HELMHOLTZ
CLIMATE INITIATIVE

PROJECT BRIEFING #3

AVOIDED AND REMOVED EMISSIONS

VERSION #2 | OCTOBER 2021

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AIM

- **PART A** is providing a description of the different components that contribute to the reduction of atmospheric greenhouse gas concentration for mitigating climate change.
- **PART B** is addressing issues related to the quantification of avoided and removed emissions.

PART A

AVOIDED AND REMOVED EMISSIONS AS CONTRIBUTION TO MITIGATING CLIMATE CHANGE

Mitigating climate change is a "… human intervention to reduce emissions or enhance the sinks of greenhouse gases" (IPCC, 2018). This involves human activities for:

→ avoiding emissions through the reduction and omission of greenhouse gases (GHG) from human activities;

→ removing carbon dioxide CO_2 from the atmosphere (carbon dioxide removal (CDR), including carbon capture and storage (CCS)), which can lead to gross negative emissions;

Many scenarios for achieving the 1.5°C target of the Paris Agreement and net-zero emissions rely on both 1) avoiding greenhouse gas emissions and 2) removing carbon dioxide from the atmosphere (IPCC, 2018; Waisman et al., 2019). However, there are also scenarios that indicate that these climate targets can still be reached without the need for carbon dioxide removal (Vuuren et al., 2018).

Within the scope of the Helmholtz Climate Initiative and the objective of achieving net-zero CO_2 emissions by 2050 in Germany, net-zero CO_2 emissions signifies that anthropogenic CO_2 emissions in Germany are balanced by means of anthropogenic CO_2 removals over the period until 2050 (IPCC, 2018). In addition, the Helmholtz Climate Initiative will consider the effects of other anthropogenic greenhouse gases and climate forcers separately *(see Project Briefing #1 "P1-Structure")*. Figure 1 shows the contribution of avoiding and removing carbon dioxide from the atmosphere toward achieving net-zero CO_2 emissions, also referred to as carbon neutrality *(see Project Briefing #4 "Carbon Budget")*.

#1

#4

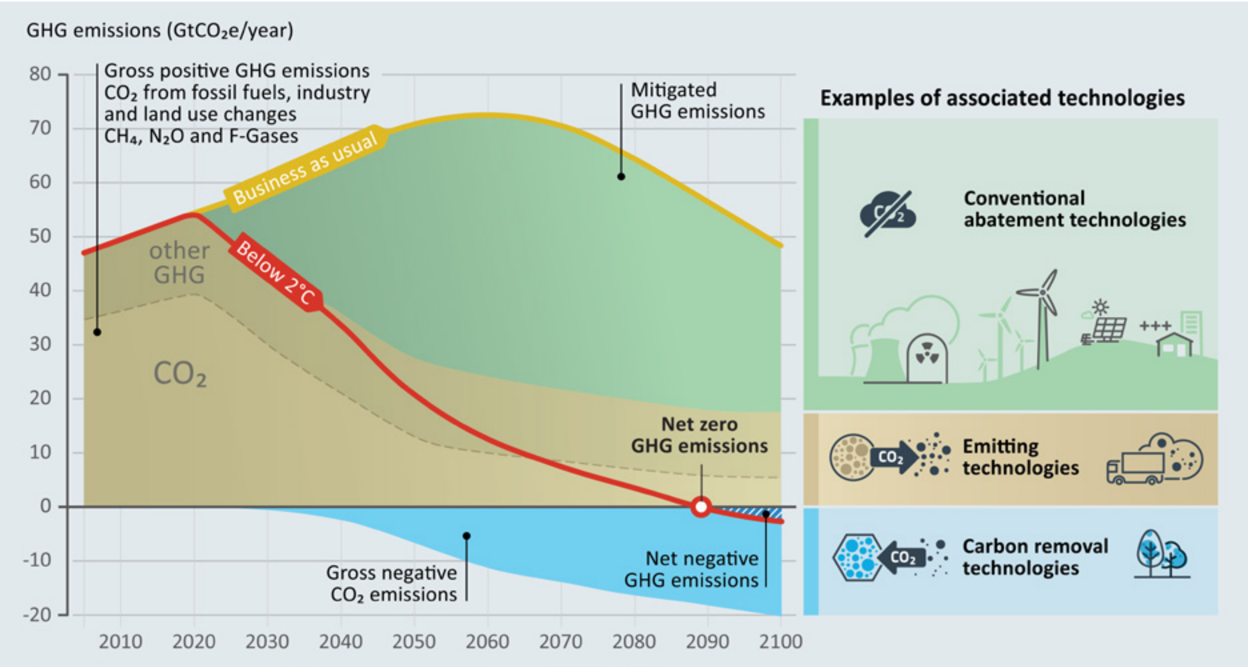

Figure 1: The mitigation of greenhouse gas emissions can be achieved by avoiding emissions (e.g. through technologies and changes in human behaviour) and carbon dioxide removal from the atmosphere. Gross negative emissions are the result of CDR from the atmosphere and "… durably storing it in geological, terrestrial, or ocean reservoirs, or in products" (IPCC, 2018). Net-negative GHG emissions are achieved when negative emissions are larger than GHG emissions at global scale. Net-zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. Net-zero CO_2 emissions are also referred to as carbon neutrality. Source of figure: UNEP Emission Gap Report (2017).

AVOIDED CARBON DIOXIDE EMISSIONS

Avoided emissions are the result of human activities that lead to lower or no CO_2 emissions. Such activities for reducing emissions can include options of technological changes (e.g. enhancing energy efficiency or changing energy production from fossil fuel to renewable energies), changes in management practices (e.g. changing land-use practices, or conserving ecosystems) and behavioural changes (e.g. reducing the use of energy or changing the mode of transportation). Changes in policies can provide incentives and regulations for technological changes, changes in management practices and behavioural changes that can lead to a reduction in CO_2 emissions.

Avoided CO_2 emissions are the quantity of CO_2 emissions that have not been emitted to the atmosphere as a result of the implementation of human interventions with lower or no greenhouse gas emissions (e.g. the implementation of technological changes, changes in management practices *(P4)*, restoration and protection of natural carbon sinks *(P4)* or behavioural changes). Avoided emissions can be reported over a period of time comparing emissions of a business-as-usual scenario (BAU) (without the implementation of an emission reduction strategy) with the actual emissions after the implementation of an emission reduction strategy. It can be reported as a total of avoided emissions or as the quantity of emissions avoided per unit (e.g. per product, per kilometre travelled or per hectare).

REMOVED (NEGATIVE) CARBON DIOXIDE EMISSIONS

Removed or negative emissions result from human activities that promote the uptake of greenhouse gases from the atmosphere, in particular carbon dioxide removal (CDR). Negative emissions are only achieved, if the entire process (life cycle) of the process is removing more emissions from the atmosphere than the process itself is creating. This includes emissions from energy and material production for any of these measures, which will be included in the energy system modelling approach in **Net-Zero-2050** *(see Project Briefing #4 "Scenario Approach")*.

#4

The IPCC (2018) defines **carbon dioxide removal** as: "…anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities."

Carbon dioxide removal (Fig. 2 and Fig. 3) can be achieved through enhancing terrestrial or marine carbon sinks or by technological means. Options for enhancing terrestrial carbon sinks include, for example, afforestation, reforestation and improving forest management and agricultural practices (e.g. enhancing the uptake and storage of carbon in soils, *P4*). Options for enhancing marine carbon sinks include, for example, ocean alkalinisation and the restoration and protection of seagrasses and salt marshes *(P4)*.

Technological means of carbon dioxide removal include the chemical processes for directly capturing carbon dioxide from the air in combination with geological carbon storage – so-called direct air carbon dioxide capture and storage (DACCS) *(P2)*, and bioenergy production in combination with geological carbon storage (BECCS) *(P2)*.

Carbon dioxide capture and storage involves the separation of CO_2 from industrial and energy related sources or directly from the air and ensuring its long-term storage. Storage of CO_2 in deep, onshore or offshore geological formations is based on on available technology (IPCC, 2005) and is already commercialised in hydrocarbon fields, but also in saline formations at intermediate depth. In-situ mineral carbonation for permanently and safely stored CO_2 has been experimentally investigated. Rocks containing "basic" silicate minerals with a high proportion of Mg and Ca have greatest mineral carbonation potential because of their high molar proportion of divalent cations. These minerals are primarily found in basalt and mantle peridotite (Matter et al., 2011). In the case of **carbon dioxide capture and utilisation (CCU)**, carbon dioxide is captured and used for other chemical process.

In the case of **bioenergy with carbon dioxide capture and storage (BECCS)** (Fig. 3), biomass is used for energy production and instead of releasing the carbon dioxide to the atmosphere it is captured and stored or combined with other uses (CCU). However, the net CO_2 removal from the atmosphere through large-scale application of bioenergy with CCS and afforestation would rely on underground CO_2 storage and competition for land with food production and biodiversity protection (Vuuren et al., 2018). Therefore, the potential of such options is constrained by other sustainable development objectives.

The process of **direct air carbon dioxide capture (DAC)** involves two steps: first, CO_2 is extracted from ambient air or from point sources through a chemical reaction of air with solid or aqueous sorbents and second, CO_2 is released in concentrated form from the sorbents through heating. When releasing CO_2 from the sorbent, it can be captured and either stored or used (Keith et al., 2018). **Direct air carbon dioxide capture and storage** is a "chemical process by which CO_2 is captured directly from the ambient air, with subsequent storage" (IPCC, 2018). Besides the development of large utilities for DAC there are proposals for retrofitting air conditioners with DAC technologies (Dittmeyer et al., 2019). The captured CO_2 can be used, for example, for generating synthetic fuels. The energy and carbon balance as well as costs of such technologies are critical factors for assessing the scalability of DAC options for contributing to climate change mitigation.

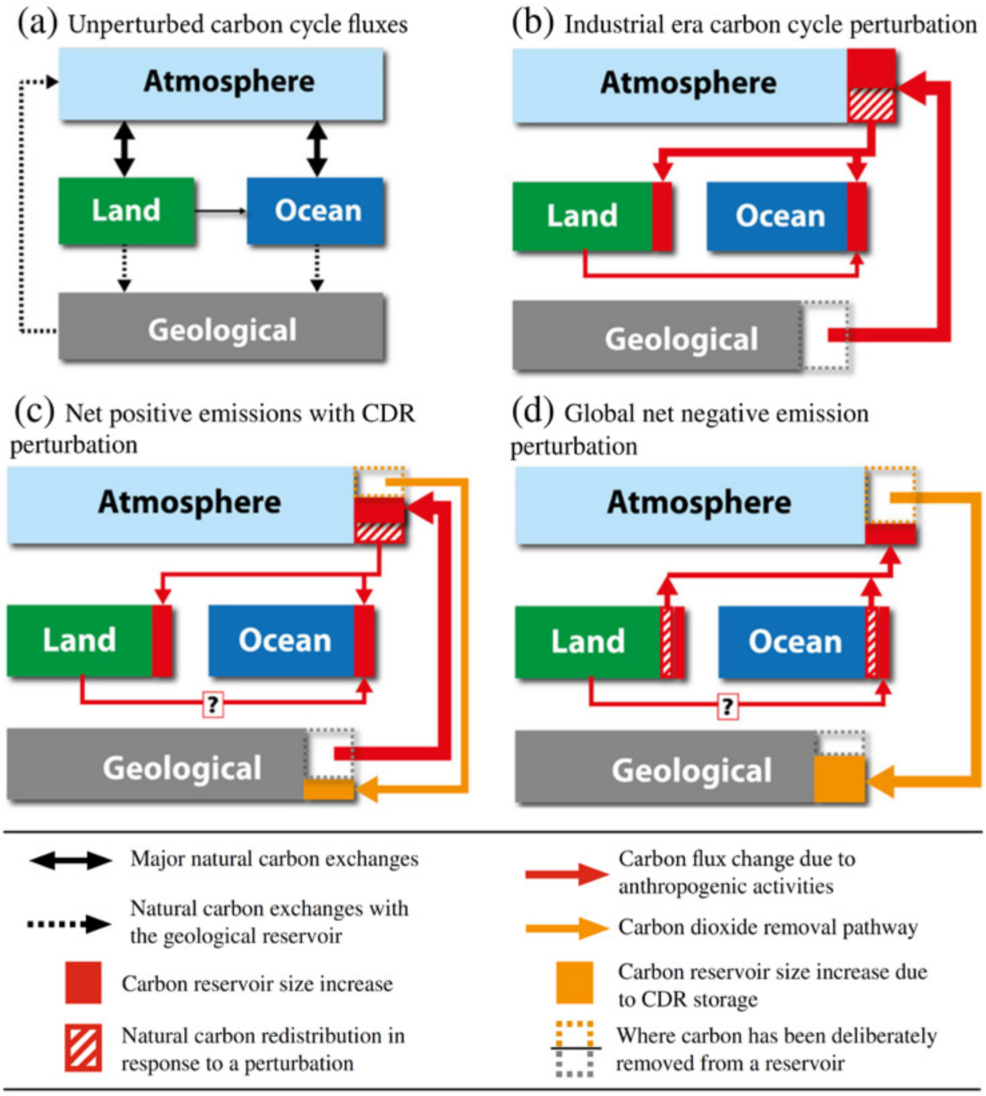

Figure 2: Main carbon flows among atmospheric, land, ocean, and geological reservoirs and the role of carbon dioxide removal. Natural carbon exchanges shown in a) (black arrows) also occur in b), c) and d). The industrial carbon cycle shown in b) is without CDR. The carbon cycle in c) includes CDR and the carbon cycle in d) includes CDR leading to net-negative emissions. Figure from Keller et al., 2018.

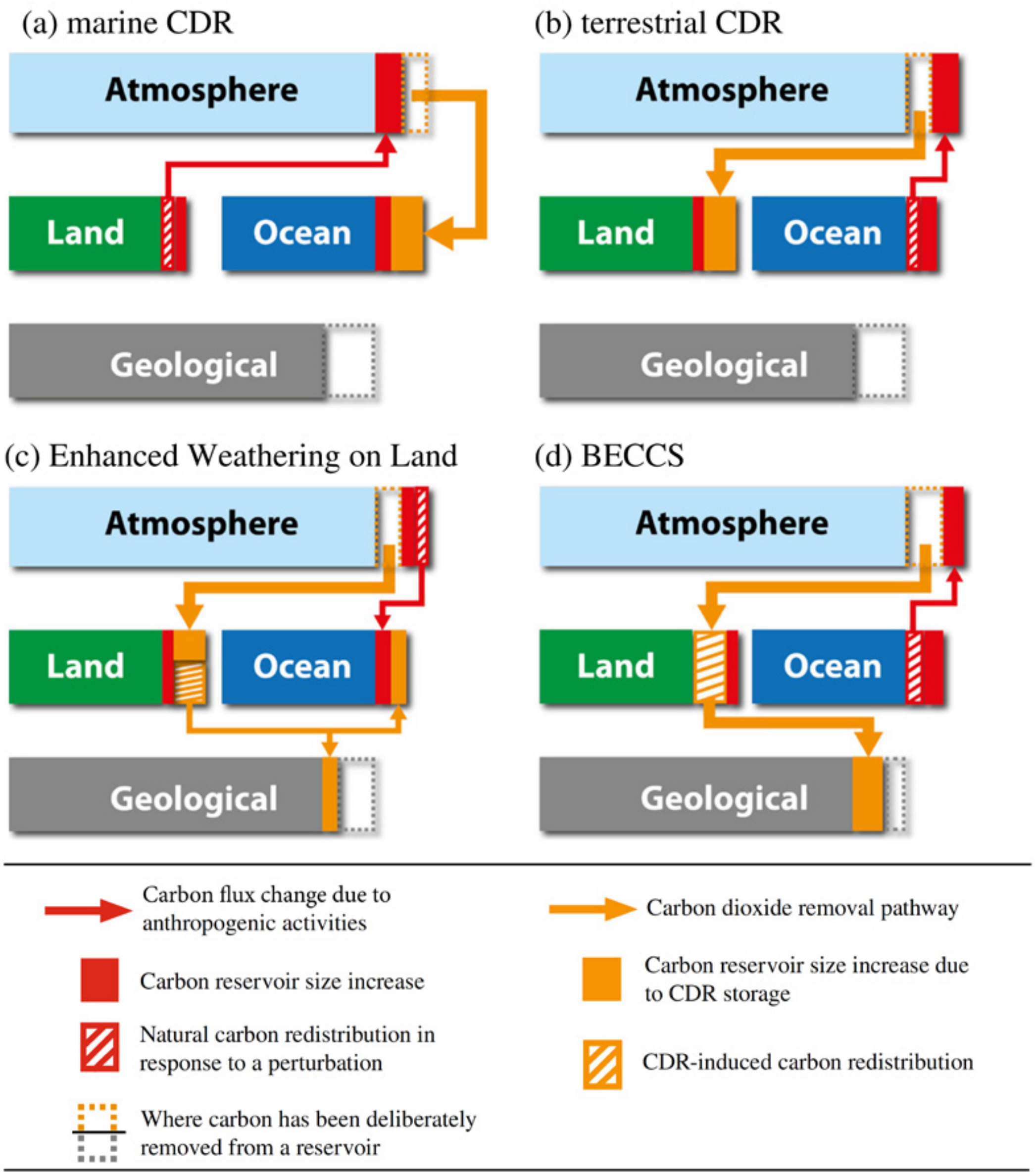

Figure 3: Main carbon flows for a) marine and b) terrestrial carbon dioxide removal, c) enhanced weathering on land and d) bioenergy with carbon dioxide capture and storage (BECCS). Figure from Keller et al., 2018.

PART B

ISSUES RELATED TO THE QUANTIFICATION OF AVOIDED AND REMOVED EMISSIONS

The quantification of the net-effect of human activities for mitigating climate change requires a systems perspective that includes information on the emission of greenhouse gas emissions along the entire process of the production and consumption of energy, goods, products and services (e.g. Life Cycle Assessments). This includes information on emissions involved in the business-as-usual scenario (e.g. carbon dioxide emission of conventional technologies or land-use practices) compared with the intervention (e.g. alternative technologies, land-use practices or behavioural changes).

Furthermore, factors that can undermine the effectiveness of human activities for achieving emission reductions include, for example:

- **carbon leakage** (e.g. shifting carbon emissions within the supply chain and/or to other countries instead of reducing and avoiding emissions),
- **rebound effects** (offset of resource efficiency by change in consumption), and the
- **permanence** of avoided or removed (negative) carbon emissions (the reduction of emissions over the long-term).

CARBON LEAKAGE

Carbon leakage can be the result from the implementation of a human intervention (e.g. implementation of a climate policy, change in technology or change in land-use practices), where carbon emissions are shifted to other places within production processes (e.g. shifting emission intensive practices to other countries). “Carbon leakage is defined as the increase in CO_2 emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries. It has been demonstrated that an increase in local fossil fuel prices resulting, for example, from mitigation policies may lead to the re-allocation of production to regions with less stringent mitigation rules (or with no rules at all), leading to higher emissions in those regions and therefore to carbon leakage” (IPCC, 2007).

The reverse effect of carbon leakage is the “import” of emissions via trade and import of products. While emissions are occurring in the country where production takes place, the consumption of many product is occurring in other countries. For carbon accounting, it is important to take into account emissions related to the production of products, even if they occur in other countries.

REBOUND EFFECT

Although a change in technology or resource efficiency can reduce emissions, this can be offset by behavioural changes known as rebound effect. The German Environment Agency (UBA) defines the rebound effect as: “Sustainable resource use necessitates efficient use of energy, raw materials and water. Increased efficiency allows products to be manufactured and services to be performed using fewer resources, and often at a lower cost. This in turn influences purchasing behaviour and product use.” … “Efficiency increase oftentimes reduces product or service costs, which can in turn ramp up consumption (due to reduced prices), thus partly cancelling out the original savings. This is known as the rebound effect.” (Umweltbundesamt 2020, URL: https://www.umweltbundesamt.de/en/topics/waste-resources/economic-legal-dimensions-of-resource-conservation/rebound-effects)

PERMANENCE OF AVOIDED OR REMOVED (NEGATIVE) EMISSIONS

The permanence of reduced or avoided emissions and of removed (negative) emissions relates to the issue of long-term storage of carbon in terrestrial and aquatic carbon sinks as well as in geological structures or chemical compounds in the case of carbon capture and storage.

In particular ecosystem-based activities for reducing and avoiding carbon emissions rely on long-term changes in management practices and the stability (permanence) of ecosystems to act as a carbon sink (e.g. carbon stored in tree biomass or other vegetation and carbon stored in soils).

Ecosystem-based measures (also described as nature-based solutions), such as forest conservation, reforestation and peatland restoration, can have a significant potential for avoiding carbon emissions and sequestering carbon dioxide from the atmosphere (negative emissions). However, ecosystems can also be degraded within a short time due to human pressures or damages caused by natural hazards (e.g. droughts, fire, pests). Furthermore, ongoing climate change can change ecological conditions with negative consequences for natural carbon sinks. Human activities, natural hazards and climate change can undermine the resilience of ecological carbon sinks and thereby reduce the permanence of the reduced, avoided and negative carbon emissions resulting from ecosystem-based activities.

The permanence of carbon in geological structures in the case of carbon capture and storage depends on the trapping mechanisms. Injection of CO_2 into suitable formations, at depths below 800 m, offers various physical and geochemical trapping mechanisms preventing CO_2 from migrating to the surface (IPCC, 2005). In general, an essential physical trapping mechanism is the presence of a cap-rock. The reaction of CO_2 with metal oxides, which are abundant in silicate minerals, produces stable carbonates. IPCC (2005) furthermore concluded that for well-selected, designed and managed geological storage sites, the vast majority of the CO_2 will gradually be immobilised by various trapping mechanisms and, in that case, could be retained for up to millions of years. Because of these mechanisms, storage could become more secure over longer time frames. In the case of mineral carbonation, the CO_2 stored will not be released to the atmosphere. Observations from engineered and natural analogues as well as models suggest that "... the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years" (IPCC, 2005).

A systems perspective is required in order to assess the net benefit of carbon dioxide removal, carbon capture utilisation, and carbon capture and storage technologies for reducing and removing greenhouse gas emissions. This includes the resources and energy required for such technologies as well as the greenhouse gas emissions occurring related to CDR, CCU and CCS processes (including carbon leakage in the sense of shifting technologies to other regions).

The glossary of IPCC (2018) contains more detailed definitions of the terminology used in this Project Briefing.

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The referenced project briefings and other results from the project Net-Zero-2050 are available here:

www.netto-null.org
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