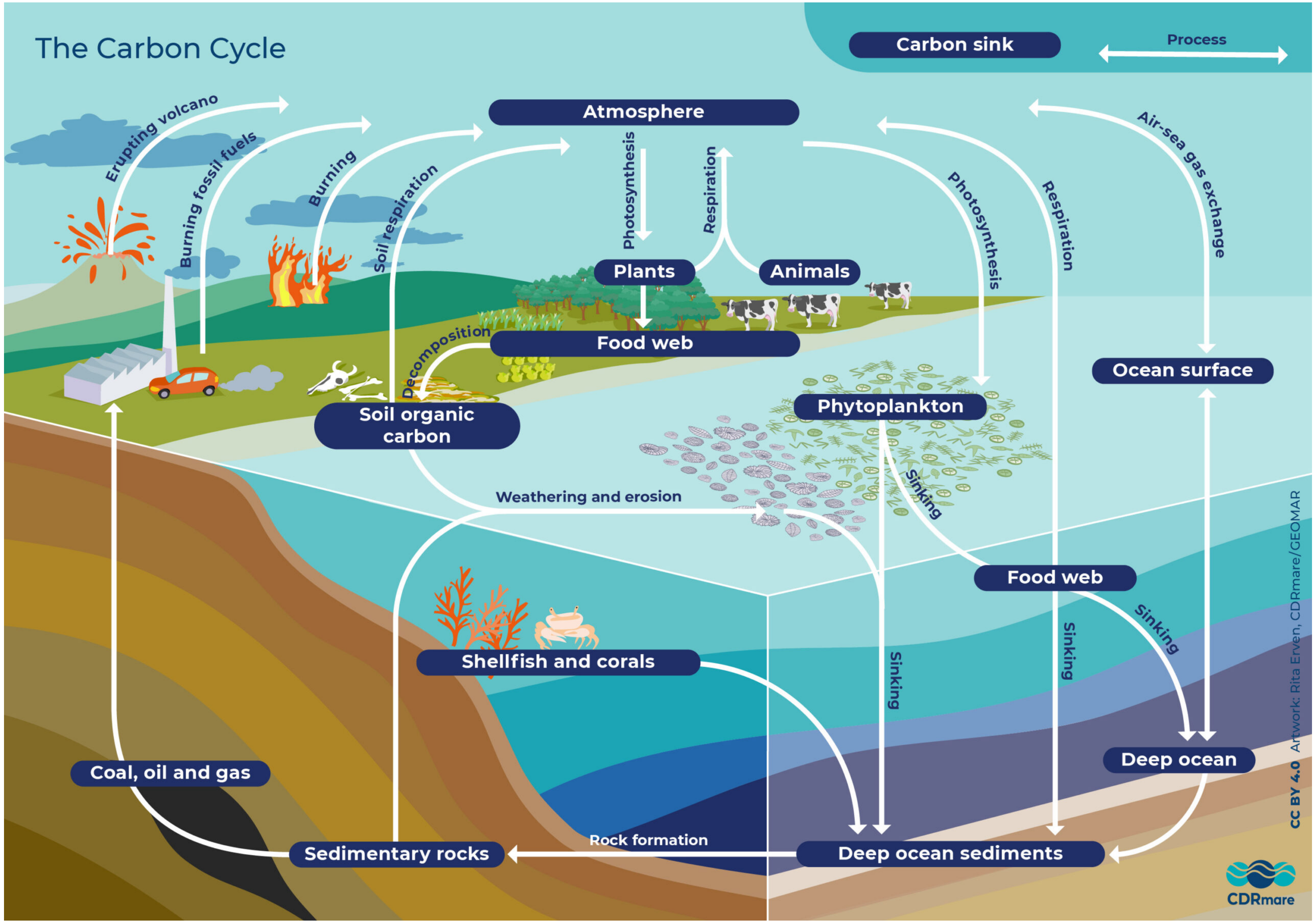
Photo by Markus Spiske on Unsplash

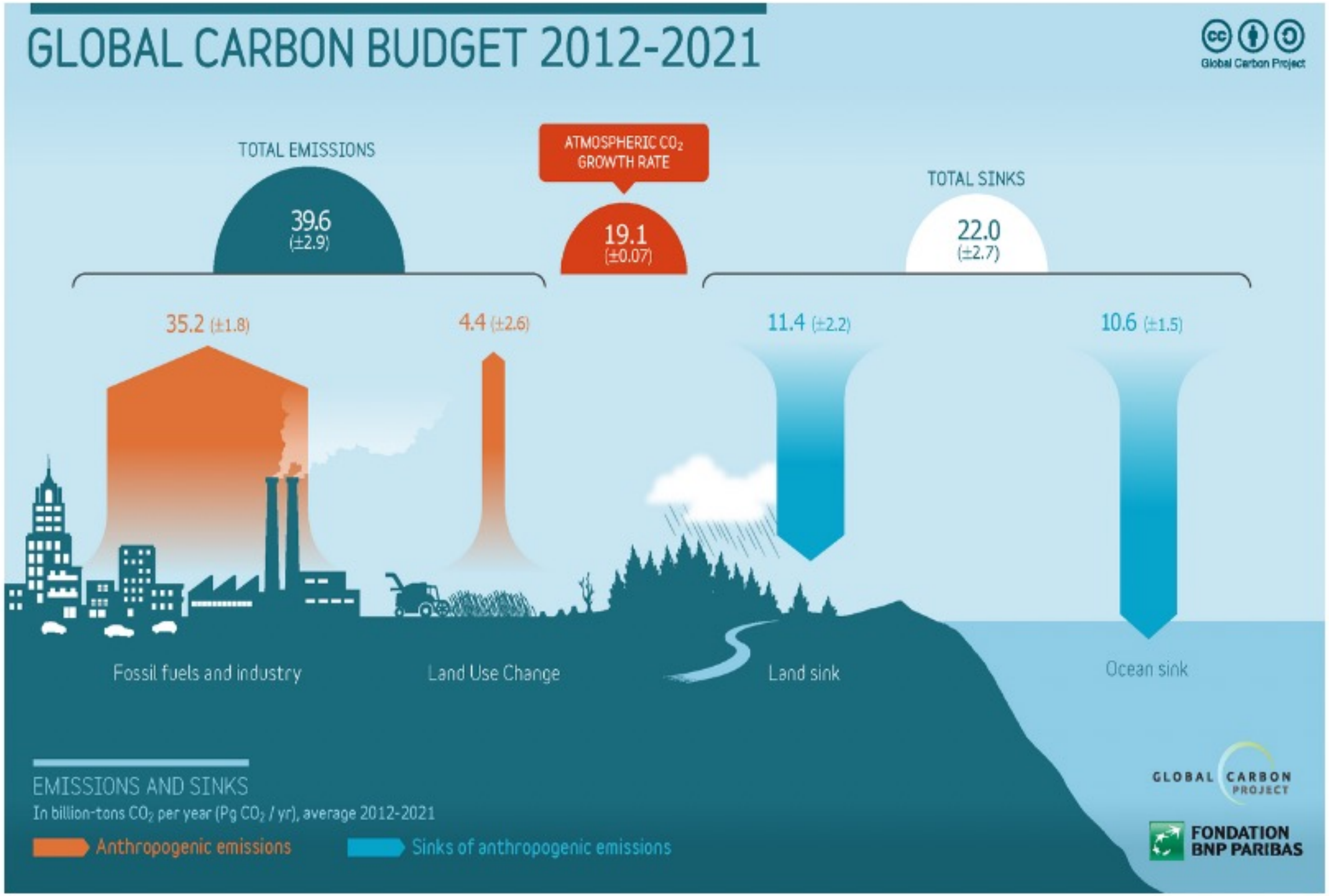
Is climate change mitigation enough?

Dr. Sally Soria-Dengg Ludwig-Maximillian University Munich

The Global Carbon Cycle



Anthropogenic Effects on the Global Carbon Cycle



Data source: Friedlingstein et al. 2022 Global Carbon Budget 2022. Earth System Science Data.

The Carbon Cycle Game

The Carbon Cycle Game

CDRSynTra CDRterra

Pre-Industrial Phase

ATMOSPHERE

1. You have been taken up for photosynthesis by a terrestrial plant. Go to **LAND PLANT.**
2. You have been taken up for photosynthesis by phytoplankton in the ocean surface. Go to **MARINE BIOTA.**
3. You diffuse into the surface of the ocean. Go to **SURFACE OCEAN.**
4. You have a long life-time in the atmosphere. Stay in the **ATMOSPHERE.**
5. You have been taken up for photosynthesis by a terrestrial plant. Go to **LAND PLANT.**
6. You have a long life-time in the atmosphere. Stay in the **ATMOSPHERE.**

LAND PLANT

1. The plant that takes you up respires you back into the **ATMOSPHERE.**
2. The plant that takes you up lives long and you are stored in its wood biomass. Stay in the **PLANT.**
3. The plant that takes you in is cut and made into firewood. You go back into the **ATMOSPHERE.**
4. The plant that takes you up dies and begins to decompose. Go to **SOILS.**
5. The plant that takes you up falls into a swamp and is buried by mud. You become coal. Go to **FOSSIL FUELS.**
6. The plant that takes you up has fungi in its roots, which fix more carbon into the soil. Go to **SOIL.**

SOIL

1. The soil you are in is undisturbed. You stay for a long time in the **SOIL.**
2. The organic matter you are a part of is decomposed by bacteria. You are oxidized and emitted back to the **ATMOSPHERE.**
3. You dissolve into the groundwater, move into a stream and flow into the **SURFACE OCEAN.**
4. You are incorporated into soil aggregates, which are stable and stored in the deeper soil for a long time. Stay in the **SOIL.**
5. You dissolve into the groundwater and are re-precipitated into the fractures of a **ROCK.**
6. You are absorbed by a bacterium, which respires you back into the **ATMOSPHERE.**

ROCKS

1. The rocks you are a part of are metamorphosed into marble. Stay in **ROCKS.**
2. The rocks you are a part of are subducted at a convergence zone. You get trapped in some melt and are erupted from a volcano. Go to the **ATMOSPHERE.**
3. The rocks you are a part of are buried. Stay at **ROCKS.**
4. The rocks you are a part of are metamorphosed into marble. Stay in **ROCKS.**
5. The rocks you are a part of is uplifted in mountains and you are exposed to weathering, erosion and oxidation. Go back to the **ATMOSPHERE.**
6. The rocks you are a part of are

SURFACE OCEAN

1. You are converted by your reaction with seawater to carbonate and taken up by calcifying organisms. Go to **MARINE BIOTA.**
2. You are carried with cold waters. Cold water can hold you better. Stay in the **OCEAN.**
3. You react with seawater and form bicarbonate. You cannot escape back to the air. Stay in the **OCEAN.**
4. The water you are in is transported to the deep. The current carrying you encounters a coastline and you are upwelled to the surface. You can escape back to the **ATMOSPHERE.**
5. You are transported to the deep ocean and carried with deep currents in the ocean for a long time. Stay in the **OCEAN.**
6. You are absorbed by a coral polyp, go to **MARINE BIOTA.**

MARINE BIOTA

1. The phytoplankton, which took you up from the air is eaten by fish, which respires you back to the **ATMOSPHERE.**
2. The organism that you are a part of dies and sinks to the seafloor. You are exposed to heat and pressure and you become **FOSSIL FUEL.**
3. The organism that you are a part of dies and sinks to the bottom. You become part of the carbonate deposits in the seafloor and later turn to **ROCKS.**
4. The organism that you are a part of dies in shallow water. As it decomposes, you are released back to the **ATMOSPHERE.**
5. The organism you are part of dies and clumps with other dead organisms. These sink to the seafloor turn to **ROCK** after millions of years.
6. The phytoplankton, which took you up respires you back to the **ATMOSPHERE**

FOSSIL FUELS

1. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.**
2. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.**
3. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.**
4. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.**
5. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.**
6. You are trapped in a bog and converted to peat. You are harvested to heat homes. You are released into the **ATMOSPHERE.**

The Carbon Cycle Game

CDRSynTra CDRterra

Industrial Phase	**ATMOSPHERE** 1. You have been taken up for photosynthesis by a terrestrial plant. Go to **LAND PLANT.** 2. You have been taken up for photosynthesis by phytoplankton in the ocean surface. Go to **MARINE BIOTA.** 3. You diffuse into the surface of the ocean. Go to **SURFACE OCEAN.** 4. You have a long life-time in the atmosphere. Stay in the **ATMOSPHERE.** 5. You have been photosynthesized by a terrestrial plant. Go to **LAND PLANT.** 6. You have a long life-time in the atmosphere. Stay in the **ATMOSPHERE.**	**LAND PLANT** 1. The plant that takes you in respires you back into the **ATMOSPHERE.** 2. The plant that takes you in lives long and you are stored in its woody biomass. Stay in the **PLANT.** 3. The plant that takes you in is cut and made into firewood. You go back into the **ATMOSPHERE.** 4. The plant that takes you in dies and begins to decompose. Go to **SOILS.** 5. The plant that takes you in is burned in a forest fire. You go back to the **ATMOSPHERE.** 6. The plant that takes you in is cut down and burned for charcoal. You go back to the **ATMOSPHERE.**	**SOIL** 1. The soil you are in is tilled exposing you to air. You are oxidized. Go back to the **ATMOSPHERE.** 2. The organic matter you were a part of was decomposed by bacteria. You are oxidized and emitted back to the **ATMOSPHERE.** 3. You dissolve into the groundwater, move into a stream and flow into the **SURFACE OCEAN.** 4. You are incorporated into soil aggregates, which are stable and stored in the deeper soil for a long time. Stay in the **SOIL.** 5. The soil you are in is eroded. You are exposed to air. Go to the **ATMOSPHERE.** 6. The soil you are in is drained and cultivated. You are exposed to air and oxidized. You are released into the **ATMOSPHERE.**
ROCKS 1. You are incorporated in a carbonate rock. You are mined and calcinated to produce cement. In the process you are released back to the **ATMOSPHERE.** 2. The rocks you are a part of are subducted at a convergence zone. You get trapped in some melt and are erupted from a volcano. Go to the **ATMOSPHERE.** 3. The rocks you are a part of are buried. Stay in **ROCKS.** 4. You are incorporated in a carbonate rock. Acidic rain reacts with the rock you are in and you are dissolved releasing you back to the **ATMOSPHERE.** 5. The rocks you are a part of is uplifted in mountains and you are exposed to weathering, erosion and oxidation. Go back to the **ATMOSPHERE.** 6. You are incorporated in a carbonate rock. You are mined and calcinated to produce cement. In the process you are released back to the **ATMOSPHERE.**	**SURFACE OCEAN** 1. You are converted by your reaction with seawater to carbonate and taken up by calcifying organisms. Go to **MARINE BIOSPHERE.** 2. The water carrying you is turning warmer and warmer. Warm water cannot hold you back. You are outgassed to the **ATMOSPHERE.** 3. The water you are in is transported to the deep. The current carrying you encounters a coastline and you are upwelled to the surface. You can escape back to the **ATMOSPHERE.** 4. You are transported to the deep ocean and carried with deep currents for a long time. Stay in the **OCEAN.** 5. The pH of the water is sinking. Seawater can hold less gases. You are outgassed to the **ATMOSPHERE.** 6. The water carrying you is turning warmer and warmer. Warm water cannot hold	**MARINE BIOTA** 1. The phytoplankton, which took you up from the air is eaten by fish, which respires you back to the **ATMOSPHERE.** 2. The organism that you are a part of dies and sinks to the seafloor. You are exposed to heat and pressure and turn, you become **FOSSIL FUEL.** 3. The organism that you are a part of dies and sinks to the bottom. You become part of the carbonate deposits on the seafloor and later turn to **ROCKS.** 4. The organism that you are a part of dies in shallow water. As it decomposes, you diffuse back into the **ATMOSPHERE.** 5. The organism incorporates you into its exoskeleton. The process of shell building releases CO_2. You are released back to the **ATMOSPHERE.** 6. The phytoplankton, which took you respires you back to the **ATMOSPHERE.**	**FOSSIL FUELS** 1. You are burned to fuel cars. Go to the **ATMOSPHERE.** 2. The fossil fuels you are a part of are buried. Stay at **FOSSIL FUELS.** 3. You are burned to fuel airplanes. Go to the **ATMOSPHERE.** 4. You are burned to heat houses. Go to the **ATMOSPHERE.** 5. You are burned in factories to produce fertilizer, cement and steel. Go to the **ATMOSPHERE.** 6. The fossil fuels you are a part of are in rocks that are uplifted and exposed. You are oxidized and released to the **ATMOSPHERE.**

The Carbon Cycle Game

Sample Results:

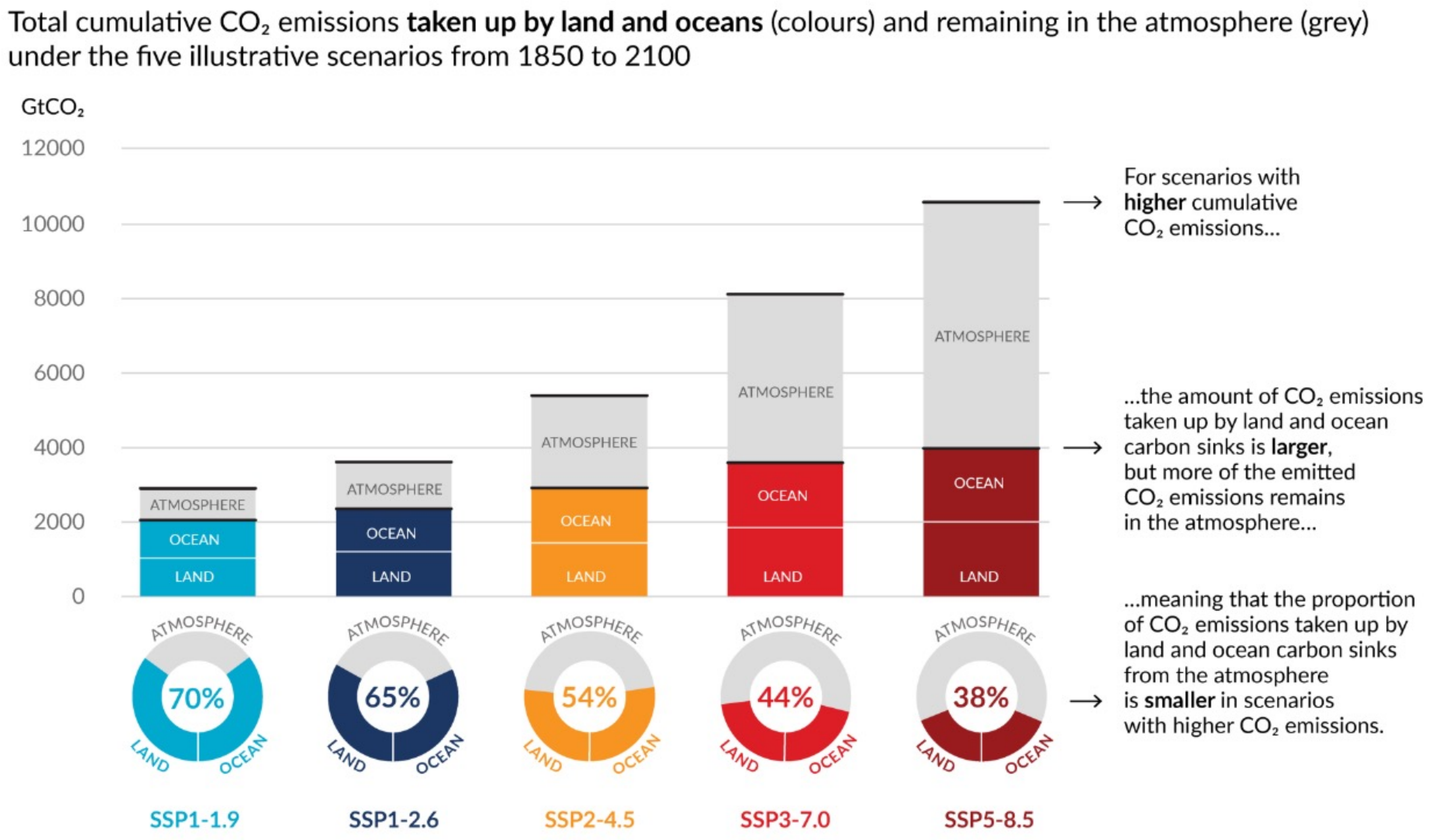
CASE 1 : All C atoms start in the atmosphere

CASE 2 : half the C atoms start in the atmosphere the other half as fossil fuel

CASE 1	Atmosphere	Other reservoirs except rocks and fossil fuels	Fossil Fuels
Pre-Industrial	28 (34%)	54 (66%)	
Industrial	58 (58%)	41 (41%)	
CASE 2	Atmosphere	Other reservoirs except rocks and fossil fuels	Fossil Fuels
Pre-Industrial	39 (42%)	53 (58%)	50
Industrial	76 (52%)	70 (47%)	9

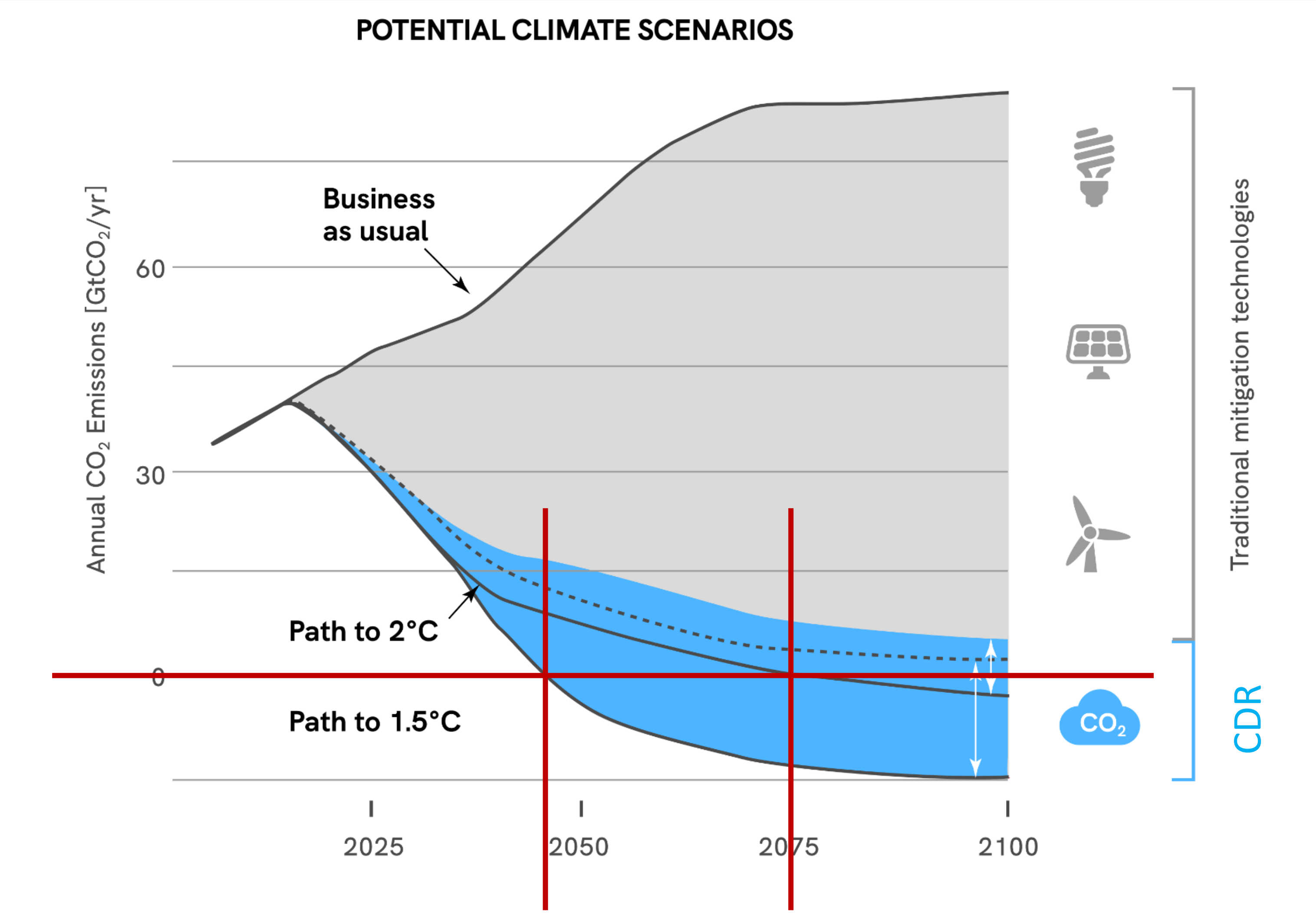
The proportion of CO_2 emissions taken up by land and ocean carbon sinks is smaller in scenarios with higher cumulative CO_2 emissions

Figure SPM.7



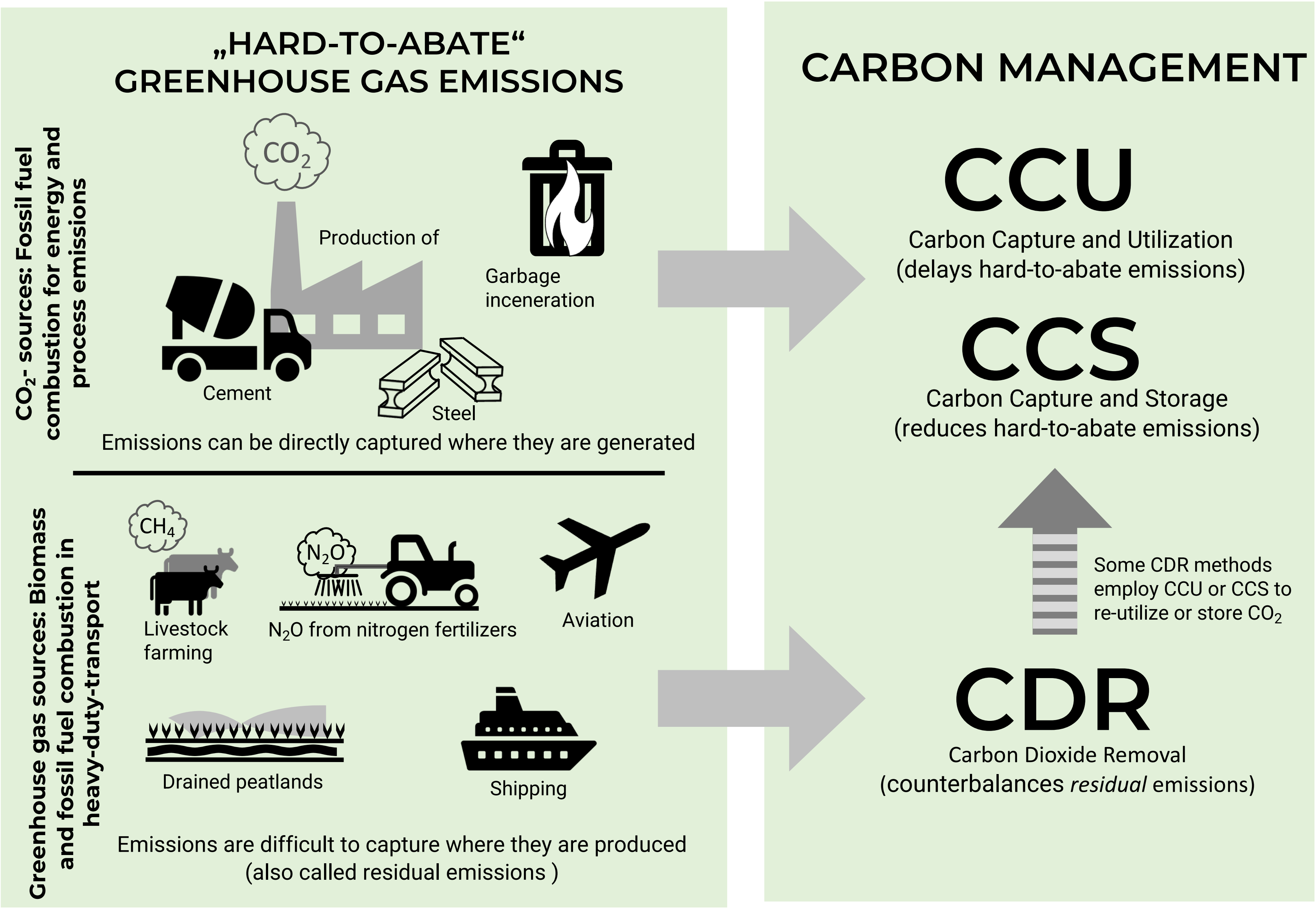
Emissions reduction vs. Carbon Dioxide Removal (CDR)

CDRSynTra CDRterra



Sources: IPCC Special Report 2018, The Conversation, MCC

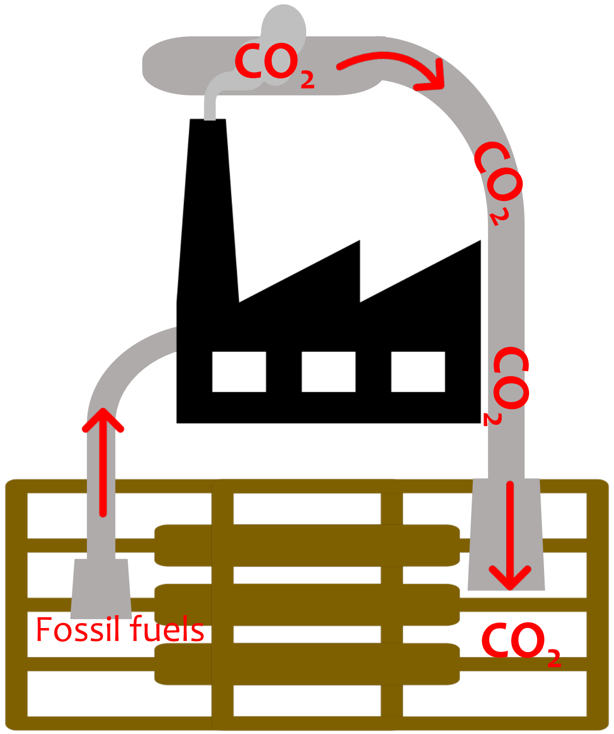
Hard-to-abate emissions



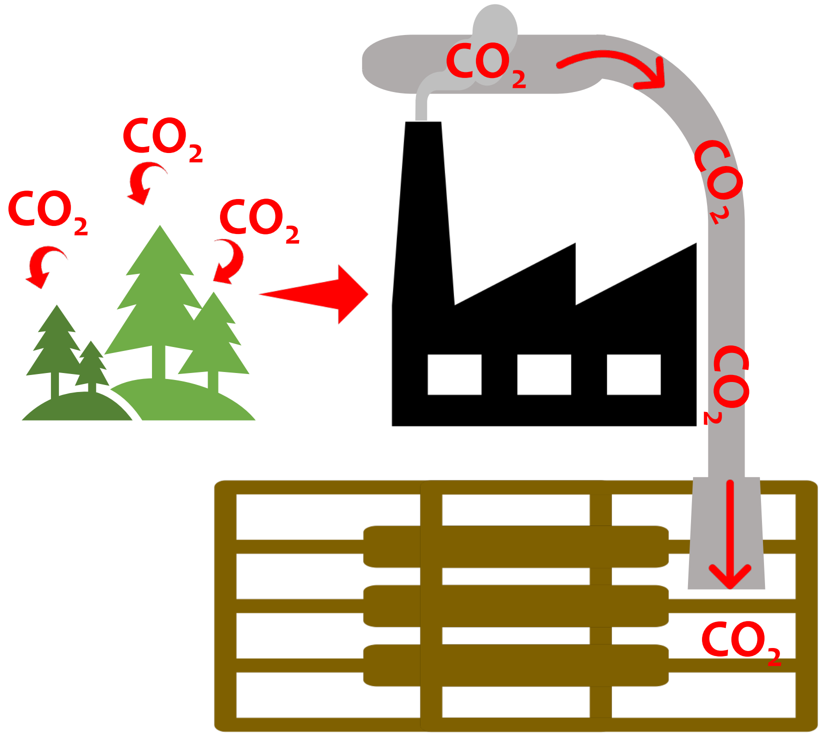
adapted from Schenuit et al. (2023): Carbon Management: Opportunities and risks for ambitious climate policy

Hard-to-abate emissions

Carbon Dioxide Capture and Storage (CCS) vs. Carbon Dioxide Removal (CDR)

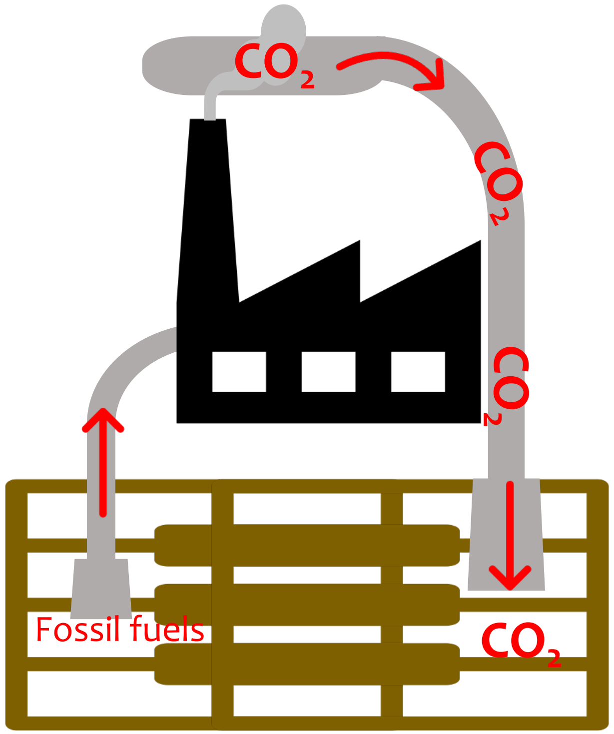


Zero CO_2 Emission
No change of CO_2 concentrations in the atmosphere



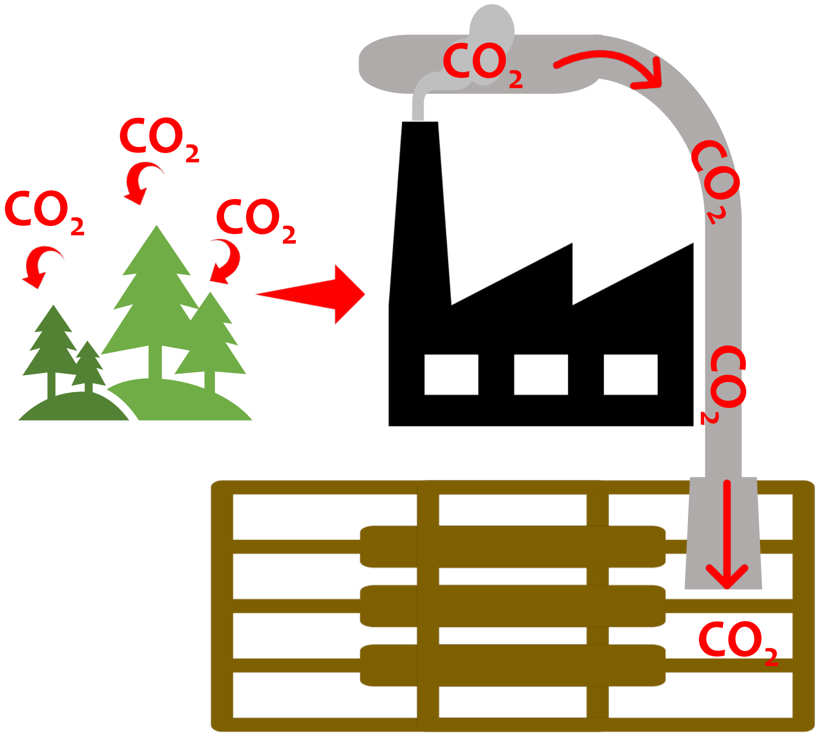
NETs
Reduction of CO_2 concentrations in the atmosphere

Carbon Dioxide Capture and Storage (CCS) vs. Carbon Dioxide Removal (CDR)



Zero CO_2 Emission

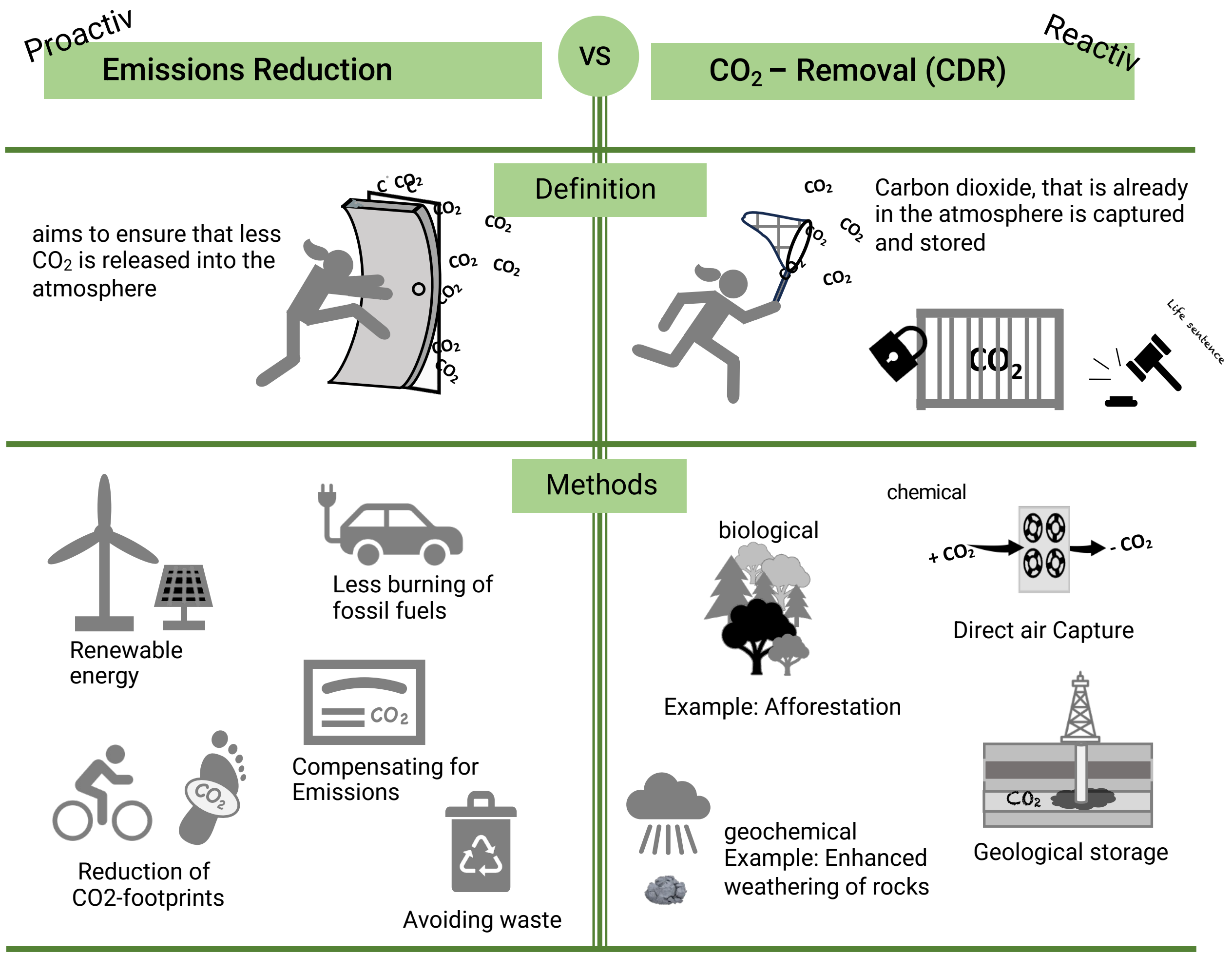
No change of CO_2 concentrations in the atmosphere



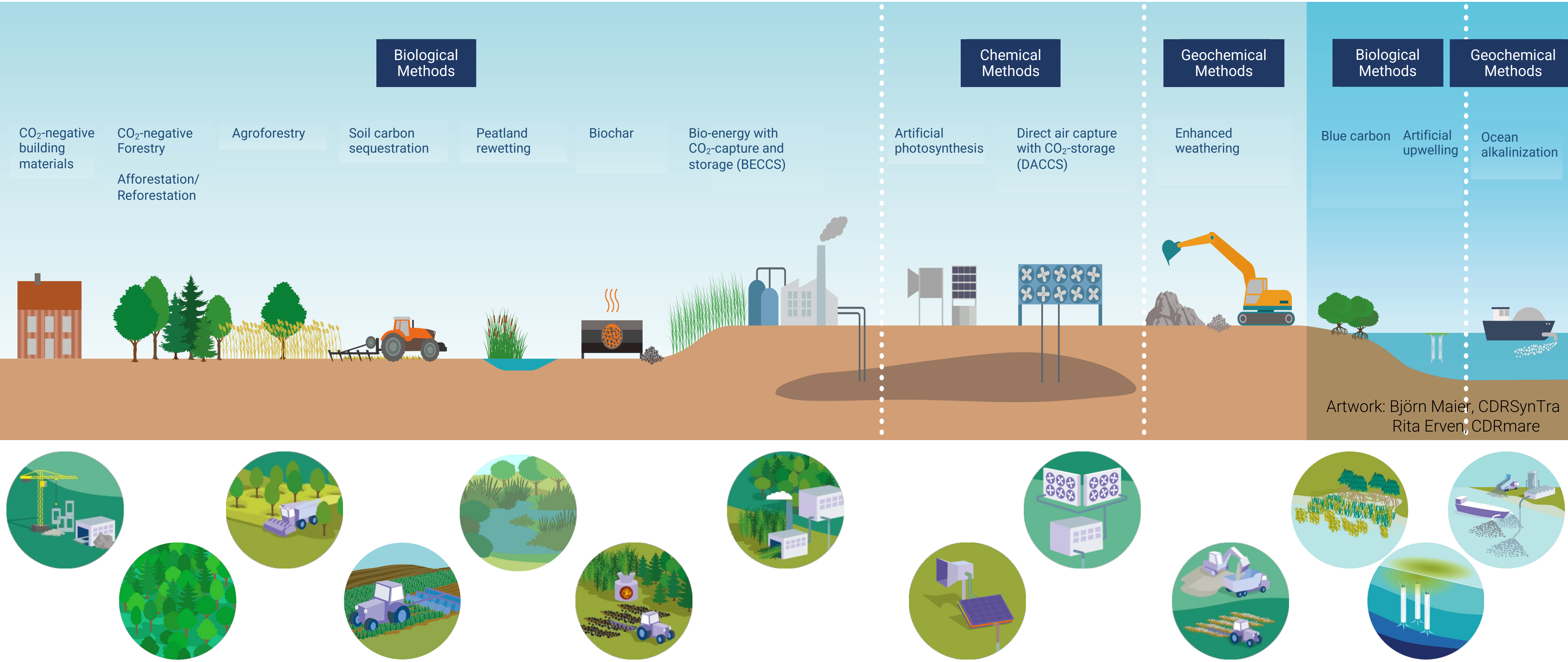
NETs

Reduction of CO_2 concentrations in the atmosphere

Emissions reduction vs. Carbon Dioxide Removal (CDR)



CDR Methods: an Overview

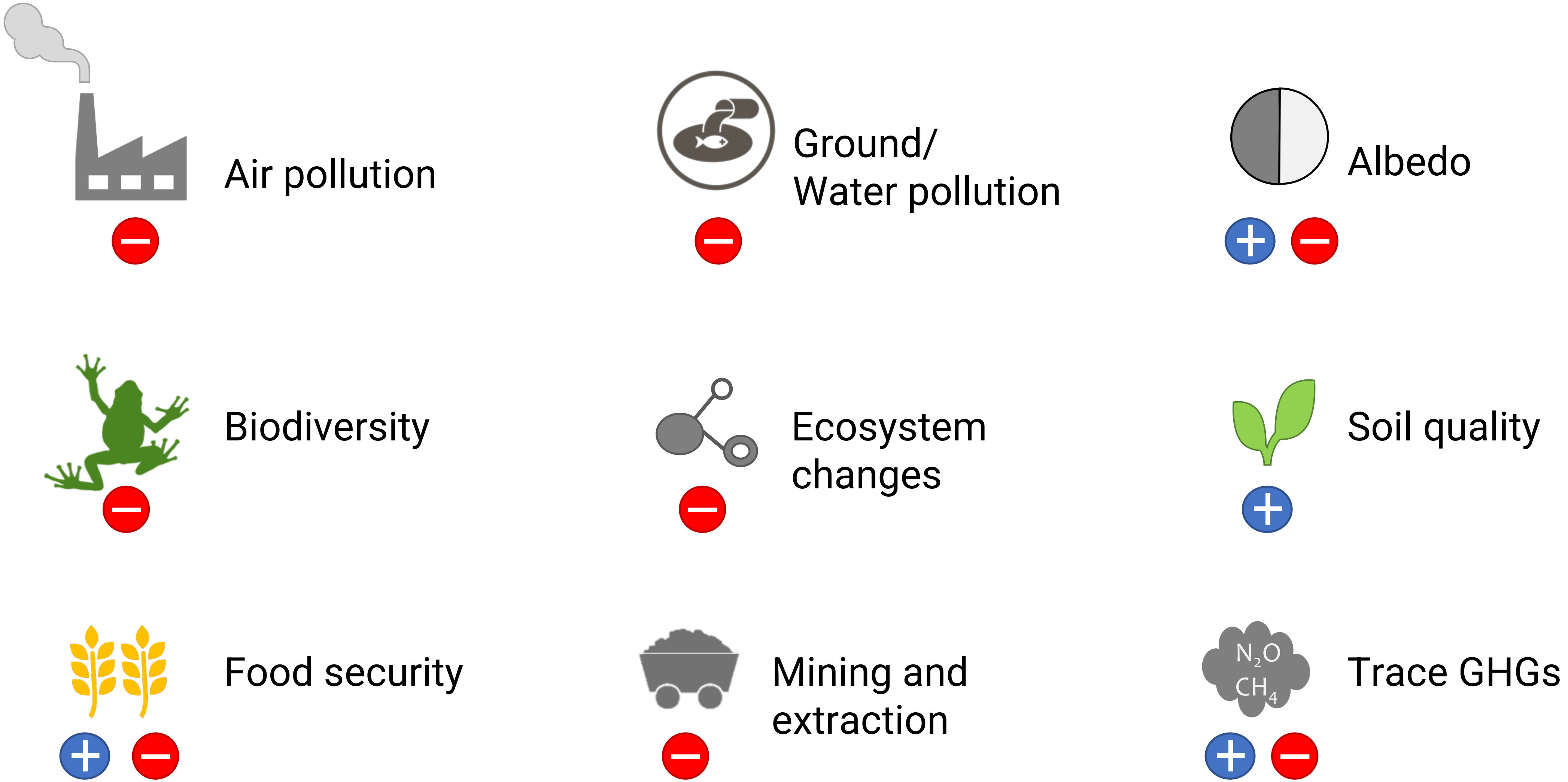


Possible Side Effects and Risks

CDR Method	Technical readiness 🟢 🟡 🔴	Side effects +	Side effects -	Permanence 🔒 🔓
Afforestation	🟢			🔓
BECCS	🟡			🔒
Biochar	🟡			🔒
Enhanced weathering	🟡			🔒
DACCS	🟡			🔒
Soil carbon sequestration	🟢			🔓

Minx et al., Environ. Res. Lett., 2018; Fuss et al., Environ. Res. Lett., 2018

Possible Side Effects and Risks



Minx et al., *Environ. Res. Lett.*, 2018; Fuss et al., *Environ. Res. Lett.*, 2018

Possible Side Effects and Risks

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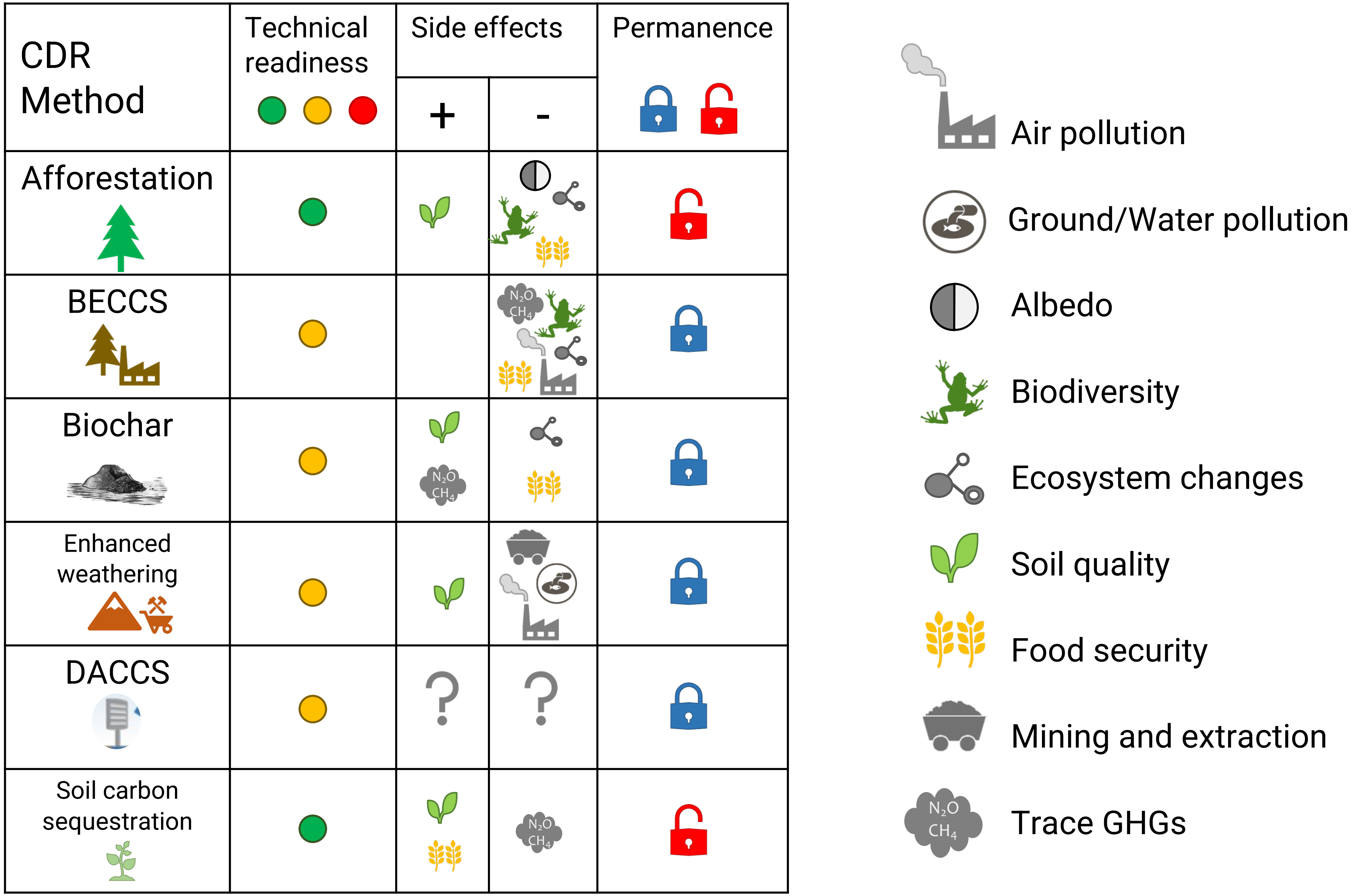
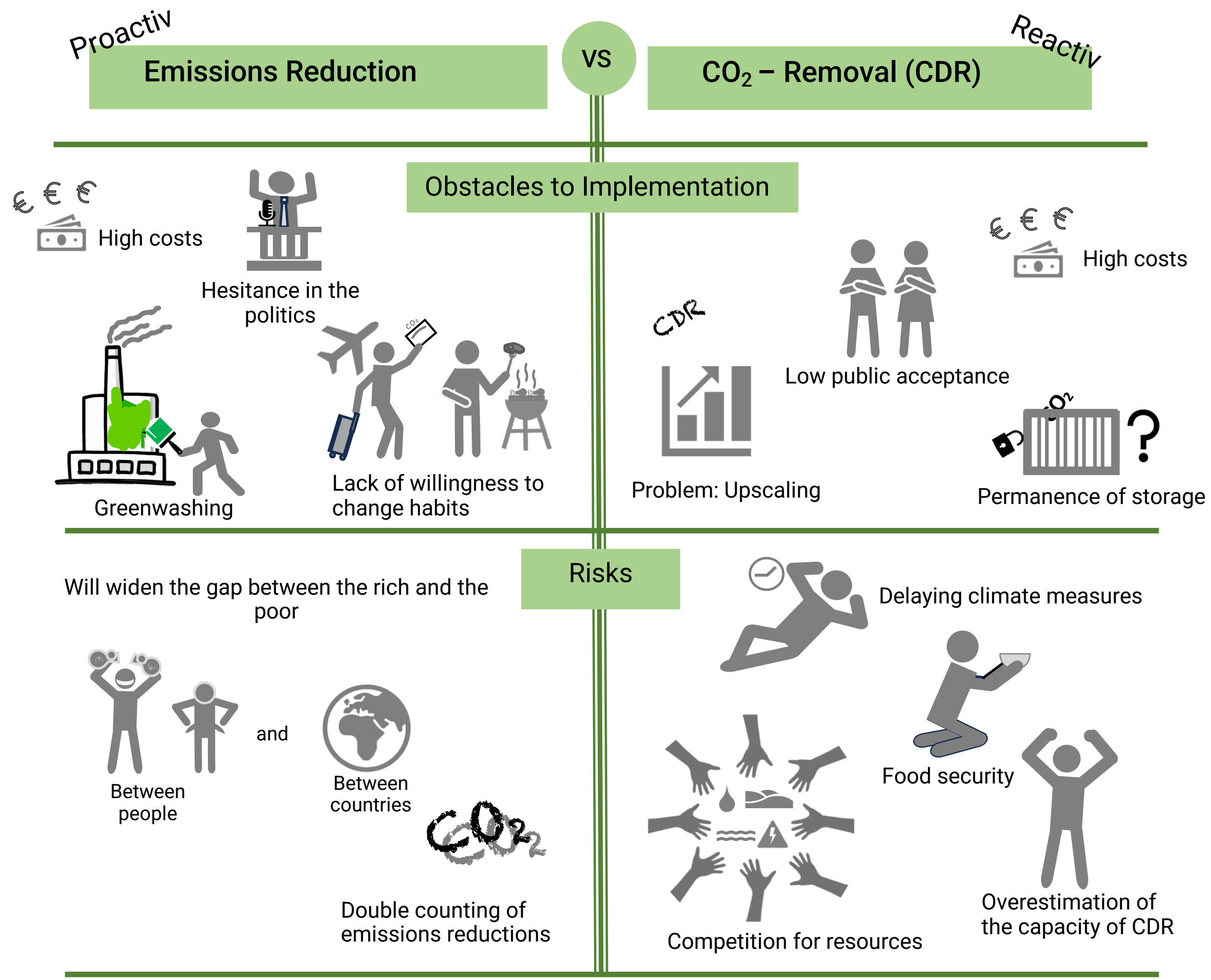


Minx et al., Environ. Res. Lett., 2018; Fuss et al., Environ. Res. Lett., 2018

Emissions reduction vs. CDR



Let‘s play

The CDR Simulation Game

CDR Simulation Game

Fact Sheets

CDRSynTra CDRterra

1

CDRterra

Afforestation/Reforestation/Forest restoration

Description
Afforestation:
establishment of new forests

Reforestation:
replacing cut trees on currently existing forests

Forest restoration:
improving conditions of existing degraded forests to re-establish forest structure, ecological structure and biodiversity

Additional benefits	increased biodiversity, flood and erosion prevention, improved soil health
Concerns	• competition with agriculture for land space • monocultures of CO_2 absorbing trees can threaten biodiversity • forests are vulnerable to fires, storms, diseases and pests. Destroyed forests can release sequestered CO_2 • forests may decrease albedo or warm the atmosphere due to evapotranspiration • saturation: old forests show zero net CO_2 uptake
Potential social impacts	• Added source of income for local communities in terms of firewood, medicine and recreation. • Improved air quality • Improved water quality

2

CDRterra

Bioenergy with Carbon Capture and Storage (BECCS)

Desription
This method involves two processes: First, biomass is converted into energy (heat, electricity or fuels) by combustion or fermentation. Second, the CO_2 emitted from energy generation is captured and stored in geological formations or used in other products where it is stored for a long time.

Additional benefits	produces energy for hard to decarbonise sectors, like aviation, shipping, cement, steel and aluminum industries
Concerns	• increased biomass production for bioenergy can: – cause competition with food production for land space – monocultures can threaten biodiversity – increase use of fertilizers – high water demand – may cause loss of soil carbon • combustion of biomass and use of biofuels can cause local air pollution
Potential social impacts	• less land space for food production may result in more expensive costs for foodstuff • less land can cause displacement of families

3

CDRterra

Biochar

Description
Biomass „burned" in a low-oxygen environment (pyrolysis) is turned into charcoal. Biochar is a kind of charcoal with many uses, as a soil additive among others. The carbon contained in biochar is in a very stable form and thus is stored for very long periods of time, even up to centuries.

Additional benefits	• adding biochar in soils improves soil health and the soil water and nutrient retention properties • burning biomass can produce energy for heat and electricity (biogas and bio-oil) • soils have a high capacity for storing biochar without detrimental effects on plants and crops
Concerns	• disturbing soils amended with biochar may release carbon captured in the biochar • adding biochars to soils can decrease albedo
Potential social impacts	• increased crop yield due to improved soil quality provides more income for farmers • „slash and char" a good alternative to „slash and burn" • easy to produce even in small scale

4

CDRterra

Enhanced Weathering or Mineralisation

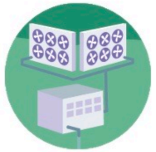
Description
Rocks like basalt or olivine are mined, finely powdered and spread on soils or in the ocean. These react with atmospheric CO_2 to form stable minerals in which the CO_2 is stored for long periods of time. Waste minerals from mining can also be used.

Additional benefits	• improved soil quality depending on what type of rocks are used • increased primary productivity in the ocean and/or increased ocean alkalinity reducing ocean acidification and increasing the capacity of the ocean to take up CO_2
Concerns	• requires extensive mining and processing of raw materials • enormous energy costs for turning rocks to powder • possible leaching of unwanted metals into soils or groundwater
Potential social impacts	• health hazards caused by increased dust in the environment due to extensive mining and when spreading powdered rocks in the fields. • deterioration of landscape because of extensive mining.

5

CDRterra

Direct Air Capture with Carbon Storage (DACCS)



Description
CO_2 is mechanically collected directly from the atmosphere and converted to liquid or solid CO_2-containing compounds. The CO_2 can be re-extracted and used for products like synthetic fuels, carbonated beverages or in greeenhouses, or can be stored in geologic reservoirs.

Additional benefits	• does not require large tracts of land; no competition with food production • extracted CO_2 can be used to manufacture long-lasting "low-carbon" products like low-carbon cement: CO_2 recycling
Concerns	• high energy costs • depending on the product, recycled CO_2 is not removed from the atmosphere • transport of captured carbon to final storage site requires complex logistics (pipelines, cargo ships) and fuel • injection of CO_2 in geologic formations may cause earthquakes, ground heaving may affect underground minerals
Potential social impacts	• additional jobs in the new technology • CO_2 may leak from underground storage and may contaminate groundwater and drinking water

CDRterra

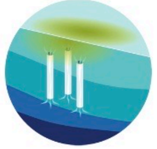
Soil Carbon Sequestration

Description
Increasing the capacity of soils to store more carbon by improving and modernising management practices specially for agricultural lands. Examples: switching to low-till or no-till farming, crop rotation, planting covercrops, use of compost, agroforestry, management of grazing. on: Also known as „carbon farming" or „regenerative agriculture".

Additional benefits	increased biodiversity, increased climate resilience of crops, increased soil quality, reduced fertilizer use, improved crop quality, can counteract desertification
Concerns	• saturation: soils have a limited capacity to store carbon • reversibility: carbon can be released to the atmosphere if the soil is disturbed. • release of nitrogen oxides to the atmosphere
Potential social impacts	• improved food quality • more income for farmers due to improved farm yields • need for new capital to acquire new equipment if farming practices are altered • improved livelihood

CDRterra

Artificial Upwelling



Description
The effectiveness of the biological pump in removing CO_2 from the atmosphere is enhanced by artificially transporting cold, nutrient-rich deep water to the surface. This stimulates the growth of otherwise nutrient-limited microalgae, which absorb CO_2 through photosynthesis. The assimilated carbon is passed on to other organisms via the food web and ultimately ends up on the sea floor after the organisms die, where it is stored for decades up to centuries.

Additionnal benefits	• Cold water from the deep can absorb more CO_2 when it is pumped to the surface. • Cold water from the deep usually has high alkalinity and can therefore increase the CO_2 removal potential of the surface water. • Depending on the location, deep water can contain less CO_2 and can absorb more CO_2 than surface water.
Concerns	• can affect the structure of plankton communities and thus influence local food webs. • depending on the location, deep water may contain more CO_2 than surface water. This can lead to CO_2 degassing. • can only be emissions-negative if the pumps used are powered by renewable energy.
Potential social impacts	• can improve fish yields due to higher primary productivity

CDRterra

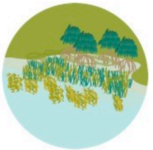
Carbon Storage in Geological Formations

Description
Carbon dioxide captured directly from the atmosphere (DAC) or at the source of emissions such as factories and bioenergy plants (BEC) is permanently stored in deep rock formations. These can be sandstone or basalt. The process of carbon capture and storage is also known as CCS (Carbon Capture and Storage).

Additional benefits	• The technical feasibility of the method is tried and tested and has been used for decades. • There is sufficient CO_2 storage capacity in the deep underground.
Concerns	• Leakages: some of the stored CO_2 or heavy metal containing water from the rock formation can escape through cracks in the rock on the seabed. • Earthquakes can possibly be triggered by disturbing the stability of the storage rock formation. • Noise caused by the exploration or construction of storage sites can affect marine mammals.
Potential social impaacts	• Conflicts with other forms of ocean utilisation such as fishing, shipping and wind farms

CDRterra

Carbon Storage in the Coastal Zone

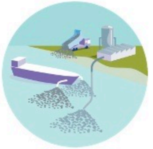


Description
Blue carbon is carbon stored in the plants and sediments of wetlands such as mangroves, mudflats, salt marshes and seagrass beds. The regeneration and expansion of these wetlands, which have been damaged by human activities, has the potential to sequester and store CO_2 from the atmosphere.

Additional Benefits	• Increase biodiversity • Protection of the coast against storms, flooding and erosion • Improvement of water quality • Protection of land against the effects of sea level rise
Concerns	• Even intact mangroves release methane into the atmosphere. Methane is a potent greenhouse gas. • Wetlands (like forests) can only store a limited amount of carbon. • The stored carbon is released again when the wetland is disturbed.
Potential social impacts	• Additional jobs are created in tourism. • More productive ecosystems mean more income for local fishermen • Expansion of the wetlands can lead to conflicts with the local population over the use of the claimed area (e.g. national parks, wind parks, aquaculture)

CDRterra

Ocean Alkalinity Enhancement



Description
The ability of the ocean to absorb CO_2 depends on the level of its alkalinity. This is determined by the minerals dissolved in it from weathered rocks. The alkalinity of the ocean can be artificially increased by the addition of such minerals. According to model calculations, this can increase the CO_2 absorption capacity of the ocean.

Additional advantages	• counteracts ocean acidification • facilitates the protection and restoration of important habitats such as coral reefs and mussel beds
Concerns	• Supersaturation of the ocean with alkaline minerals can lead to the precipitation of lime, a process, which releases CO_2. • Some rocks may contain toxic metals that can affect the environment or alter the plankton community. This has unpredictable consequences for biodiversity.
Potential social impacts	• The noise and dust pollution that often accompany mining activities often lead to local environmental and health concerns. • Unforeseen accompanying biogeochemical processes can affect fish stocks and have a major impact on the livelihood of local fishermen.

CDR Portfolio

Line									
1	**CDR (Carbon Dioxide Removal) Portfolio** Starting Budget of each Group 800 million Euro								
2	Methods		Affores-tation	BECCS	En-hanced rock weathe-ring	Artificial upwelling			
3	max. Potential ($Mt\ CO_2$/Year)		2	12	4	10			
4	Cost (Mio €/ $Mt\ CO_2$)		30	160	135	40			
5	Investment (€ Mio)								Sum
6	Target amount of CO_2 to be removed ($Mt\ CO_2$/year)								Sum
7	Amount of CO_2 effectively removed ($Mt\ CO_2$/year)	2025-2030 (Phase 1)							Sum (x5)
8		2031-2035 (Phase 2)							Sum (x5)
9		2036-2040 (Phase 3)							Sum (x5)
10		2041-2045 (Phase 4)							Sum (x5)
11		2046-2050 (Phase 5)							Sum (x5)
12	Sum of CO_2 effectively removed in 25 years (Mt)								Total

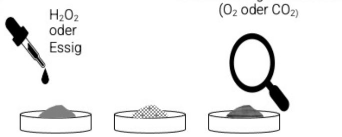
Experiments

Die Stabilität des Kohlenstoffs in Pflanzenkohle

Was du brauchst:
Pipette, Petrischalen, 3%-iges Wasserstoffperoxid (H_2O_2), Essig, Lupe oder Mikroskop,, Pflanzenkohle (Biochar), Holzasche, Holzspäne.

- Gib die gleiche Menge an Pflanzenkohle, Holzasche und Holzspänen in separate Petrischalen.
- Gib zu den Proben ein paar Tropfen H_2O_2 bzw. Essig.
- Beobachte die Blasenbildung in jeder Probe mit der Lupe oder unter dem Mikroskop.

Versuchsaufbau

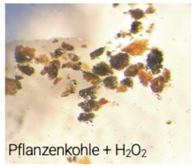


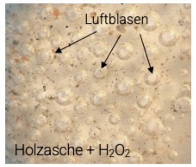
Zu erwartendes Ergebnis:
Je nach Form des Kohlenstoffs reagiert er mehr oder weniger mit H_2O_2 und Säure. Eine der reaktivsten Formen von Kohlenstoff ist Kalziumkarbonat ($CaCO_3$). Wenn H_2O_2 oder Säure zu Kalziumkarbonat zugegeben wird, erfolgen diese Reaktionen:

$$2H_2O_2 + 2CaCO_3 \longrightarrow 2H_2CO_3 + 2CaO + \mathbf{O_2}$$

$$2CH_3COOH + CaCO_3 \longrightarrow Ca(CH_3COO)_2 + \mathbf{CO_2} + H_2O$$

Die beobachteten Blasen sind je nach zugegebener Substanz entweder Sauerstoff oder Kohlendioxid.

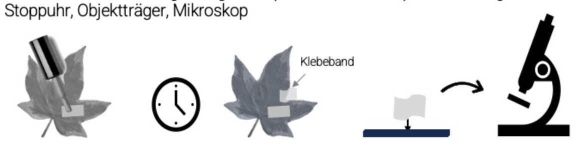




- H_2O_2 kommt im Boden natürlich vor. Es kann durch Enzyme zu Sauerstoff und Wasser abgebaut werden. Auch Kohlenstoff kann H_2O_2 abbauen.
- Holzasche entsteht durch Verbrennung und Biochar durch Pyrolyse (das Erhitzen organisches Materials unter Ausschluss von Sauerstoff).
- Die meisten Blasen werden bei der Zugabe von H_2O_2 und Essig in der Holzasche gebildet, da ein großer Anteil des Kohlenstoffs in Holzasche als reaktivem Kalziumkarbonat (Ca**CO**$_3$) vorkommt. In Pflanzenkohle und in Holzspänen ist er in aromatischen Verbindungen festgebunden und reagiert mit H_2O_2 und Essig nicht.
- Holzspäne können durch bakterielle Abbauprozesse abgebaut werden, wobei unter O_2-Verbrauch CO_2 freigesetzt wird.

Wie Pflanzen atmen

Was du brauchst:
Efeublätter, durchsichtiger Nagellack (schnell trocknend), durchsichtiges Klebeband, Stoppuhr, Objektträger, Mikroskop

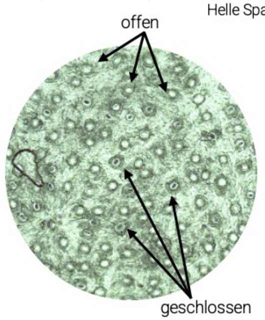


1. Nagellack auf der Unterseite des Blattes auftragen
2. Ein paar Minuten Warten
3. Klebeband auf dem Nagellack anbringen
4. Klebeband vorsichtig vom Blatt abziehen und auf einem Objektträger kleben
5. Stomata unter dem Mikroskop beobachten und zählen

Den Versuch variieren:
Vergleiche die Anzahl der geöffneten und geschlossenen Spaltöffnungen (Stomata) in Blättern, die noch an der Pflanze hängen (frisch), frisch von der Pflanze abgeschnitten wurden (nass) und 6 Stunden zuvor abgeschnitten wurden (trocken).

Zu erwartendes Ergebnis:

Helle Spaltöffnungen sind offen und dunkle sind geschlossen.



Beispielergebnisse:

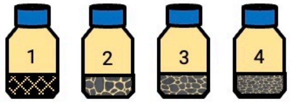
Stomata	% geschlossen	% offen
Frisch	20	80
„nass"	24	76
„trocken"	70	30

- Spaltöffnungen (Stomata) regulieren den Gas- und Wasseraustausch zwischen dem Blatt und der Umgebung.
- Um großen Wasserverlust und Austrocknung während trockenen Perioden zu verhindern, schließen sich mehrere der Stomata.
- Dennoch wird gewährleistet, dass der Gasaustausch weiterhin stattfindet, sodass Photosynthese und Atmung nicht verhindert werden.

Wie beschleunigte Verwitterung von Gesteinen funktioniert

Was du brauchst:
Glasflaschen mit Deckeln, Trinkhalm, Universal pH-Indikator, Gartenerde, Urgesteinsmehl (UGM)

- 5 Teile Erde mit 1 Teil Urgesteinsmehl mischen.
- Erde-Gestein-Gemisch in die Flaschen geben.
- Mit Universal Indikator versetztes Leitungswasser hinzugeben. Deckel aufsetzen, mischen und über Nacht stehen lassen.



1 Erde und 2,3,4 Erde + Urgesteinsmehl.
Urgesteinsmehl zu unterschiedlichen Partikelgrößen sieben:
(2 grob, 3 mittel, 4 fein)

Den Versuch variieren:
Das Leitungswasser kann mit oder ohne Zugabe von CO_2 vorbereitet werden. In ein separates Becherglas Leitungswasser füllen und mit dem Trinkhalm Luft hineinblasen. Das Probewasser mit Universal pH-Indikator versetzten.

Zu erwartendes Ergebnis:

Anfangszustand

nach 24 Stunden

1 Gartenerde
2 Gartenerde + UGM grob
3 Gartenerde + UGM mittel
4 Gartenerde + UGM fein
5 UGM grob
6 UGM mittel
7 UGM fein

pH Skala
Sauer -------- Basisch

- In dem Glas ohne Gesteinsmehl (1) bleibt das Wasser sauer. Auch durch mikrobielle Atmung in der Erde wird mehr CO_2 ins Wasser freigegeben.
- Durch Zugabe von Gesteinsmehl (2,3,4) wird das Wasser basisch, und zwar desto mehr je feiner das Gesteinsmehl ist.
- In den Flaschen mit nur Gesteinsmehl (5,6,7) ist das Wasser basischer als in den Flaschen mit Erde. In der Flasche mit feinem Gesteinsmehl (7) ist das saure Wasser gleich nach der Zugabe basisch geworden.
- Je feiner die Partikel des Gesteinsmehls sind, desto schneller wandelt sich das Wasser in dem Glas von sauer zu basisch. Die feineren Partikel bieten eine größere Oberfläche, die mit CO_2 reagieren kann.

Link to the materials

https://cloud.geomar.de/s/wN43EBTcBKKpPHi

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