Extracting CO_2 from the air: carbon capture and storage

Condensed version of the study, "Opportunities and Risks Associated With Carbon Capture and Storage Methods – recommendations based on an analysis of the current status of knowledge and a systematic survey of specialists in Switzerland"

TA-SWISS, the Foundation for Technology Assessment and a centre for excellence of the Swiss Academies of Arts and Sciences, deals with the opportunities and risks of new technologies.

This condensed version is based on a scientific study carried out on behalf of TA-SWISS by an interdisciplinary project team comprising members from the Öko-Institut e.V. (Institute of Applied Ecology, Germany) and the Federal Laboratories for Materials Science and Technology (Empa) under the leadership of Dr. Martin Cames (Institute of Applied Ecology) and Dr. Clemens Mader (Empa). The condensed version presents the most important findings and conclusions, and is addressed to a broad audience.

Chancen und Risiken von Methoden zur Entnahme und Speicherung von CO_2 aus der Atmosphäre: Empfehlungen aufgrund der Analyse des Wissensstandes und einer systematischen Befragung von Fachleuten in der Schweiz.

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Negative emission technologies: an overview

If CO_2 is extracted from the air and transferred to long-term storage facilities, already produced emissions can be reversed. The various methods and processes applied for the purpose of carbon extraction are therefore referred to as "negative emission technologies".

Capturing and storing carbon: how can this be accomplished?

There are several ways in which CO_2 can be captured and stored. They differ in terms of how they remove CO_2 from the air and how they subsequently store the carbon in order to permanently keep it out of the atmosphere.

Some negative emission technologies are based on biological principles. These methods utilise the ability of plants to absorb CO_2 and convert it into biomass through photosynthesis. Other methods are based on technologies that enable the extraction of CO_2 and its subsequent storage in geological repositories or in the form of chemical compounds (for descriptions of the various methods, cf. pages 7–12). Extraction can only have a long-term impact on the climate if the CO_2 can be bound for the longest time possible and does not find its way back into the atmosphere.

Why use negative emission technologies? Because the objectives cannot be achieved without them

With the 2015 Paris Climate Agreement, the international community undertook the commitment to keep global warming well below 2° C, and if possible below 1.5° C. The best way of achieving this target would be to reduce the quantity of emitted greenhouse gases as quickly as possible. This could be accomplished by, for example, using renewable energy instead of fossil-based fuels, and substituting high-emission technologies with climate-friendlier options.

In the view of the Intergovernmental Panel on Climate Change, however, the measures that have been resolved to date with the aim of reducing emissions will no longer suffice to overcome the problem of man-made climate warming. And this is where the concept of negative emissions comes in: the aim here is to additionally apply technological solutions ("negative emission technologies") in order to extract a portion of already emitted and still difficult to avoid residual greenhouse gases from the atmosphere and subsequently store them in a suitable manner. According to the calculations of the Intergovernmental Panel on Climate Change, depending on the applied model scenario, between a hundred and a thousand billion tonnes of CO_2 will have to be removed from the atmosphere in the course of this century in order to achieve a net-zero balance. By way of comparison, the annual global level of CO_2 emissions is currently around 37 billion tonnes.

What does the term "net-zero emissions" mean?

Net-zero emissions means that the quantity of greenhouse gases emitted into the atmosphere does not exceed the capacity of natural (forests and soil) or technical sinks to bind these gases. On balance, no additional greenhouse gases would be emitted and the warming of the planet due to human activity would then no longer increase.

Two methods for achieving the target: CO_2 reduction and CO_2 capture

Climate models show that, for the compensation of difficult to avoid residual emissions, negative emission technologies are an essential complement, but at the same time they are no more than that. They cannot under any circumstances act as a substitute for ambitious CO_2 reduction measures. For this purpose, they do not have sufficient potential, and their application is associated with very high costs and too many uncertainty factors. Achieving the declared climate objectives will require both methods for reducing the level of greenhouse gases in the atmosphere: primarily the reduction of the volume of emitted greenhouse gases, and in addition the application of carbon capture processes, together with the use of greenhouse gas sinks for the residual emissions.

Switzerland, too, has declared a net-zero target

The Federal Council wants Switzerland to be climate-neutral by 2050. It primarily aims to achieve this ambitious goal with the aid of reduction measures, while only residual emissions, i.e. greenhouse gas emissions that cannot be completely avoided (for example, laughing gas from the agriculture sector or CO_2 emissions from cement production and waste incineration), are to be compensated through the reduction of greenhouse gases. This means that the same quantity of CO_2 that is emitted has to be removed from the atmosphere. Because every tonne of CO_2, regardless of when and where it is emitted, contributes to an equal extent towards climate warming, this can occur anywhere in the world.

Why has TA-SWISS commissioned a study on negative emission technologies?

Although they could make a valuable contribution towards the achievement of the declared climate objectives, negative emission technologies have barely been applied to date. This is mainly attributable to the fact that the involved technological processes are still partly in their infancy, have not been fully researched, remain largely untested to date, are technically complex, extremely costly and cannot yet be put into practice on a large scale. In addition, questions remain concerning their potential environmental impact and the transport of CO_2 to the storage sites – as well as the associated high additional need for (renewable) energy.

This is the situation that prompted TA-SWISS to commission a study in order to draw the attention of policy makers and the public to the opportunities, limits (costs, feasibility, durability, impact on the climate) and risks (environmental aspects, secondary effects on agriculture and the population) of the various carbon capture and storage methods. With this study, TA-SWISS wants to support a balanced and fact-based debate on the importance of negative emission technologies in Switzerland's climate strategy. How the development of negative emission technologies is to take place and within which time frame, as well as which methods and technology mix are to be applied, are aspects that should be the subject of social and political debate.

Technology assessment explores the relationship between technological developments, society and the environment. In this context, the TA-SWISS study evaluates five negative emission technologies of relevance for Switzerland. With the aid of an online survey method called Landscape of Opinions for Technology Assessment (LOTA), a method that was jointly developed by the University of Zurich and the Federal Laboratories for Materials Science and Technology (Empa) and was used for the first time here, it was possible to produce a kind of map depicting the views of a broad range of stakeholders. In the subsequent methodological procedure, these views facilitated the incorporation of a broad range of perspectives with respect to the opportunities and risks envisaged by various expertise and opinion groups with the aid of in-depth interviews and a stakeholders' workshop. The various opinions were jointly examined from a systemic and scientific perspective and as a result of this transdisciplinary approach they had an influence on the development of the recommendations for action. The surveyed stakeholders included representatives from the economy, science, the public administration and civil society. The comprehensive and detailed study, the main points and findings of which are summarised in this condensed report, was carried out jointly by the Institute of Applied Ecology and Empa.

Recommendations for action

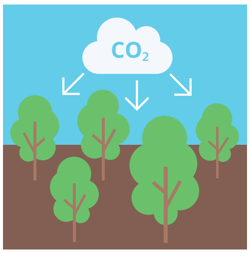
To ensure that the contribution of negative emission technologies towards Switzerland's net-zero target can be realised, according to the study the following comprehensive recommendations should be implemented in Switzerland. Some of these have meanwhile been initiated, but in view of their importance they are explicitly cited again here:

- The public should be provided with fact-based, consistent and comprehensible information about negative emission technologies so that it can be included in the social debate on the development of these technologies.
- A multi-stakeholder task force under the leadership of the Federal Office for the Environment (FOEN) should secure the constructive cooperation between the involved players from the federal government, the cantons and the municipalities, as well as from the economy and the research sector, and develop the necessary legal bases, infrastructure and market conditions for the prompt and efficient implementation of negative emission technologies.
- The federal government should formulate a comprehensive strategy for the use of limited resources (water, biomass, soil, etc.) with precisely defined objectives, priorities, limit levels and guidelines.
- The financing of the development and implementation of negative emission technologies should be clarified as early as possible so that it can be borne by greenhouse gas emitters in line with the "user pays" principle, for example through an appropriate CO_2 price. The responsibilities for the financing of the search for suitable sites for geological repositories and their development and operation also need to be clarified and secured.
- The minimum duration of carbon fixation, as of which a technology or a negative emission technology project in the context of the climate strategy is recognised, should be specified in the Federal CO_2 Ordinance as a clearly defined and plausible quality seal. The CO_2 storage duration of 30 years that is currently under discussion should be questioned and extended.
- Transparent, science-based and easily implementable calculation and data collection methods should be developed for the various negative emission technologies in order to strengthen the evaluation framework for these technologies and avoid double calculations.
- Separate targets should be defined for negative emissions and emission reductions. In this way it will be possible to clearly determine the role of negative emission technologies as a supplementary option for achieving the net-zero target, and thus avoid a watering down of reduction efforts.
- Switzerland should consolidate its pioneering role in the development of negative emission technologies. To accomplish this, national and international research programmes need to be coordinated and the necessary funding should be provided for researching existing gaps in knowledge.
- Accompanying research on the opportunities and risks associated with negative emission technologies should be promoted in the framework of "living labs".

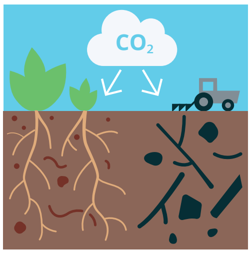
In addition to these general recommendations, the full study ("Chancen und Risiken von Methoden zur Entnahme und Speicherung con CO_2 aus der Atmosphäre: Empfehlungen aufgrund der Analyse des Wissensstandes und einer systematischen Befragung von Fachleuten in der Schweiz") also presents and discusses in detail a list of 26 specific recommendations concerning each of the analysed negative emission technologies.

Description of the negative emission technologies analysed in the study

The five negative emission technologies at a glance

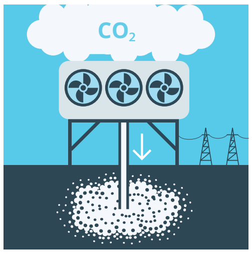


Storage of CO_2 in forests in the form of biomass/utilisation of wood: trees absorb CO_2 from the atmosphere and store the carbon in their wood over the long term, which can be processed into long-lasting products.



Storage of CO_2 in soil in the form of humus or biochar: with the aid of targeted soil management, carbon is integrated into the soil where it is stored, for example with the aid of agri-forestry systems or conservation agriculture concepts.

Capture of CO_2 from chimneys (use of bioenergy with carbon capture and storage – BECCS): plants convert CO_2 into biomass, which produces energy when burned. The resulting CO_2 that is thus released again is then captured and stored beneath the ground.



Extraction of CO_2 from the atmosphere (direct air capture and carbon sequestration – DACCS): here, CO_2 is extracted from the atmosphere with the aid of technical systems instead of by plants. The carbon is then stored beneath the ground.

Accelerated weathering of demolition concrete and rock: in nature, minerals react with CO_2 and in this way bind the carbon. This carbonation process can be accelerated through the application of technological methods.

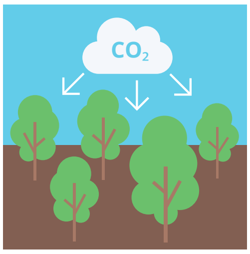
Negative emission technologies: overall opportunities …

- The application of negative emission technologies could help Switzerland achieve its climate protection objectives without losing sight of the development of economic prosperity.
- The sustainable management of forests and land, and the utilisation of wood and biochar, not only function as CO_2 sinks, but also have the potential to foster biodiversity, improve soil quality and the water supply, and strengthen resilience against drought and heavy precipitation.
- Negative emission technologies can support the circular economy, for example when CO_2 is embedded in concrete waste and bound into new construction materials for recycling.
- Switzerland is currently leading the way in the development and use of various negative emission technologies. The development of these technologies will open up opportunities for Switzerland to further strengthen its position as a centre of research and industry.

… and risks

- Failure to investigate, implement and scale the potential of negative emission technologies could mean that Switzerland will not be able to meet its climate objectives.
- Possible conflicts of interest could arise, for example associated with the use of limited resources such as biomass, water, land and renewable energy.
- The extent to which individual negative emission technologies could harm the environment is not yet clear. The transport and underground storage of CO_2 may also be associated with certain risks.
- Placing too much reliance on negative emission technologies could mean that ambitious climate protection legislation and emission reduction efforts may be neglected.

Forests as carbon sinks: forest management and utilisation of wood



Principle: trees convert atmospheric CO_2 into biomass through photosynthesis, and subsequently store the carbon (C) in wood, roots and the soil. The storage capacity of Switzerland's forests is between 1.6 and 4.5 million tonnes of CO_2 per annum. But forests can only function as CO_2 sinks if they continue to grow and the quantity of wood that is formed exceeds the quantity that rots, is incinerated or is harvested. With all these processes, CO_2 is released into the atmosphere again.

Sustainable forest management ensures that a forest is able to perform its many functions (protection, space for economic and recreational activities, etc.) and at the same time contribute towards the reduction of greenhouse gases. Managed forests store more CO_2 than forests left in their natural state.

Forest management includes:

Afforestation: planting of trees in previously unforested land.
Reforestation: natural reforestation of unused mountain pastures, resulting in an increase in biomass.

Forest management/utilisation of wood: in a healthy forest, the CO_2 initially remains stored in the trees for several decades. Forest management can be made sustainable through the targeted harvesting of timber, which should be efficiently processed in several stages (cascaded use) into products with a lengthy useful life. In this way, the carbon can be kept out of the atmosphere for as long as possible. At the end of its useful life, the wood is then utilised for heating purposes.

Costs: depending on the source, between 1 and 100 US dollars per tonne of CO_2 (Switzerland).

Negative emission technology potential[1]: if the forest is sustainably managed and the wood is utilised (including substitution effect), approx. 3 million tonnes of CO_2 p.a. (Switzerland).

Level of technological maturity: 9 – 10

[1] The State of Carbon Dioxide Removal, Report on the first comprehensive global assessment of the current state of carbon dioxide removal, January 2023

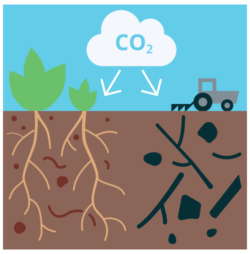
Opportunities

- Promotion of biodiversity, variety and natural rejuvenation of forests.
- Because the source of energy for photosynthesis is natural solar irradiation, this negative emission technology only requires low quantities of technically produced energy for forestry machinery and timber transport.
- Over the long term, the CO_2 balance of Switzerland's forests could be optimised thanks to the promotion of timber growth and taking account of the ecological functions of dead wood. The cascaded use of the wood is a key factor here.
- The use of timber as a construction material means that the embedded carbon remains stored for decades. At the same time, timber could to some extent be used in the construction industry as a substitute for other CO_2-intensive materials such as steel and concrete.

Risks

- The long-term storage of carbon is less assured than the storage of CO_2 beneath the ground.
- Due to climate change, forest fires, periods of drought, forest clearance, pest infestations, etc., the CO_2 could be released into the atmosphere again.
- Shortage of suitable land: there are not enough areas of unforested land in Switzerland to permit large-scale afforestation.
- Natural or planned afforestation could give rise to land use conflicts, for example if potential forest zones in mountain regions are retained in the form of meadows in order to preserve arable land. The use of land for forest management could also influence the storage capacity for other negative emission technologies.

Soil management and biochar



Principle: it is not only trees, but also all other plants that convert atmospheric CO_2 into biomass through photosynthesis and store the carbon in their leaves, stems, roots and fruits. When a plant dies, organisms in the soil break down the plant material and release CO_2. However, some of the plant material is converted into organic matter (humus) and is retained in the soil for a longer period of time.

The balance between humus formation and depletion can be influenced through soil management. When humus is formed, the soil absorbs more CO_2 than it releases. The length of time the carbon is retained in the humus ranges from decades to centuries, depending on the type of soil, the method of soil management and the environmental conditions. With the aid of targeted soil management, it is possible to increase the storage duration of organic carbon in the form of humus. This can be accomplished by, for example, minimising the working of agricultural land, improving crop rotation, leaving harvest residue in fields, cultivating deep-rooted plants, converting farm land into pasture land – in other words, by applying conservation agriculture methods.

Through the use of agri-forestry systems, i.e. integrating trees and shrubs into crop and animal farming, it is possible to increase the formation of biomass and store organic carbon in the soil.

Biochar, i.e. biomass that is charred at a high temperature and in an oxygen-free environment (pyrolysis) and subsequently worked into the soil, also binds CO_2 as carbon for lengthy periods of time. Biochar is used as a fertiliser additive and in livestock farming as a raw material, and in environmental and energy technology. The carbon content of biochar is only released again very slowly.

Costs of soil management: depending on the source, between 0 and 80 US dollars per tonne of CO_2.
Costs of production and use of biochar: depending on the source, between 10 and 135 US dollars per tonne of CO_2.

Negative emission technology potential of soil management: around 2.7 million tonnes of CO_2 p.a. (while the soil remains saturated with carbon, i.e. several decades).
Negative emission technology potential of agri-forestry systems: if 13.3 percent of Switzerland's agricultural land were to be converted into agri-forestry systems it would be possible to compensate up to 13 percent of the greenhouse gas emissions attributable to the agriculture sector.
Negative emission technology potential of biochar in soil: up to 2.2 million tonnes of CO_2 p.a.

Level of technological maturity: soil management and agri-forestry 10, biochar 9

Opportunities

- Increased humus formation, improved ecosystem performance, enhanced soil quality.
- Agri-forestry systems could restrict soil erosion, facilitate water infiltration, improve the physical properties of the soil and act as a buffer against extreme events.
- Biochar binds carbon over the long term and could be used in a variety of sectors.

Risks

- The organically bound carbon in the soil could be released again due to natural occurrences or human activities and climate fluctuations.
- The use of agri-forestry systems could reduce crop yields and increase production costs. This could give rise to utilisation conflicts with the foodstuffs industry. No long-term studies have yet been carried out concerning the feasibility, productivity and improvement of carbon storage in Swiss soil.
- Through the output of biochar, it is possible that harmful substances (e.g. heavy metals) could pollute the soil and subsequently enter the food chain.
- Because of its need for biomass, biochar is in competition with other negative emission technologies.

Bioenergy production with carbon capture and storage (BECCS)

Principle: plants bind CO_2 extracted from the atmosphere and convert it into biomass. During the incineration, smouldering or gasification of biomass, the CO_2 content is released again. In bioenergy systems, it is directly separated from the exhaust gas and stored in deep geological layers or transported in sealed tankers or pipelines to a storage facility abroad. Thus in the case of BECCS, biomass is used on the one hand for the production of energy (i.e. is converted into electricity or heat) and on the other hand as a means of producing negative emissions through the application of suitable technologies.

Because carbon capture and storage is simultaneously combined with the production of renewable energy, high hopes are being placed in this negative emission technology, which plays a major role in all the scenarios drawn up by the Intergovernmental Panel on Climate Change.

Carbon capture pilot plants are already in operation in the USA and the UK. Identifying suitable sites for the construction of safe geological repositories is one of the main prerequisites for the use of this technology. In Switzerland there are currently no storage facilities for captured CO_2, though it could be transported to geological repositories abroad, for example via (new) pipelines. Within Switzerland, this technology would probably be most suitable for use in waste incineration plants, cement factories, sewage treatment plants and the chemicals industry.

Costs: depending on the source, between 30 and 400 US dollars per tonne of CO_2.

Negative emission technology potential of BECCS: if the entire quantity of available biomass in Switzerland were to be utilised, around 5.1 million tonnes of CO_2 p.a. (from 2050).

Level of technological maturity: 9

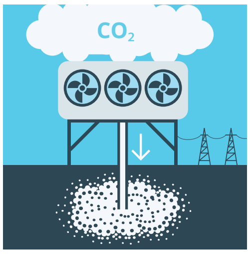
Opportunities

- In theory, CO_2 can be stored in geological repositories for very long periods of time.
- With BECCS, carbon capture could be accomplished more cost-effectively and energy-efficiently than would be the case with direct air capture and carbon sequestration (DACCS), because the concentration of carbon is much higher in exhaust gases than in the atmosphere.
- The BECCS method has economic potential because the cascaded use of the biomass that is no longer suitable for other purposes could become an additional source of revenue for farmers and foresters.

Risks

- If biomass has to be produced specially for BECCS, due to the high requirements for land, water and fertilisers there is potential for utilisation conflicts with the foodstuffs industry, as well as for negative impacts on biodiversity (especially in the case of biomass monocultures).
- The transport of biomass to BECCS storage facilities, the energy and materials required for their operation and the process of storing the CO_2 in geological repositories, are all associated with high energy and material costs and could lead to dependencies on third countries.
- There are still pending issues relating to the duration of CO_2 storage: with respect to storage in geological repositories the risk exists that the CO_2 could gradually escape due to faults or fractures in the rock. This could give rise to social controversies.

Direct air capture and carbon sequestration (DACCS)



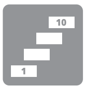
Principle: with DACCS, CO_2 is mechanically filtered out of the atmosphere and stored beneath the ground. Here, carbon is captured with the aid of a technical system instead of by plants.

By removing CO_2 from the atmosphere, it is possible to compensate other difficult to avoid residual emissions of greenhouse gases (for example, from the agriculture sector), theoretically including gases that do not contain any carbon at all (for example, laughing gas). The removal of CO_2 from the ambient air is effected with the aid of chemical binding agents (absorption and adsorption processes). The pure CO_2 thus separated by the binding agent is then liquefied, transported and permanently stored deep below the earth's surface. For this purpose, suitable deep geological repositories are available abroad, for example in Iceland and Norway.

The world's first commercial DACCS facility was inaugurated in Iceland in 2021. It was developed by a Swiss company (Climeworks) in collaboration with the Icelandic firm, Carbfix. At full load, it is able to extract around 4,000 tonnes of CO_2 p.a. from the atmosphere. For larger-scale extraction the technology will have to be further developed.

Costs at the current status of development: depending on the process, between 80 and 210 US dollars per tonne of CO_2 (absorption process) and between 560 and 730 US dollars per tonne of CO_2 (adsorption process). **Anticipated costs in the long term:** 100 US dollars per tonne of CO_2.

Negative emission technology potential of DACCS: the total geological storage potential in Switzerland is estimated at a maximum of around 2,500 million tonnes of CO_2.



Level of technological maturity: 7–8

Opportunities

- It should be possible to store CO_2 beneath the ground over very lengthy periods of time. Furthermore, this technology is readily scalable and is not dependent on biomass.
- DACCS is not location-dependent. In order to minimise the costs of transporting the CO_2, as well as the overall associated costs, DACCS facilities could be installed at locations at which renewable energy sources and geological repositories for CO_2 are available.
- Since the process primarily requires heat, either district heat from industrial processes or geothermal energy could be used, depending on the process concerned.

Risks

- DACCS is cost-intensive and in competition with renewable energy sources. Because the proportion of CO_2 in the atmosphere is low, the facilities have to filter enormous quantities of air. This means that carbon sequestration is both costly and energy-intensive. Furthermore, some of the applied processes require large quantities of chemicals and water.
- With respect to the geological storage of the sequestrated CO_2, certain risks could arise relating to the storage duration and the triggering of seismic activity, and thus the potential for causing social controversies.
- Switzerland's long-term climate strategy is oriented on scenarios in which negative emissions will be purchased abroad. This could give rise to infrastructure-related and contractual dependencies on third countries, similar to the current situation regarding oil and gas supplies.

Weathering through carbonation

Principle: during weathering, certain minerals such as silicate rocks react with CO_2 and bind the carbon. This chemical process, which is referred to as carbonation, occurs very slowly in nature, but can be technically accelerated. One method consists in finely grinding the rock and distributing it over large areas of agricultural land or forest terrain.

Weathering also takes place in concrete (and is normally undesirable because it causes steel girders in concrete to rust). This process, too, can be technically accelerated. This is good news for the climate: with the aid of new carbonation methods, demolition concrete is able to reabsorb up to 33 percent of the greenhouse gases that were released during its production. Here, concrete rubble is finely ground and combined with pure CO_2 (for example, from BECCS facilities). This produces limestone powder that can subsequently be reused as filler or aggregate for the production of new concrete. This reduces the CO_2 footprint of concrete production.

Swiss companies Neustark, zirkulit and Sika are developing new methods of storing CO_2 in demolition and recycling concrete.

Costs: in the case of demolition concrete, depending on the source and taking account of the investment costs for special equipment, between 140 and 940 US dollars per tonne of CO_2. By 2050 the costs could fall to 75 US dollars per tonne of CO_2. Natural rock: estimated costs are between 70 and 130 US dollars per tonne of CO_2.

Negative emission technology potential: up to 2.5 million tonnes of CO_2 in 2050.

Level of technological maturity: carbonation 5 – 6, distribution 3

Opportunities

- The accelerated weathering of demolition concrete has the potential to rebind up to 33 percent of the original CO_2 emissions resulting during cement production.
- The chemical binding of carbon in demolition concrete is highly stable and permits long-term CO_2 storage, potentially for centuries.
- Spreading carbonated demolition concrete over agricultural land could also contribute towards the reduction of laughing gas emissions.

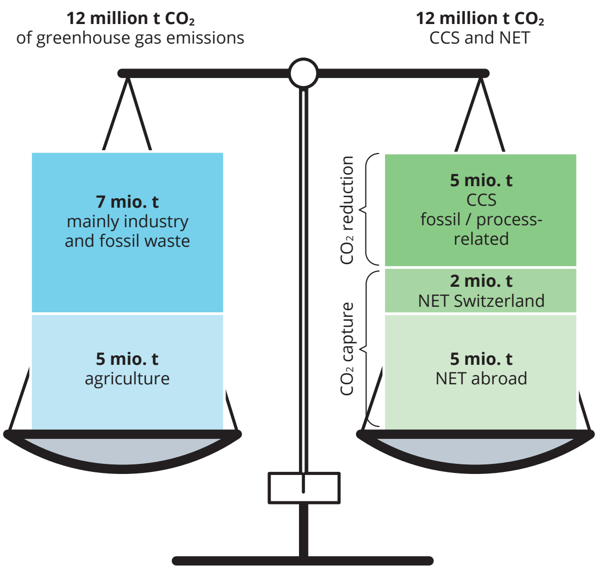
Risks

- Spreading finely ground concrete could result in an increase in pollutants in the soil and have a negative impact on plants and organisms. It also involves the use of large areas of land.
- Grinding rock and demolition concrete is associated with a high level of energy consumption.
- The stability of CO_2 fixation as a carbonated material in soil has not yet been sufficiently researched.

Negative emission technologies as key elements in Switzerland's climate policy

As a mountainous country, Switzerland is especially susceptible to the impacts of climate change. Here, temperatures are rising twice as quickly as the global average. In 2019, the Federal Council declared that Switzerland is to reduce its net greenhouse gas emissions to zero by 2050. From 2050 onwards, it may only emit a quantity of CO_2 that is equivalent to the volume that can be reabsorbed naturally and in technical sinks.

The aim is to achieve this net-zero target primarily by reducing emissions produced in Switzerland to the greatest possible extent. The role to be played by negative emission technologies in achieving the net-zero target is to compensate those residual emissions that will be difficult to avoid. Specific measures are to be implemented with the aim of supporting the step-by-step development of these technologies. In the view of the Federal Council, this strategy is not only a key climate policy element, but also opens up opportunities for Switzerland as a centre of industry and research.



By 2050, Switzerland wants to be in the position to remove 7 million tonnes of CO_2 a year from the atmosphere at home and abroad. It also aims to capture at source and permanently store an additional 5 million tonnes of CO_2 emissions a year (principle of carbon capture and storage, CCS) from fossil sources. Thus the Federal Council estimates that the quantity of residual emissions that Switzerland will not be able to avoid despite all the efforts aimed at reducing them will reach 12 million tonnes of CO_2 p.a. by 2050.

By way of comparison, in 2020 a total of 43.4 million tonnes of CO_2 were emitted in Switzerland.

In 2022, Parliament adopted an indirect counter proposal to the people's initiative calling for a healthy climate ("Glacier Initiative") in which it essentially favours the adoption of the net-zero target into the Federal Constitution. Because a referendum against the new legislation was successfully launched, the electorate will vote on this matter in June 2023.

Climate protection instruments

It will not be possible to achieve the climate protection objectives of the Paris Agreement without the application of negative emission technologies. At the same time, however, these technologies must not be allowed to undermine climate protection efforts: as before, priority has to be attached to reducing greenhouse gas emissions to the greatest possible extent with the aid of conventional measures such as the more moderate use of energy, substitution of fossil-based fuels with renewable energy, or the implementation of technical measures aimed at increasing the energy efficiency of production processes, buildings and vehicles. A variety of mechanisms and incentive systems are intended to support such measures. In simplified terms, this entails increasing the price for the emission of greenhouse gases. This will make the substitution of fossil-based fuels with alternative energy sources, and investment in more energy-efficient systems and production methods, more economically viable.

In Switzerland, the most important instruments for this purpose are CO_2 levies on combustibles, target agreements for companies and the emissions trading system. In the latter, the government defines the limit levels of the emissions concerned and allocates an annually decreasing quantity of emission rights to the most greenhouse-gas-intensive industrial systems – partially free of charge, and partially via auctions – which entitle the recipients to emit a specified quantity of CO_2. Recipients who do not fully utilise their emission rights can sell the balance to less efficient companies. The fact that emission rights are traded on the market means that a price is created for the emission of greenhouse gases. Switzerland's emissions trading system is coupled with the EU emissions market.

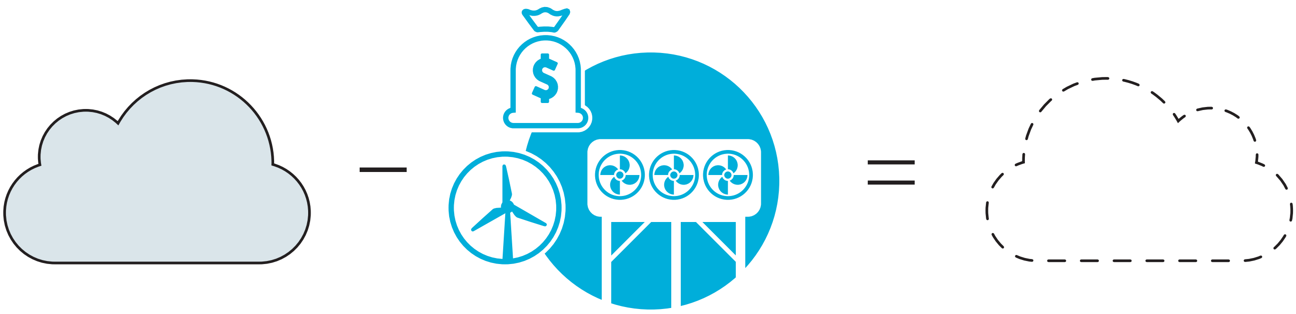
Compensation projects in Switzerland and abroad also bring about emission reductions. For example, producers and importers of fossil fuels are required to offset a portion of the CO_2 emissions from the transport sector by supporting climate protection projects. For the greenhouse gas emission reductions attained in these projects they receive national or international certificates which they can offset against their own reduction targets. And projects focusing on CO_2 storage have also been admissible since 2022.

The federal government and various cantons and municipalities also foster climate-friendly behaviour through a variety of promotion programmes and incentives. One of the aims of these mechanisms is to secure support among the population. After the Swiss electorate had rejected the proposed revision of the Federal CO_2 Act in 2021, the new version does not include any new levies. The Federal Council declared that the population should not have the impression of being penalised by the country's climate policy.

Net-zero mission

Carbon reduction

Carbon removal



How negative emission technology projects differ from conventional compensation projects

In order for Switzerland to compensate its own emissions, it is financing climate projects that reduce emissions elsewhere to the same extent. This does not change the quantities of CO_2 that have already been emitted into the atmosphere.

As a means of offsetting its own emissions, Switzerland is financing negative emission technology systems elsewhere, with the aid of which the same quantity of CO_2 can be removed from the atmosphere. Thus on balance, no more emissions remain in the atmosphere. To accomplish this, however, it is essential that the energy requirement of the respective negative emission technologies is met from renewable energy sources.

Recommendations for incorporating net emission technologies into Switzerland's climate policy

The study indicates which initial support and adaptations will be required so that the full potential of the negative emission technologies can be realised in Switzerland's climate policy, while at the same time avoiding the associated risks. These measures include the formulation of regulations and standards and the specification of limit levels, plus the definition of clear objectives.

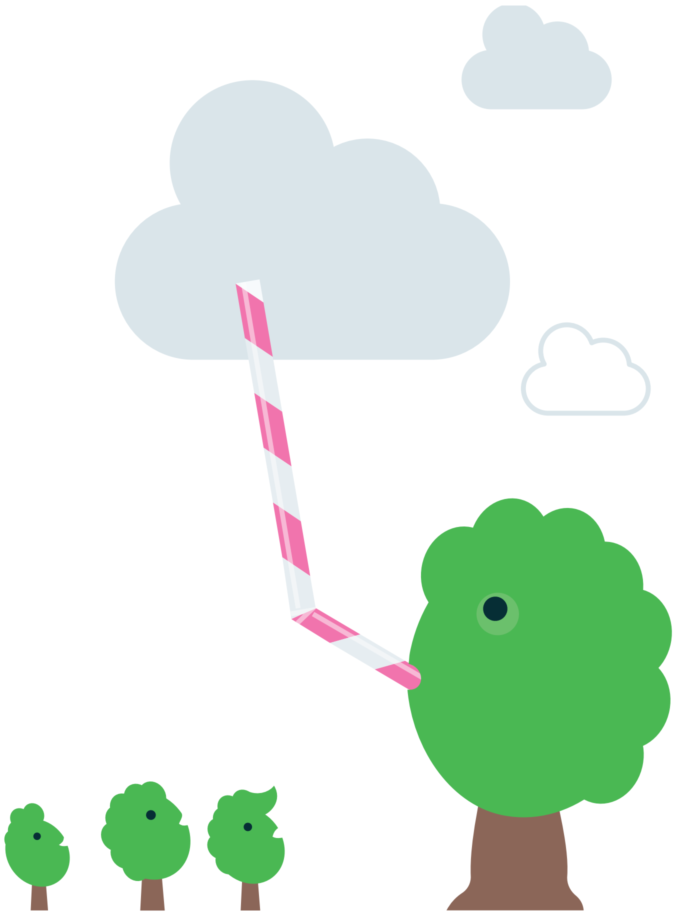
Financing of net emission technologies via CO_2 levies: at their current level of development, the costs for the complex negative emission technologies are significantly higher than the current CO_2 prices in the European Emissions Trading System (70 to 90 US dollars per tonne of CO_2). Through the use of revenue from the emissions trading system, or by increasing the levels of existing, or introducing new, greenhouse gas levies, it would be possible to subsidise the development and implementation of negative emission technologies. For companies and private individuals, this measure would guarantee a fixed amount for each verifiable tonne of CO_2 they remove from the atmosphere. This subsidy could be gradually reduced in line with the development of Switzerland's net capacity.

Creation of a negative emission technologies market: the federal government should create incentives for the use of systems designed to remove CO_2 from the atmosphere (bioenergy production with carbon capture and storage – BECCS), for example by establishing a separate carbon capture and storage market.

Creation of an evaluation framework and harmonisation of the calculation metric: in addition to a comprehensive uniform process for the certification and calculation of negative emissions, specific monitoring methods for the individual negative emission technologies and the operation of DACCS facilities need to be established. The calculation of the carbon capture performance of the respective negative emission technologies – for example, carbonated demolition concrete – should be based on reliable international guidelines.

International cooperation: for the reduction of the greenhouse gas effect, the specific location at which CO_2 is removed from the atmosphere is immaterial. Because certain natural resources (such as land) and geological storage systems are limited in Switzerland, in both practical and economic terms it makes good sense for Switzerland to participate in the development of DACCS systems at locations where there are already sufficient geological repositories for CO_2. In keeping with the principle of "global climate justice", a contractual framework at the UN level is required for this kind of international cooperation. These agreements have to ensure that obligations and benefits are equally distributed among the participating countries, and that climate protection projects are duly certified and transparently calculated at the supranational level.

Prevention of false incentives: separate targets for the reduction of emissions and the various negative emission technologies can ensure that priority continues to be attached to the reduction of emissions and that negative emission technologies will only be applied for the purpose of capturing a limited quantity of difficult to avoid residual greenhouse gas emissions, primarily from the agriculture sector and certain other industries.



Use of resources: interactions and conflicts of objectives

As the fact sheets (pages 7–12) show, the various negative emission technology concepts differ from one another in terms of their level of development, their reduction potential and thus the associated opportunities and risks. The costs for natural-based options such as forest management are clearly calculable, but these negative emission technologies require a great deal of land, and CO_2 is not extracted from the atmosphere uninterruptedly. When trees die and timber rots or is incinerated, the carbon is released into the atmosphere again. The duration of carbon fixation is significantly longer when biomass is incinerated in BECCS facilities, where the released CO_2 is recaptured and stored in deep geological repositories. But this high-tech solution is associated with high infrastructure costs and also requires a large quantity of biomass.

Thus significant conflicts of objectives could arise between the various technologies. These may include:

Competition for land and biomass

Forest management and utilisation of wood, soil management and BECCS require large areas of land for the cultivation of biomass. Land is also required when carbon is to be worked into the soil in the form of biochar, or carbonated rock powder is to be distributed in the landscape. And land is also required for the construction of the necessary infrastructure for BECCS, carbonation and DACCS facilities and CO_2 pipelines. Negative emission technologies can thus enter into competition with the production of foodstuffs or with the sustainability goals of other industry sectors that want to substitute fossil-based materials with bio-based resources. Furthermore, the increasing demand for the cultivation of biomass can result in losses of habitat and biodiversity.

Competition for water

All negative emission technologies – and in particular BECCS – depend directly or indirectly on water. But the electricity supply, agriculture and industry, also depend on this resource – in a geographic environment that is becoming increasingly dry due to climate change.

Competition for renewable energy

DACCS and accelerated weathering require a great deal of energy. This requirement can only be met appropriately from renewable energy sources – but the competition for green energy is very high.

Recommendations concerning the use of resources

Since various stakeholders rely on the use of limited resources such as biomass, water, land and renewable energy, a consistent and comprehensive strategy needs to be formulated which includes precisely defined targets, priorities, limit levels and guidelines for the use of these resources. This strategy should identify the potentials and availability of the resources, take account of possible developments and trends, and clarify the necessary prioritisation regarding access in times of scarcity. This should also apply to resources such as critical raw materials, finance, specialised personnel and know-how, all of which are essential for Switzerland to achieve its sustainability goals.

In addition, for projects of national interest a concept and the corresponding criteria should be developed that facilitate the speeding up of licensing procedures while taking account of other legitimate interests.

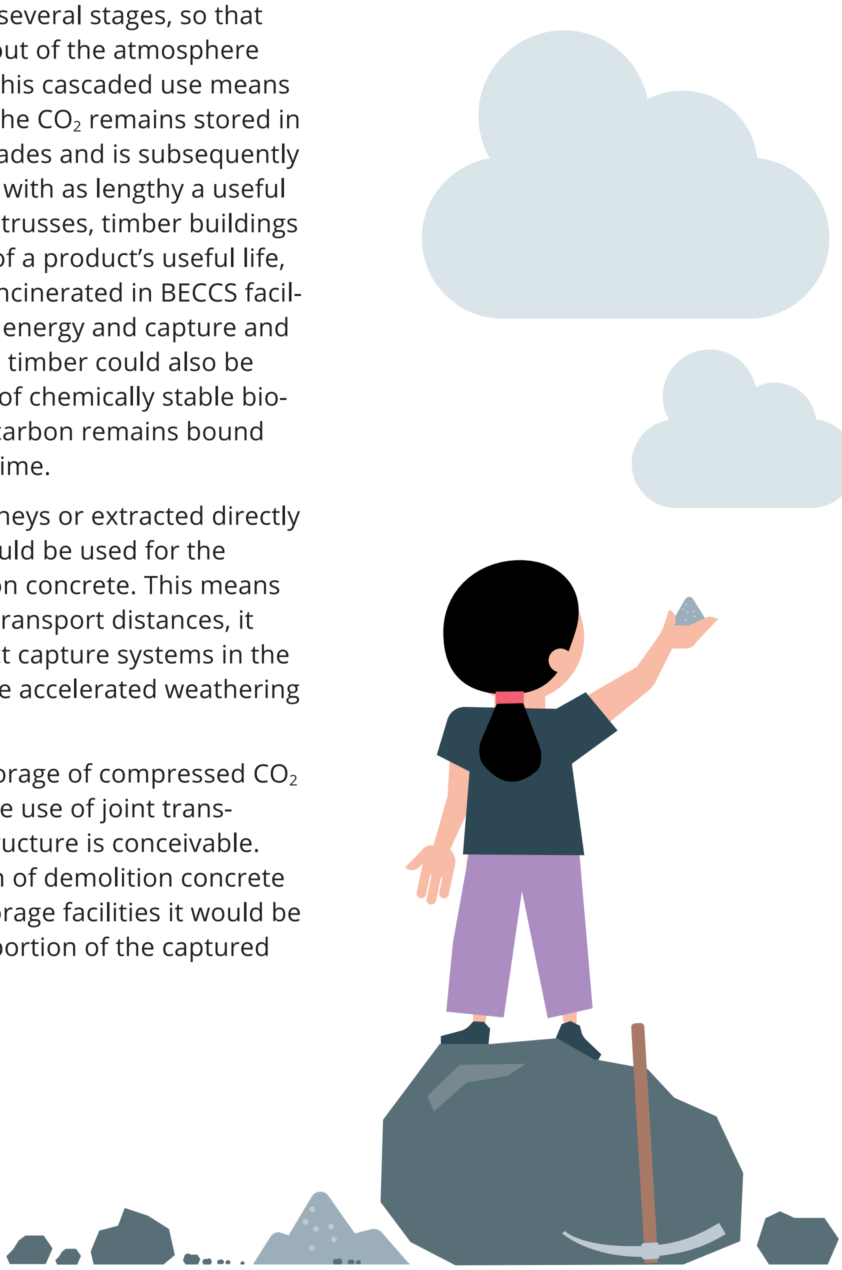
Synergies and cascaded use

But there are also many synergies between the various negative emission technologies or between the technologies and other industry sectors, and these could be exploited to the benefit of climate protection.

- In combination with agri-forestry, forest and soil management could optimise this negative emission technology.
- With sustainable forest management, timber is harvested in a targeted manner and used as efficiently as possible in several stages, so that the carbon can be kept out of the atmosphere for as long as possible. This cascaded use means that in a healthy forest, the CO_2 remains stored in the trees for several decades and is subsequently processed into products with as lengthy a useful life as possible, e.g. roof trusses, timber buildings or furniture. At the end of a product's useful life, the waste wood can be incinerated in BECCS facilities in order to produce energy and capture and store the CO_2. Untreated timber could also be used for the production of chemically stable biochar. In both cases, the carbon remains bound over lengthy periods of time.
- CO_2 captured from chimneys or extracted directly from the atmosphere could be used for the carbonation of demolition concrete. This means that, in order to reduce transport distances, it makes sense to construct capture systems in the vicinity of facilities for the accelerated weathering of demolition concrete.
- For the transport and storage of compressed CO_2 from capture facilities the use of joint transport and storage infrastructure is conceivable. Through the carbonation of demolition concrete or by finding suitable storage facilities it would be possible to also store a portion of the captured CO_2 in Switzerland.

Recommendations concerning the exploitation of synergies

Because various negative emission technologies are still in the early stages of market maturity, it is important to consistently exploit such synergies in order to use the available resources as efficiently as possible. This calls for forward-looking coordination and planning in which all the involved players (federal government, cantons and industry) should participate, for example by attending round table discussions.



An essential complement, not a substitute

All the negative emission technologies are still associated with open technical, economic, social and political questions. It is not yet clear whether these technologies will be able to make the anticipated contribution towards the net-zero target by 2050. One of the reasons for this concerns the fact that none of these technologies can be regarded as entirely risk-free. In addition, suitable incentive systems, framework conditions and political instruments have yet to be developed and implemented.

Recommendations concerning the implementation framework

The findings of the study indicate that, in Switzerland, in order for the negative emission technologies to accomplish the targeted compensation of difficult to avoid residual emissions, the following measures will be necessary:

Understanding and addressing the opportunities and risks: for most of the negative emission technologies there is still a need for further research so that the processes can be better understood and scaled, and their costs can be reduced. The knowledge concerning the capture and storage potentials, the impacts on the environment, as well as the associated synergies and costs, needs to be systematically deepened and the risks have to be analysed so that they can be minimised as comprehensively as possible with the aid of adequate regulatory measures (monitoring, specification of limit levels, definition of liabilities, etc.).

Fostering of development and implementation: a comprehensive range of policy instruments will be required (promotion of research, subsidies for investment and operation, formulation of standards, etc.) in order to speed up the use of negative emission technologies and thus facilitate “technological learning”, and to reduce the costs and bring the various technologies to market maturity in the medium term. In addition to the development of the various process steps, it will also be necessary to test and optimise the interaction between all the processes in the entire chain, including infrastructure and logistics. This could primarily be accomplished through a systematic and participatory “learning by doing” process within the framework of the increasing application of the negative emission technologies.

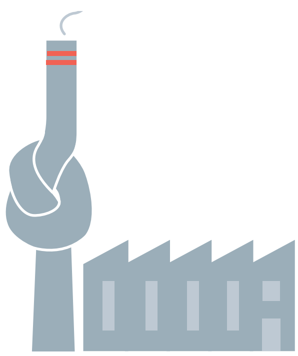
Finding the appropriate Swiss mix: none of the studied negative emission technologies can act as a universal remedy that could compensate all difficult to avoid emissions in Switzerland. But if the carbon capture potential should prove to be realisable, it would be possible to meet the projected need for compensation via a portfolio of complementing negative emission technology options. With respect to implementation it is important to find the right combination of complementing technologies and practices: i.e. the Swiss mix that takes account of the country’s specific circumstances.

Communication and participation: in order to help the population understand the role that negative emission technologies can play in Switzerland’s climate policy and to conduct the social debate on a factual basis, the current findings should be communicated to the general public and all the involved parties should be included in the dialogue processes relating to the further development and use of negative emission technologies.

Conclusions

The main conclusion of the study is that negative emission technologies cannot substitute the necessary efforts to reduce greenhouse gas emissions. As before, priority has to be attached to avoiding emissions. Whether they are high-tech or low-tech, negative emission technologies do not provide a pretext for a "business as usual" approach. These technologies are too costly and too energy-intensive, and should therefore be reserved solely for offsetting unavoidable emissions. This means that negative emission technologies cannot be regarded as a suitable alternative to the reduction of emissions if the objectives of the Paris Climate Agreement are to be achieved. But they are nonetheless practically indispensable as a complementary solution.

Why "indispensable"? All the examined negative emission technologies have secondary effects and therefore cannot be applied without certain concerns. But at the same time we have to face the basic or sobering fact that compared with the risks associated with climate change, none of the risks associated with the negative emission technologies are so high that it would be necessary to advise against the application of these technologies. It is precisely in view of this that it is essential to weigh up the pros and cons, and the costs and consequences of the various technologies, against one another. It is also essential to publicly determine the role that a Swiss mix of negative emission technologies is to play in our country's climate policy. At the social level, the discussion has to focus on the volume of greenhouse gas emissions Switzerland still wants to "afford" in the future, who is to be responsible for the financing of the negative emission technologies, and what steps need to be taken after 2050 if further reductions of greenhouse gases in the atmosphere should be necessary.



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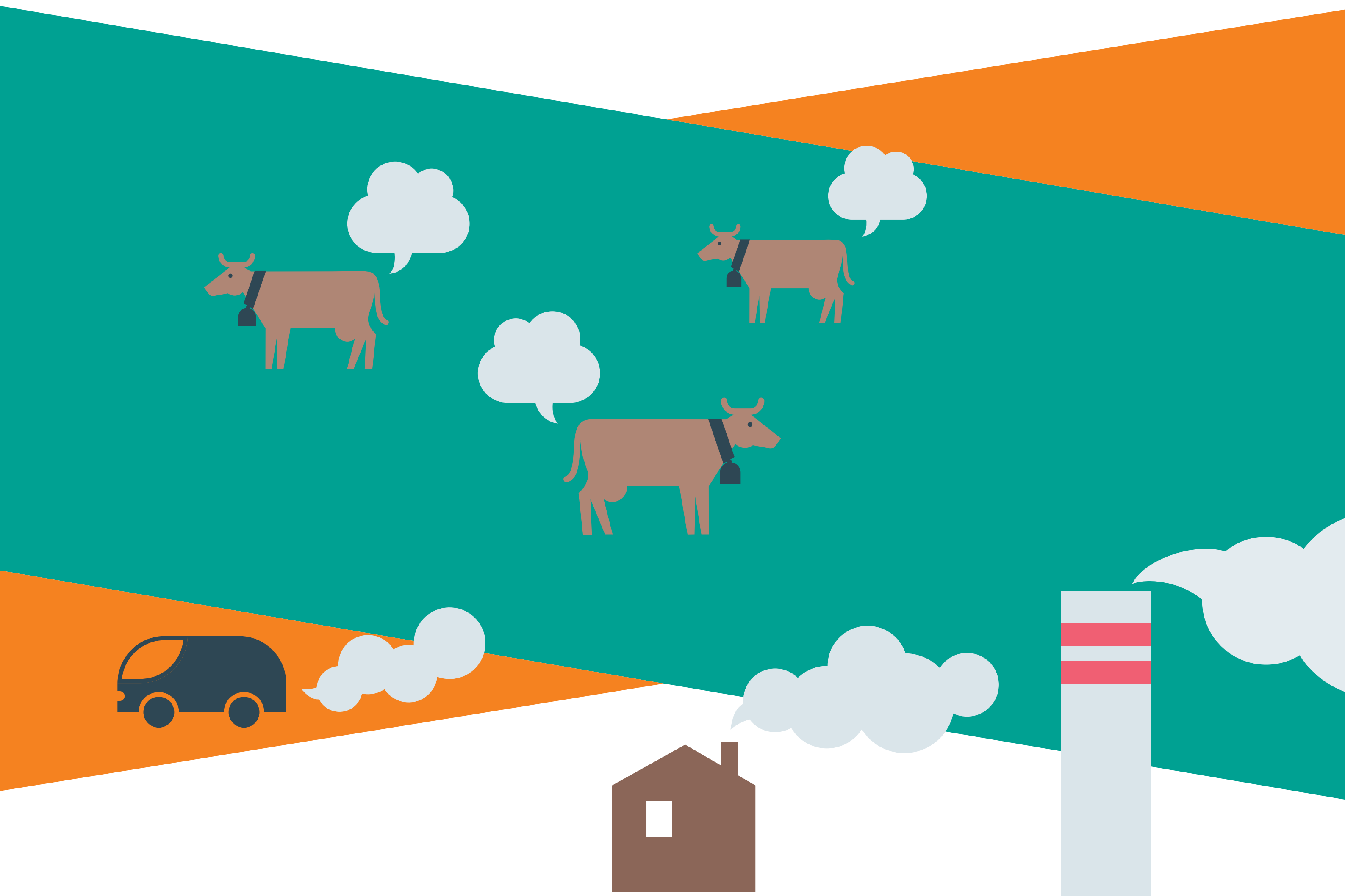

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