdf. Retrieved on: 30 July 2023

UNEP - United Nations Environment Programme (2022a). Emissions Gap Report 2022. On the Internet at: https://www.unep.org/resources/emissions-gap-report-2022. Accessed on: 14 April 2023.

UNEP - United Nations Environmental Programme (2022b). State of Finance for Nature - Time to act: Doubling investment by 2025 and eliminating nature-negative finance flows. On the Internet at: https://www.unep.org/resources/report/state-finance-nature-2022 Accessed on: 1 January 2023.

UNEP - United Nations Environment Programme (2023). What is an Inclusive Green Economy? On the Internet at: https://www.unep.org/explore-topics/green-economy/why-does-green-economy-matter/what-inclusive-green-economy. Retrieved on: 2 May 2023.

UNFPA - United Nations Population Fund (2023). State of World Population 2023 - 8 Billion Lives, Infinite Possibilities, The Case for Right Choices. On the Internet at: https://www.unfpa.org/sites/default/files/swop23/SWOP2023-ENGLISH-230329-web.pdf. Accessed on: 26 April 2023.

UNIDO - United Nations Industrial Development Organization (2023): Montreal Protocol. On the Internet at: https://www.unido.org/climate-action/multilateral-agreements/montreal-protocol. Accessed on: 13 July 2023.

Vahrenholt, F. (2023). *The great energy crisis and how we can overcome it*. Rottenburg: Kopp.

Van Reybrouck, D. (2022): *Revolusi. Indonesia and the Making of the Modern World*. Berlin: Suhrkamp.

Vistra (2022). Vistra Announces Expansion of World's Largest Battery Energy Storage Facility. On the Internet at: https://investor.vistracorp.com/2022-01-24-Vistra-Announces-Expansion-of-Worlds-Largest-Battery-Energy-Storage-Facility. Accessed on: 27 July 2023.

Von Weizsäcker, E. U. (1994). *Earth Policy. Ecological Realpolitik an der Schwelle zum Jahrhundert der Umwelt*, 4th edition. Darmstadt: Wissenschaftliche Buchgesellschaft.

Warwick et al. (2022). Atmospheric implications of increased Hydrogen use. *UK Government Policy Paper, Dept for Energy Securit y and Dept for Business, Energy & Industrial Strategy*. 8 April 2022.

WBCSD - World Business Council for Sustainable Development (2021). Vision 2050 - Time to Transform. On the Internet at: https://www.wbcsd.org/contentwbc/download/11765/177145/1 Accessed on: 3 August 2023.

WBCSD - World Business Council for Sustainable Development (2023). PETRONAS collaborates with Partners to Accelerate Methane Emissions Reduction. On the Internet at: https://www.wbcsd.org/Overview/News-Insights/Member-spotlight/PETRONAS-collaborates-with-Partners-to-Accelerate-Methane-Emissions-Reduction. Accessed on: 3 August 2023

WEF - World Economic Forum (2020). 395 Million New Jobs by 2030 if Businesses Prioritize Nature, Says World Economic Forum. On the Internet at: https://www.weforum.org/press/2020/07/395-million-new-jobs-by-2030-if-businesses-prioritize-nature-says-world-economic-forum/. Accessed on: 2 May 2023.

Wind Energy: The Facts (2022). Growth of Wind Turbine Size. On the Internet at: https://www.wind-energy-the-facts.org/growth-of-wind-turbine-size.html. Accessed on: 3 March 2023.

Winkelhahn, R. (2023). Emerging and developing countries face "debt wall" of 39 billion dollars. *Handelsblatt* 31.5.2023. On the Internet at: https://www.handelsblatt.com/finanzen/geldpolitik/staatsanleihen-schwellen-und-entwicklungslaendern-droht-schuldenwall-von-39-milliarden-dollar/29111424.html. Retrieved on:4 July 2023.

Wernicke, H.-J. (2022). Potential of hydrogenated vegetable oils and vegetable waste oils as "green" fuel. On the Internet at: https://global-energy-solutions.org/wp-content/uploads/2022/11/HVO-Papier_final_HJW_17.9.22_update-3.10..pdf. Retrieved on: 2 August 2022.

World Bank (2023). World Development Indicators. On the Internet at: https://databank.worldbank.org/source/world-development-indicators. Retrieved on: 16 May 2023.

World Bank & IMF - International Monetary Fund (2015). From billions to trillions: Transforming development finance post-2015 financing for development: Multilateral development finance. Development committee discussion note. Available online at: https://siteresources.worldbank.org/DEVCOMMINT/Documentation/23659446/DC2015-0002%28E%29FinancingforDevelopment.pdf. Accessed on: 25 April 2023.

World Commission on Environment and Development (1987). *Our Common Future*. Oxford: Oxford University Press.

World Nuclear Association (2022). Plans For New Reactors Worldwide. On the Internet at: https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx. Retrieved on: 27 July 2023.

WRI - World Resource Institute (2014). Atlas Forest and Landscape Restoration Opportunities. On the Internet at: https://www.wri.org/data/atlas-forest-and-landscape-restoration-opportunities. . Retrieved on: 24 May 2023.

WVI - World Vision International (2022). Restore Land, Restore Climate. On the Internet at: https://www.wvi.org/publications/report/hunger-crisis/restore-land-restore-climate. Retrieved on: 24 May 2023.

Yunus, M. (1998). Grameen: A Bank for the World's Poor, Cologne: Lübbe Verlag

Zheng, B. (2023). Record-high CO_2 emissions from boreal fires in 2021. *Science 379*(6635), 912-917. On the Internet at: https://www.science.org/doi/10.1126/science.ade0805. Accessed on: 18 May 2023.

Ziltener, P., Suter, C. (eds.) (2022). African-Asian Relations: Past, Present, Future. Volume 2022 of the World Society Foundation. On the Internet at: https://www.worldsociety.ch/lib/exe/fetch.php?media=wss_2022_preprint.pdf. Accessed on: 14 April 2023.

Appendix

A Supplementary information on the subdivision of states

A.1 Classification of country groups

The information in this annex are summary results. A detailed Excel file with all invoices is in a digital attachment and can be ordered via the email address mail@global-energy-solutions.org.

Data source: World Development Indicators of the World Bank (https://databank.worldbank.org/source/world-development-indicators)

The countries considered in the three categories "extended OECD", "China Club" and "Challenge Group" cover more than 99 % of the world's population and more than 98 % of the world's GDP.

Population figures of the three country groups and their development

	2025	2050
Erweiterte OECD	1,5 (1,40)	1,5 (1,40)
China Club	1,5 (1,56)	1,5 (1,44)
Challenge Gruppe	5 (5,1)	7 (6,7)
Welt gesamt	**8 (8,06)**	**10 (9,53)**

Table 14: Population figures in 2025 and 2050 (in billions)

Enlarged OECD (38 + 9 countries):

OECD countries:

Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Rep., Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkiye, United Kingdom, United States

Other countries:

Bahamas, Bermuda, Cyprus, Greenland, Liechtenstein, Malta, Monaco, Puerto Rico, Singapore

China Club (10 countries):

Bahrain, China (CN), Hong Kong (CN), Kuwait, Macao (CN), Oman, Quatar, Russian Fed., Saudia Arabia, UAE

Challenge Group (128 countries):

Afghanistan, Albania, Algeria, Angola, Argentina, Bangladesh, Brazil, Bosnia and Herzegovina, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Rep, Chad, Comoros, Congo (Dem. Rep.), Congo (Rep.), Cote d'Ivoire, Croatia, Cuba, Djibouti, Dominican Republic, Ecuador, Egypt (Arab Rep.), El Salvador, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Fiji, French Polynesia, Gabon, Gambia (The), Georgia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Iran (Islamic Rep.), Iraq, Jamaica, Jordan, Kazakhstan, Kenya, Korea (Dem. People's Rep.), Kosovo, Kyrgyz Republic, Lao PDR, Lebanon, Lesotho, Liberia, Libya, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Caledonia, Nicaragua, Niger, Nigeria, North Macedonia, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Romania, Rwanda, Samoa, Sao Tome and Principe, Senegal, Serbia, Sierra Leone, Solomon Islands, Somalia, South Africa, South Sudan, Sri Lanka, Sudan, Suriname, Syrian Arab Republic, Tajikistan, Tanzania, Thailand, Timor-Leste, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkmenistan, Tuvalu, Uganda, Ukraine, Uruguay, Uzbekistan, Vanuatu, Venezuela (RB), Vietnam, West Bank and Gaza, Yemen (Rep.), Zambia, Zimbabwe

Least Developed Countries (LDCs) are shown in red. Here, the problem is often that countries are stuck in a poverty trap (civil war, no access to the sea, etc.).

On the definition of Least Developed Countries

Since 1971, the United Nations has recognised least developed countries (LDCs) as a category of countries that are deemed highly disadvantaged in their development process, for structural, historical and also geographical reasons. LDCs face more than other countries the risk of deeper poverty and remaining in a situation of underdevelopment. More than 75 per cent of the LDCs' population still live in poverty. These countries are also characterised by their vulnerability to external economic shocks, natural and man-made disasters and communicable diseases. As such, the LDCs are in need of the highest degree of attention from the international community.

Currently, the 46 LDCs comprise around 880 million people, 12 percent of the world population, which face severe structural impediments to growth. However, the LDCs account for less than 2 percent of world GDP and around 1 percent of world trade.

The list of LDCs is reviewed every three years by the United Nations Economic and Social Council, in the light of recommendations by the Committee for Development Policy (CDP). The following three criteria are used by the CDP to determine LDC status:

- **Per capita income** (gross national income per capita)
- **Human assets** (indicators of nutrition, health, school enrolment and literacy)
- **Economic vulnerability** (indicators of natural and trade-related shocks, physical and economic exposure to shocks, and smallness and remoteness).

By periodically identifying LDCs and highlighting their structural problems, the United Nations gives a strong signal to the international community to the need of special concessions in support of LDCs. Concessions associated with LDC status include benefits in the areas of:

- **Development financing**, notably grants and loans from donors and financial institutions.
- **Multilateral trading system**, such as preferential market access and special treatments.
- **Technical assistance,** notably, towards trade mainstreaming (Enhanced Integrated Framework)

Six countries have so far graduated from LDC status: Botswana in 1994, Cape Verde in 2007, Maldives in 2011, Samoa in 2014, Equatorial Guinea in 2017, and Vanuatu in 2020.

UNCTAD extends to all graduating countries a range of services aimed at supporting their progress towards graduation from LDC status. These include preparing vulnerability profiles of countries with the challenges of graduation, supporting them in their preparation for a smooth transition to post-LDC life. UNCTAD also assists ex-LDCs in their quest for continued socio-economic progress, notably, towards enhanced economic specialisation.

Source: https://unctad.org/topic/least-developed-countries/recognition

A.2 Economic development in the Reference Solution

In summary, the following tables contain the key data for examining the economic developments in the Reference Solution, which are dealt with in Chapter 4.4. The period 2025 - 2050 is covered, based on assumptions about the development of the GDP of the individual countries, which are then aggregated at the level of the country groups.

GDP developments under the Reference Solution

Table 15 shows which GDP developments the Reference Solution should enable in the coming years from 2025 - 2050 in the three groups under consideration.

	2025	BIP-Zuwachs durch Bev.-wachstum	BIP-Zuwachs durch andere Faktoren	2050
Erweiterte OECD	75 (72,8)	3 (2,6)	35 (33,8)	110 (109,1)[1]
China Club	30 (28,7)	-4 (-3,8)	25 (26,3)	50 (51,1)[2]
Challenge Gruppe	20 (18,5)	10 (11,2)	50 (51,0)	80 (80,7)[3]
Welt gesamt	**120 (120)**	**10 (9,6)**	**110 (110)**	**240 (241,1)**

Table 15: GDP developments from 2025 to 2050 (in trillions of US dollars)

The calculated GDP values in 2050 are based on the following projections:

[1] Expanded OECD: 25 years á 1.6 % growth per year; factor 1.5; per capita 1.6 %

[2] China Club: 25 years á 2.3% growth per year; factor 1.8; per capita 2.6

[3] Challenge Group: 25 years 6% growth; LDCs 7% per year; factor 4.4; per capita 4.9%.

Energy situation due to GDP increases

Table 16 shows the distribution of GDP increases between volume effects on the one hand and efficiency effects in the area of energy production on the other.

	2025	Mengen-effekt	Effizienz-effekt	2050
Erweiterte OECD	75 (72,8)	10 (11,5)	25 (24,9)	110 (109,1)
China Club	30 (28,7)	5 (5,3)	15 (17,1)	50 (51,1)
Challenge Gruppe	20 (18,5)	30 (30,8)	30 (31,3)	80 (80,7)
Welt gesamt	**120 (120)**	**10 (9,6)**	**110 (110)**	**240 (241,1)**

Table 16: GDP growth based on energy quantity and efficiency effects (in trillions of US dollars)

The digital appendix contains detailed calculations on GDP development, the resulting primary energy quantity, etc. The following table shows schematically the structure of the underlying file.

Country	Population growth 2021 (annual abs.)	Population growth 2021 (annual %)	Population 2025	Population 2050	GDP 2021 (current US$)	GDP per capita 2021 (current US$)	GDP growth (annual %)	...	Energy Intensity 2019 (kWh/$2017 PPP GDP)	Energy Intensity 2025 (kWh/$2017 PPP GDP)	...	Energy used 2025 (GWh)	Energy used 2050 (GWh)
Extended OECD													
Australia													
Austria													
...													
China Club													
Bahrain													
China													
...													
Challenge Group													
Argentina													
Bulgaria													
...													
Bangladesh													
India													
Indonesia													
...													
Yemen													
Zimbabwe													

A.3 Cap-and-trade system and challenge index

Challenge index for deriving a cap-and-trade system

Within the Challenge Group in particular, the conditions for achieving Net Zero vary greatly. With the help of a "Challenge Index", the countries of the Challenge Group are divided into three sub-groups, depending on the size of the "challenge" to achieve Net Zero. The index is derived from data on different sizes that influence the challenges to be overcome.

The Challenge Index is built up by adding six individual values, i.e. it is a so-called composite indicator. These include GDP per capita, absolute population growth, the availability of fossil fuels, the potential of solar energy, the potential for nature-based solutions and a value with a statement on good governance.

Criterion 1: GDP per capita
Source: World Bank data (World Development Indicators); https://databank.worldbank.org/source/world-development-indicators

Score	GDP per capita
10	>10.000
9	>9.000
8	>8.000
7	>7.000
6	>6.000
5	>5.000
4	>4.000
3	>3.000
2	>2.000
1	Otherwise

With this criterion, it can be discussed whether a high income is a big challenge or not. However, there is a danger that countries with already high incomes will go the way of China, because there is already a level of fossil energy capacity and this will be expanded if no cross-financing comes.

Therefore: the greater the income, the higher the score.

Criterion 2: Absolute population growth

Source: World Bank data (World Development Indicators); https://databank.worldbank.org/source/world-development-indicators

Score	Number of people per year
10	> 4.000.000
9	< 4.000.000
8	< 3.500.000
7	< 3.000.000
6	< 2.500.000
5	< 2.000.000
4	< 1.500.000
3	< 1.000.000
2	< 500.000
1	< 0

The absolute number of people per year is chosen because this has direct consequences on emissions and the material input needed to enable them to live adequately. Percentage growth does not reflect this point in the same way. There is great variability between countries on this criterion. What can be discussed is how to deal with outliers, such as India (about 11,000,000 people per year) or Nigeria (about 5,000,000 people per year) or Pakistan (about 4,000,000 people per year).

Therefore, the more people that are added per year, the higher the value.

Criterion 3: Good governance

Source: World Bank data (Worldwide Governance Indicators)
https://info.worldbank.org/governance/wgi/Home/Reports

Score	Governance indicator, averaged
10	< 0,4
9	< 0,8
8	< 1,2
7	< 1,6
6	< 2,0
5	< 2,4
4	< 2,8
3	< 3,2
2	< 3,6
1	Otherwise

For this criterion, six World Bank good governance indicators are combined.
All six values are available for each country in the value range from -2.5 to 2.5. The mean value is calculated for all six individual values. For a better overview, all values with 2.5 are added to reach the range > 0. The six individual indicators are:

(1.) Voice and Accountability,
(2.) Political Stability and Absence of Terrorism/Violence, (3.) Government Effectiveness, (4.) Regulatory Quality, (5.) Rule of Law, (6.) Control of Corruption

The lower the averaged value across all six indicators of a country, the higher the value for this criterion.

Criterion 4: Potential for nature-based solutions

Source: Global Footprint Network (biocapacity per capita); World Bank for population (see above).
https://www.footprintnetwork.org/

Score	Biocapacity per capita (gha)
10	< 0,25
9	< 0,5
8	< 0,75
7	< 1,5
6	< 3,0
5	< 4,5
4	< 6,0
3	< 7,5
2	< 9
1	Otherwise

According to the methodology of the Global Footprint Network, the unit is "global hectares". This is a well-established figure that gives a measure of the biological quality of individual areas (e.g. rainforest higher than agricultural land, higher than desert). This value was divided by the number of people to get global hectares per capita for the individual countries. This is relevant for the potential profits that countries could make in the cap-and-trade system.

Some countries have less than one global hectare per person, the values are below one. Therefore, there is no linear distribution of points here.

Therefore: The lower the capacity, the higher the score for this criterion.

Criterion 5: Reserves of fossil energy sources

Source: BGR - Federal Institute for Geosciences and Natural Resources (2022): BGR-Energiestudie 2021 - Daten und Entwicklungen der deutschen und globalen Energieversorgung.
https://www.bgr.bund.de/DE/Themen/Energie/Downloads/energiestudie_2021.html

This criterion describes the potential of fossil energy reserves. The energy sources considered are natural gas, crude oil and hard coal. For each country, a score of 1-10 is given for each of the three energy sources. The mean value is then calculated to obtain a value per country for this criterion. The table shows the threshold values according to which the rating is made for the individual energy sources. What needs to be discussed here is from which reserve quantity it is attractive for the respective country to enter into significant promotion or to further expand the existing one. However, such an assessment goes far beyond what is feasible in this report. Nevertheless, the classification can provide a rough orientation.

Score	Natural gas (bn m³)	Score	Crude oil (Mt)	Score	Coal (Mt)
10	>= 4.500	10	>= 18.000	10	>= 20.000
9	< 4.500	9	< 18.000	9	< 20.000
8	< 4.000	8	< 16.000	8	< 17.500
7	< 3.500	7	< 14.000	7	< 15.000
6	< 3.000	6	< 12.000	6	< 12.500
5	< 2.500	5	< 10.000	5	< 10.000
4	< 2.000	4	< 8.000	4	< 7.500
3	< 1.500	3	< 6.000	3	< 5.000
2	< 1.000	2	< 4.000	2	< 2.500
1	< 500	1	< 2.000	1	< 500

The higher the existing reserves of fossil energy sources, the greater the value of this criterion.

Criterion 6: Potential for renewable energy

Source: Global Solar Atlas (Average Practical Potential, PVOUT)
https://globalsolaratlas.info/global-pv-potential-study/

Score	Potential solar energy (kWh/kWp/day)
10	< 3.250
9	< 3.500
8	< 3.750
7	< 4.000
6	< 4.250
5	< 4.500
4	< 4.750
3	< 5.000
2	< 5.250
1	Otherwise

This criterion describes how much potential for solar energy is available in a country on average. It is measured in the amount of energy (kWh) that can be expected per output of a photovoltaic system per day. For Germany, for example, this value is 2,960 kWh/kWp. Locations with high solar irradiation will have an advantage in the future in covering their energy needs with renewable energies. We base our calculations on current prices, which can generate electricity via PV systems at around 1ct/kWh. These are achieved in North Africa, for example.

Unfortunately, to our knowledge, no comparable aggregated country-level data are available for wind energy. For the scope of this report, it is therefore sufficient to consider solar energy as a proxy for renewable energies in general. Otherwise, a combined criterion could be created following the procedure of criterion 3 (good governance) via averaging.

Therefore, the lower the potential for solar energy, the higher the value of this criterion.

Grouping on the basis of the Challenge Index

The countries within the groups are sorted in descending order according to the level of the respective challenge index.

Group 1:

French Polynesia, Egypt (Arab Rep.), Ethiopia, Thailand, Trinidad and Tobago, Croatia, Algeria, Bosnia and Herzegovina, Brunei Darussalam, Ecuador, Korea (Dem. People's Rep.), Mauritius, Montenegro, North Macedonia, Syrian Arab Republic, Uganda, Burundi, Dominican Republic, Babon, Moldova, Mozambique, Sao Tome and Principe, Sri Lanka, Turkmenistan, Vanuatu, Kenya, Tanzania, Uzbekistan, Georgia, Guatemala, Haiti, Jamaica, Kyrgyz Republic, Lebanon, Papua New Guinea, Tuvalu, Afghanistan, Somalia, Albania, Armenia, Belize, Comoros, Congo (Rep.), Eswatini, Guinea, Tajikistan, West Bank and Gaza, Yemen (Rep.), Zimbabwe, Sudan, Cameroon, Cote d'Ivoire, Madagascar, Nepal, Botswana, Djibouti, Guyana, Lao PDR, Myanmar, Nicaragua, Togo, Tunisia, Angola, Ghana, Cambodia, Chad, El Salvador, Fiji, Liberia, Malawi, Peru, Rwanda, Sierra Leone, Solomon Islands, South Sudan, Tonga, Burkina Faso, Benin, Gambia (The), Guinea-Bissau, Honduras, Jordan, Mali, Uruguay, Eritrea, Morocco, Niger, Paraguay, Samoa, Timor-Leste, Zambia, Bhutan, Central African Republic, Cuba, Mauritania, Senegal, Lesotho, Suriname, Bolivia, Mongolia, Namibia

Group 2:

Iran (Islamic Rep.), Iraq, Indonesia, Pakistan, Malaysia, Congo (Dem. Rep.), Ukraine, Equatorial Guinea, Libya, New Caledonia, Kosovo, Venezuela (RB), Bangladesh, Brazil, Philippines, Azerbaijan, Belarus, Argentina, Bulgaria, Panama, Romania, South Africa, Vietnam, Serbia

Group 3:

Kazakhstan, India, Nigeria

Development of CO_2 emissions of the three country groups under the cap-and-trade system of the Reference Solution

Data source for individual country emissions: https://globalcarbonatlas.org/

Based on the emissions data, the aggregated values for the individual country groups are slightly lower than the baseline distribution in 2025, with 4 and 5 billion tonnes of CO_2 for groups 1, 2 and 3 respectively. This is because the last available data is from 2021 and we expect a further increase in emissions, especially in the Challenge Group. In addition, the source only provides data on CO_2 emissions, but not on CO_2 equivalent emissions, e.g. methane emissions. For the conservative derivation of the cap-and-trade system, higher values of a total of 13 billion tonnes of CO_2 are therefore estimated for the. The additional emissions were added proportionally.

The following table shows the development of emissions of the individual country groups under the cap-and-trade system, broken down over the period 2025 - 2050.

Year	Extended OECD	China Club	Group 1 (Challenge Group)	Group 2 (Challenge Group)	Group 3 (Challenge Group)	Cap values for all years
2025	13	13	4	5	4	39
2026	11,96	12,545	3,85	4,8	3,85	37,005
2027	10,92	12,09	3,7	4,6	3,7	35,01
2028	9,88	11,635	3,55	4,4	3,55	33,015
2029	8,84	11,18	3,4	4,2	3,4	31,02
2030	7,8	10,725	3,25	4	3,25	29,025
2031	7,41	10,27	3,1	3,8	3,1	27,68
2032	7,02	9,815	2,95	3,6	2,95	26,335
2033	6,63	9,36	2,8	3,4	2,8	24,99
2034	6,24	8,905	2,65	3,2	2,65	23,645
2035	5,85	8,45	2,5	3	2,5	22,3
2036	5,46	8,02	2,3333	2,8667	2,4667	21,147
2037	5,07	7,59	2,1667	2,7333	2,4333	19,993
2038	4,68	7,16	2	2,6	2,4	18,84
2039	4,29	6,73	1,8333	2,4667	2,3667	17,687
2040	3,9	6,3	1,6667	2,3333	2,3333	16,533
2041	3,51	5,87	1,5	2,2	2,3	15,38
2042	3,12	5,44	1,3333	2,0667	2,2667	14,227
2043	2,73	5,01	1,1667	1,9333	2,2333	13,073
2044	2,34	4,58	1	1,8	2,2	11,92
2045	1,95	4,15	0,8333	1,6667	2,1667	10,767
2046	1,56	3,72	0,6667	1,5333	2,1333	9,6133
2047	1,17	3,29	0,5	1,4	2,1	8,46
2048	0,78	2,86	0,3333	1,2667	2,0667	7,3067
2049	0,39	2,43	0,1667	1,1333	2,0333	6,1533
2050	0	2	0	1	2	5
2051	0	1,8	0	0,9	1,9	4,6
2052	0	1,6	0	0,8	1,8	4,2
2053	0	1,4	0	0,7	1,7	3,8
2054	0	1,2	0	0,6	1,6	3,4

2055	0	1	0	0,5	1,5	3
2056	0	0,8	0	0,4	1,4	2,6
2057	0	0,6	0	0,3	1,3	2,2
2058	0	0,4	0	0,2	1,2	1,8
2059	0	0,2	0	0,1	1,1	1,4
2060	0	0	0	0	1	1
2061	0	0	0	0	0,9	0,9
2062	0	0	0	0	0,8	0,8
2063	0	0	0	0	0,7	0,7
2064	0	0	0	0	0,6	0,6
2065	0	0	0	0	0,5	0,5
2066	0	0	0	0	0,4	0,4
2067	0	0	0	0	0,3	0,3
2068	0	0	0	0	0,2	0,2
2069	0	0	0	0	0,1	0,1
2070	0	0	0	0	0	0

B Overview of contents Basic documentation

B.1 Technical Toolbox

The following chapters can be found on the first outline level

- Renewable electricity generation
- Generation of electricity by nuclear power
- Electricity storage
- Hydrogen production
- Transport and storage of hydrogen
- Production and use of hydrogen derivatives
- Climate-neutral fuels
- Technical capture and storage of CO2 (CCS)
- Carbon Capture and Usage (CCS)
- Nature-based solutions
- Oceans as sinks for anthropogenic CO2
- Other greenhouse gases besides CO2
- Critical raw materials
- Infrastructures and energy transport

B.2 Major greenhouse gas emitting sectors

- Power generation from fossil fuels
- Major process industries
- Transport
- Housing and buildings

The individual chapters can be found at https://global-energy-solutions.org/en/basic-documentation-of-the-ges-reference-solution/

Global Energy Solutions e.V. develops global solutions and business models for energy, climate and development issues. Our goal is a climate-neutral energy system - with the following elements: green electricity, green hydrogen, biological as well as technical CO_2 recycling, climate-neutral energy sources and fuels - including methanol. During production, CO_2 is used materially and thus becomes an interesting economic good. Together with industrial and scientific partners, we are developing technical, entrepreneurial and administrative foundations for significant investments in this field of the future. Investments that pay off.

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