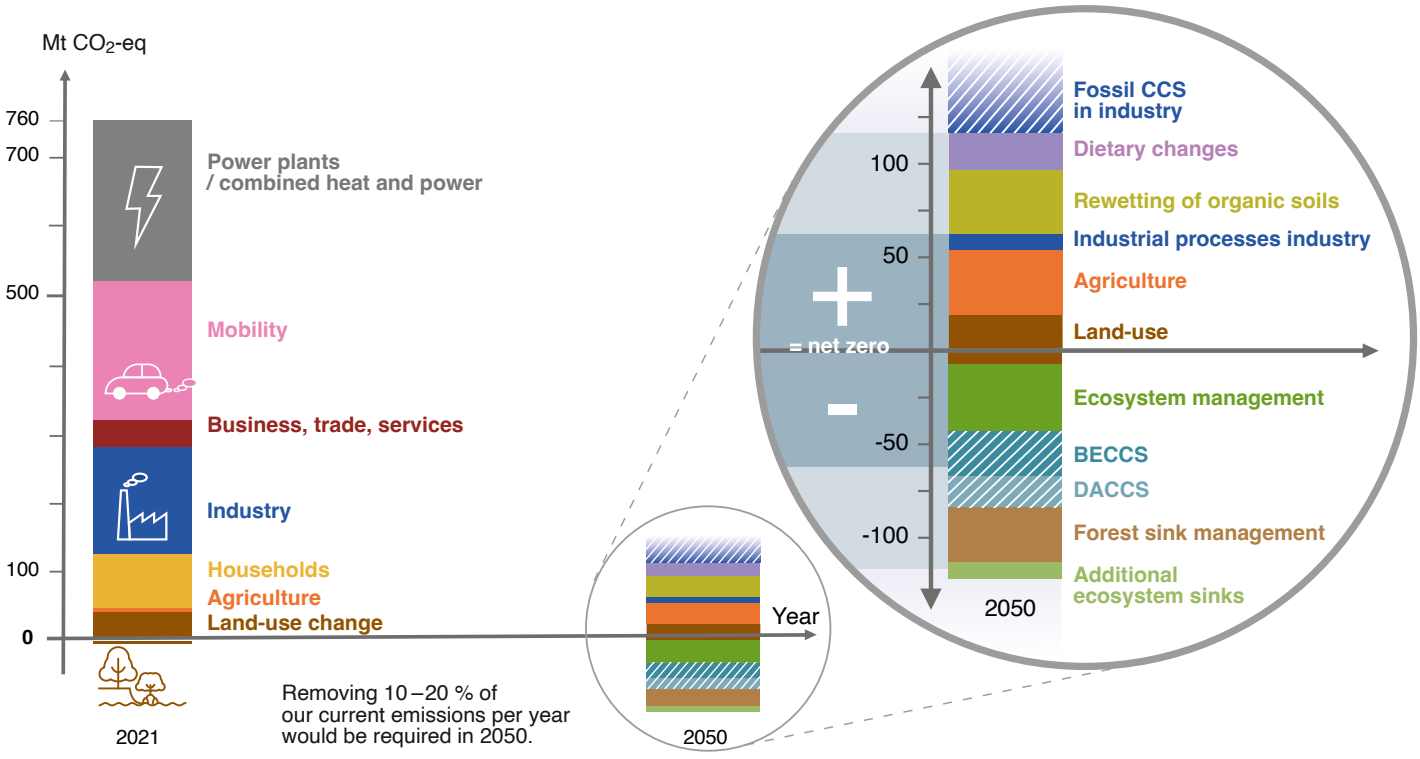
Background I: Societal pressure to act

Removing carbon dioxide from the atmosphere: urgently needed

Even with ambitious climate policies, Germany is still expected to release 10 to 20 percent of current greenhouse gas emissions within the next three decades, further driving global warming. One solution is to compensate these emissions through targeted carbon dioxide removal and storage.

The challenge: Net Zero carbon dioxide emissions

- There is a **consensus** in scientific climate research that humanity will only curb global warming and the resulting climate impacts and risks if it reduces its **carbon dioxide emissions** into the atmosphere to **net zero**.
- Human-caused carbon dioxide emissions result from the **burning of fossil fuels** such as oil, natural gas, and coal, and from **changes in land use**. So far, nobody knows how humankind can avoid 100 percent of these emissions in the future in an environmentally and socially responsible way.
- On the contrary, experts assume that Germany will still be emitting **residual carbon dioxide** and other greenhouse gases in the middle of the 21st century. In optimistic scenarios, their level is estimated at **10 to 20 per cent of current emissions**. This corresponds to annual emissions of about 60 to 130 million tonnes of greenhouse gases, most of which are methane and nitrous oxide.
- However, there is still **no social consensus** on how high possible residual emissions may be and which sectors may cause them. Currently, residual emissions are difficult to avoid, for example, in cement production, air and heavy goods transport, but also in agriculture and waste incineration.



Nadine Mengis, Rita Erven after: Anne Merfort, Miodrag Stevanović, Jessica Strefler (2023): Energiewende auf Netto-Null: Passen Angebot und Nachfrage nach CO_2-Entnahme aus der Atmosphäre zusammen? Kopernikus-Projekt Ariadne, Potsdam.

This graphic compares the emissions of the Federal Republic of Germany from the year 2021 with an emissions scenario for the year 2050, in which the country achieves its goal of a net zero emissions. The prerequisites for this are the avoidance of large quantities of emissions, a reduction in emissions in sectors that cannot completely avoid greenhouse gas emissions, and the removal of carbon dioxide from the atmosphere with the help of nature-based and technical approaches.

In search of: strategies for offsetting residual emissions

> Residual emissions will need to be offset with **some type of CO_2 removal** from the atmosphere. In addition, the release of some residual emissions can be prevented if the carbon dioxide is captured at the emission source and subsequently stored geologically. This is important for those industrial sectors that cannot currently avoid emissions of fossil origin. However, companies are not allowed to refer to the capture of carbon dioxide from fossil sources as carbon dioxide extraction. Here, a clear distinction must be made between prevented emissions and the quantities of carbon dioxide actually removed from the atmosphere.

> Many carbon dioxide removal and storage approaches are land-based. Since land is already a scarce resource, **ocean-based approaches** are being increasingly explored.

Ocean: what is its carbon dioxide uptake potential?

> The Earth's climate system has **physical, chemical, and biological processes** that remove carbon dioxide from the atmosphere and store it on land, in the ocean, or in the geological subsurface. The world ocean utilises these processes to such an extensive degree that it has buffered very large changes in atmospheric carbon dioxide concentrations throughout Earth's history. Because of its natural CO_2 uptake capacity, the **ocean is a major player in the global carbon cycle**. However, CO_2 uptake processes in the ocean and ocean floor occur on **long time scales**. Various proposed methods could accelerate such processes and thereby increase the ocean's carbon dioxide uptake rate.

CDRmare: Research provides answers

> In the interdisciplinary **research mission CDRmare**, researchers investigate a **broad spectrum of marine approaches for carbon dioxide removal and storage**.

> The scientists view the **ocean as a global, interconnected system**: changes in one area lead to interactions with other linked sub-areas and forms of use (e.g. fisheries and tourism). Only on the basis of a holistic research approach can the **potentials, costs, and risks** of human-enhanced carbon dioxide uptake by the ocean be realistically evaluated. It is important to understand which methods are applicable at all, under which local and global conditions they work, and which approaches should ultimately be eliminated. In this context, science has the task of providing **public and transparent information**. Which solutions may be used in the future must be negotiated politically and in society as a whole in an open debate.

The six CDRmare research consortia

> The research mission of the German Marine Research Alliance (DAM) CDRmare is composed of **six consortia**, in which various methods of marine carbon dioxide removal and storage are investigated and subsequently evaluated together with external experts. Important to know: All methods have **different carbon dioxide removal and/or storage potential** and have varying degrees of **technological readiness**.

> The six consortia are:

- Carbon dioxide removal by alkalinity enhancement: potential, benefits and risks (RETAKE).
- Searching for solutions for carbon-sequestration in coastal ecosystems (sea4soCiety).
- Submarine carbon dioxide storage in geological formations of the German North Sea (GEOSTOR)
- Road testing ocean artificial upwelling (Test-ArtUp)
- Alternative scenarios, innovative technologies, and monitoring approaches for sub-seabed storage of carbon dioxide (AIMS³).
- Assessment framework for marine carbon dioxide removal and synthesis of current knowledge (ASMASYS).

All marine research conducted within the mission is subject to German and international environmental regulations.

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