SETTING THE CONTEXT FOR AN EU POLICY FRAMEWORK FOR NEGATIVE EMISSIONS

Scoping paper

Milan Elkerbout
Julie Bryhn

CEPS Policy Insights
No 2021-12 / September 2021

Setting the context for an EU policy framework for negative emissions

Scoping paper

Milan Elkerbout and Julie Bryhn

Abstract

Negative emissions – the removal of carbon dioxide from the atmosphere – will be needed in the EU and globally to reach long-term climate targets. This scoping paper explores the different concepts relevant to discussing negative emissions in an EU policy context, starting with the scientific basis described by the Intergovernmental Panel on Climate Change (IPCC). The paper then discusses different ways negative emissions technologies can be categorised, and the potential trade-offs associated with their deployment. Finally, some political considerations for negative emissions policy are discussed. The paper will form the basis for an upcoming policy paper on how the EU should approach negative emissions in its climate policy framework.

Milan Elkerbout is a Research Fellow and Julie Bryhn is a Researcher at CEPS.

Contents

List of Tables

1. Introduction: Why discuss negative emissions?

Negative emissions deployment in the EU is needed to compensate for residual emissions and to deliver net-negative emissions. Net-negative emissions reduce the concentration of greenhouse gases in the atmosphere, thereby directly affecting the main driver of climate change.

The scale of negative emissions to be delivered is dependent upon key political choices. How many tonnes of greenhouse gas (GHG) emissions will remain once emissions reductions (policies) are exhausted? How many tonnes should the EU remove from the atmosphere? The answer may depend on progress in emissions reductions in other parts of the world, or the acceptability of temporarily 'overshooting' a temperature target. It will also depend on the EU's political interpretation of the principle of common but differentiated responsibilities, as applied to negative emissions, and whether or not it will want to compensate for historical emissions.

The new Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6, WG1)[1] confirms that emissions pathways that limit global warming to 1.5C or 2C "typically assume" the use of carbon dioxide (CO_2) removal. The IPCC Special Report on 1.5°C states that throughout the 21st century between 100 to 1000 Gigatonnes (Gt) of carbon dioxide removal (CDR) will be required. Annual global CO_2 emissions are just under 40 Gt. Depending on the scenario, the annual volume of negative emissions ranges from a few Gt to more than 20 Gt. In most of the scenarios that limit warming to 1.5°C, net-negative emissions are needed after reaching 'climate neutrality[2]'; i.e., net-zero GHG emissions. The more there is an overshoot of global temperatures, the greater the volume of negative emissions required to reduce atmospheric concentrations and to return global warming to 1.5°C after a peak.

Negative emissions also play an important role in two of the EU's Long-Term Strategy scenarios – those deemed to be in line with the Paris Agreement's 1.5°C target – which rely to a different extent on natural sinks or technological removals depending on the scenario. The 1.5C Tech scenario focuses more on technological carbon removal and ends up with an annual negative emissions volume of 600 million tonnes. The 1.5C LIFE scenario has a relatively greater focus on nature-based removals, with total removals at slightly more than 500 million tonnes per year.[3]

Recent EU policy initiatives have taken this further. The Climate Law includes specific reference to the key role removals can play in reaching EU targets. While net removals are limited to contributing no more than 225 Mt of CO_2 equivalents towards the 2030 target, it also focuses on enhancing the carbon sink in order to reach net-zero in 2050.[4] Within the Circular Economy Action Plan, carbon removals are also highlighted as one of the means to achieve climate neutrality. Indeed, establishing a regulatory framework for the certification of carbon removals

---

[1] See https://www.ipcc.ch/report/ar6/wg1/#FullReport (The Full Report is subject to final editing; as a result this scoping paper only refers to the summaries).

[2] Climate neutrality is a political term used by the EU to describe the state of 'net-zero GHG emissions'. This definition is also used for this paper.

[3] European Commission (2018), In-Depth Analysis in Support of The Commission Communication, COM(2018) 773, Figure 91, p. 196.

[4] See https://data.consilium.europa.eu/doc/document/PE-27-2021-INIT/en/pdf, p. 29.

features as one of the key crosscutting actions in the Circular Economy Action Plan.[5] The importance of a robust certification mechanism is also noted in the Farm to Fork Strategy, which notes that it would be a first step towards enabling incentives for carbon sequestration by farmers and foresters.[6] A carbon farming initiative is also expected to be launched at the end of 2021, which may provide a way to compensate farmers for climate change mitigation activities.

The Fit-for-55 package released in July 2021 proposes updates to several pieces of legislation that will affect the policy framework for negative emissions in the EU. The EU Emissions Trading System (ETS) revision contains updates to how captured CO_2 will be treated, by removing an obligation to surrender allowances if the carbon is stored in long-lived products, i.e., carbon capture and utilization (CCU). This can indirectly affect the business case for negative emissions, as aspects of carbon capture, utilisation and storage (CCUS) infrastructure can be shared between technologies that reduce emissions and those used to deliver negative emissions.

The Land-Use Change and Forestry (LULUCF) Regulation will affect incentives to maintain and/or expand the natural carbon sinks in the EU. Likewise, the Effort-Sharing Regulation (ESR), even if applied to fewer sectors after potentially extending the EU ETS, will affect emissions in agriculture and thereby influence remaining negative emissions goals.

2. Getting the terms right

2.1 Definitions

Several terms occupy discussion around negative emissions. Crucially, there is some debate around the definition of negative emissions and how it relates to other terms. A clear definition is essential to avoid confusion, as well as ensure appropriate, coherent, and clear policy approaches. For this paper, we prioritise definitions provided by the IPCC and the United Nations Framework Convention on Climate Change (UNFCCC) where available.

The IPCC defines **negative emissions** as "Removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural carbon cycle processes."[7] **Net negative emissions** simply refer to a situation where more GHG emissions are removed than emitted, though permanency matters depending on timelines. Here, the IPCC also emphasises a focus on human activity in their definition.[8]

Negative emissions technologies (NETs), on the other hand, refer to the processes or ways in which negative emissions are achieved. Specifically, these may refer to a "technology or management option referring to a set of techniques that aim to remove CO_2 directly from the

[5] European Commission (2020), "Circular Economy Action Plan: For a cleaner and more competitive Europe", https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf

[6] European Commission (2020), "Farm to Fork Strategy: For a fair, healthy and environmentally-friendly food system", https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf.

[7] IPCC (2018), Special Report on Global Warming of 1.5C, Annex I: Glossary.

[8] Ibid.

atmosphere by either (1) increasing natural sinks for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration".[9]

Similarly, **Carbon dioxide removal (CDR**) generally refers to the action of removing CO_2 from the atmosphere. According to the IPCC, it can be defined as "Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. […]".[10] Tanzer et al present a definition of CDR requires four conditions to be met: 1) that CO_2 is physically removed from the atmosphere, 2) that the CO_2 is stored out of the atmosphere in a manner intended to be permanent, 3) that associated upstream and downstream GHG emissions are included in the emission balance, and 4) that the total quantity of atmospheric CO_2 removed and permanently stored is greater than the total quantity of CO_2 emitted to the atmosphere.[11] This differs from the definition used by the IPCC in a few ways. The IPCC's definition does not include the net negative aspect of the process of removing CO_2 and does, by contrast, explicitly exclude what is not directly caused by human activity.

It is worth noting that it is not just CO_2 that can be removed from the atmosphere. As such, the term **greenhouse gas removal (GHG removal)** is favoured by some. Nevertheless, the technologies needed for removing other greenhouse gases are less developed than CDR processes. The short-lived nature of many other greenhouse gases also means that focusing on CO_2, with its significantly long lifespan, remains more important.[12] Furthermore, (additional) CO_2 removal can compensate for the warming effect of other greenhouse gases.

With regards to the term **'sink'**, definitions vary between the IPCC and the UNFCCC. The former defines a sink as a "reservoir (natural or human, in soil, ocean, and plants) where a greenhouse gas, an aerosol or a precursor of a greenhouse gas is stored."[13] The UNFCCC on the other hand, focuses on the process, activity, or mechanism that removes GHGs, aerosols, or precursors from the atmosphere.[14]

The IPCC defines climate change **mitigation** as "human intervention to reduce emissions or enhance the sinks of greenhouse gases".[15] While explicitly including the enhancement of sinks, some researchers nevertheless discuss whether all NETs should be considered as contributing to mitigation activities under this definition; for example, NETs that rely on geological storage.[16]

---

[9] S. Fuss et al. (2018), "Negative emissions—Part 2: Costs, potentials and side effects", *Environmental Research Letters*, p. 37.

[10] See footnote 7.

[11] Paraphrased from S. E. Tanzer and A. Ramirez, (2019), "When are negative emissions negative emissions?", *Energy and Environmental Science*.

[12] Note that the lifetime of different GHG varies. See IPCC (2018), Special Report on Global Warming of 1.5C, Annex I: Glossary. pp. 66-67.

[13] See footnote 7.

[14] See Article 1(8) of UNFCCC (1992) *United Nations Framework Convention on Climate Change*, United Nations, FCCC/INFORMAL/84 GE.05-62220 (E) 200705, Secretariat of the United Nations Framework Convention on Climate Change.

[15] See footnote 7.

[16] Minx, J. C. et al. (2018), "Negative emissions—Part 1: Research landscape and synthesis", *Environmental Research Letters*.

Table 1. Definitions of key concepts

Concept	Definition	Source
(Climate change) mitigation	A human intervention to reduce emissions or enhance the sinks of greenhouse gases.	IPCC, 2018
Carbon dioxide removals	Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks, and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.	IPCC, 2018
Climate neutrality	Concept of a state in which human activities result in no net effect on the climate system. Achieving such a state would require balancing of residual emissions with emission (carbon dioxide) removal as well as accounting for regional or local biogeophysical effects of human activities that, for example, affect surface albedo or local climate.	IPCC, 2018
	The EU defines climate neutrality as net-zero GHG emissions, or "no net emissions of greenhouse gases".	EU, 2018
Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC)	Common but Differentiated Responsibilities and Respective Capabilities (CBDR–RC) is a key principle in the United Nations Framework Convention on Climate Change (UNFCCC) that recognises the different capabilities and differing responsibilities of individual countries in tacking climate change. The principle of CBDR–RC is embedded in the 1992 UNFCCC treaty. The convention states: "… the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions." Since then, the CBDR-RC principle has guided the UN climate negotiations.	IPCC, 2018
	A foundational principle of the UNFCCC, described in Art 3 (1) UNFCCC that states that developed countries should take the lead in combating climate change. It is also the principle that explains the differentiated nature of commitment under the Paris Agreement through "Nationally Determined Contributions".[17]	UNFCCC, 1992
Emissions reductions	Art 1 (4) of the UNFCCC defines emissions as "the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time". Emissions reductions can therefore be defined as: a reduction in the release of greenhouse gases from an emitting source into atmosphere. GHG emissions reductions are a form of climate change mitigation.	UNFCCC, 1992, authors' own elaboration
Geoengineering	Geoengineering refers to a broad set of methods and technologies that aim to deliberately alter the climate system in order to alleviate the impacts of climate change.	IPCC, 2013
	In this report, separate consideration is given to the two main approaches considered as 'geoengineering' in some of the literature: solar radiation modification (SRM) and carbon dioxide removal (CDR). Because of this separation, the term 'geoengineering' is not used in this report.	IPCC, 2018
GHG removal	Withdrawal of a GHG and/or a precursor from the atmosphere by a sink.	IPCC, 2018

[17] The application of this principle can be extended to negative emissions, implying that developed countries should take the lead in deploying them. See: Honegger et al. (2021).

Land use, land-use change and forestry (LULUCF)	In the context of national greenhouse gas (GHG) inventories under the UNFCCC, LULUCF is a GHG inventory sector that covers anthropogenic emissions and removals of GHG from carbon pools in 'managed land', excluding non-CO_2 agricultural emissions. Following the 2006 IPCC Guidelines for National GHG Inventories, 'anthropogenic' land-related GHG fluxes are defined as all those occurring on 'managed land', i.e., "where human interventions and practices have been applied to perform production, ecological or social functions". Since managed land may include CO_2 removals not considered as 'anthropogenic' in some of the scientific literature assessed in this report (e.g., removals associated with CO_2 fertilization and Nitrogen (N) deposition), the land-related net GHG emission estimates included in this report are not necessarily directly comparable with LULUCF estimates in National GHG Inventories.	IPCC, 2018
Negative emissions	Removal of greenhouse gases (GHGs) from the atmosphere by deliberate human activities, i.e., in addition to the removal that would occur via natural carbon cycle processes.	IPCC, 2018
Negative emissions technologies (NETs)	A technology or management option referring to a set of techniques that aim to remove CO_2 directly from the atmosphere by either (1) increasing natural sinks for carbon or (2) using chemical engineering to remove the CO_2, with the intent of reducing the atmospheric CO_2 concentration.	Fuss et al., 2018
Net negative emissions	A situation of net negative emissions is achieved when, as result of human activities, more greenhouse gases are removed from the atmosphere than are emitted into it. Where multiple greenhouse gases are involved, the quantification of negative emissions depends on the climate metric chosen to compare emissions of different gases (such as global warming potential, global temperature change potential, and others, as well as the chosen time horizon).	IPCC, 2018
Net zero CO_2 emissions	Net zero carbon dioxide emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.	IPCC, 2018
Sink	A reservoir (natural or human, in soil, ocean, and plants) where a greenhouse gas, an aerosol or a precursor of a greenhouse gas is stored.	IPCC, 2018
	"Sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.	UNFCCC, 1992

2.2 Categorisation

The IPCC Special Report on 1.5C[18] global warming describes seven negative emissions technologies, including their potentials as well as side effects both positive and negative. These are briefly summarised before discussing the various challenges of categorisation and why it matters for policy.

[18] The IPCC 6th Assessment WG1 report was released as this paper was being finalised. The AR6 report makes some further distinctions between different NETs, for example by adding "blue carbon"and other oceanic carbon uptake methods as well as peatland restoration.

Table 2. NETs featured by the IPCC Special Report on 1.5C (2018)

NET	Summary[19]
Afforestation and Reforestation	Afforestation and Reforestation deliver negative emissions by absorbing CO_2 in (an increasing volume of) trees. While afforestation refers to planting of trees on new land that did not previously contain forests, reforestation refers to the planting on land which previously did contain forests. *[It has positive side-effects for soil quality, which further supports carbon sinks. However, due to the impact on land, negative side-effects are possible including the Albedo effect,[20] threats to food security, and potentially negative implications for biodiversity in cases where more biodiverse grasslands are displaced by forests. Permanence and accounting are also concerns.]*
Bioenergy with CCS (BECCS[21])	BECCS deliver negative emissions by capturing and storing the CO_2 released from biomass when combusted. *[BECCS comes at a high cost due to the costs of CCS, but also has a lower land footprint. BECCS carries the risk of negative side-effects for biodiversity, air pollution, trace GHGs, and for food security.]*
Soil carbon sequestration	Soil carbon sequestration comprises a series of practices that deliver negative emissions by organically storing CO_2 in soils. *[It can deliver a concomitant reduction of N2O as another (hard to reduce) greenhouse gas. Permanence is a concern, however, as increased carbon uptakes in soil can be reversed in certain conditions.]*
Biochar	Biochar is a charcoal formed by pyrolysis of biomass, which results in negative emissions. When the charcoal with high carbon contents is added to soils, the carbon uptake in soils increases. *[Biochar is reliant on biomass availability. It can have positive side effects for soil quality. Permanence differs depending on soil type but can be as high as centuries.]*
Enhanced Weathering	Enhanced weathering delivers negative emissions by accelerating the mineral weathering process of rocks and distributing the ground-up rock over land. Enhanced weathering results in carbonation (i.e., carbonate rock formation), which may be considered a form of geological storage. *[Negative side-effects include water and ground pollution, as well as supply chain risks involving mining, extraction, and the energy-intensive process of grinding rocks, which may undermine the efficiency of these technologies in a climate neutrality perspective.]*
Ocean fertilisation	Ocean fertilisation delivers negative emissions by enhancing the carbon uptake of oceans. This is achieved by increasing the nutrient supply in the near-surface, by adding micro- or macro-nutrients. *[In contrast to the other approaches discussed above, the IPCC considers there to be limited evidence for, and low agreement on issues such as potentials, technological readiness, and permanence.]*
Direct Air Capture and Storage (DACS)	DACS technology extracts CO_2 directly from the atmosphere through chemical processes. This is then permanently stored to achieve negative emissions. If CO_2 captured with Direct Air Capture is used in short-lived products such as fuels, it is an example of CCU, and therefore not negative emissions. *[DACS has little known side-effects and has high potential (only constrained by global CO_2 storage), but also faces significant potential opportunity costs. The energy intensity of the direct air capture process may involve trade-offs with a scarce supply of climate neutral electricity and heat.*

[19] Based on IPCC (2018), Special Report on Global Warming of 1.5C

[20] i.e., global temperatures rising due to increased solar radiation absorption as a result of increased dark-coloured forests.

[21] Some literature and stakeholders (although not the IPCC) refer to the related concept of BiCRS – Biomass Carbon Removal and Storage – which puts the emphasis on carbon removal and the fact that the biomass does not necessarily need to be used for bioenergy. (see e.g., ICEF BiRCS Roadmap January 2021).

One of the common ways to categorise NETs/CDR has been to distinguish between those that are considered nature-based and those that are based on technology. It is also possible to distinguish between NETs based on either the capture (biological or technological) or storage approach (biological or geological). Some however, for example BECCS, could be considered as hybrids, having both natural and technological/chemical aspects. To bridge this gap, a distinct hybrid category may need to be added, or alternatively a more precise categorisation defined. Furthermore, calling some NETs natural implies that others are 'unnatural', which may unduly be seen as undesirable[22].

In its 1.5C report, the IPCC differentiates between two main types of CDR: those that enhance existing natural processes that remove carbon from the atmosphere, and those that use chemical processes. Afforestation and reforestation are mentioned as examples of the former, while DACCS is brought as an example of the latter.[23] This differentiation focuses on the way in which emissions are removed from the air or atmosphere. It does not focus on how the CO_2 is stored. As such, it may not pose the same difficulties to grouping negative emissions technologies as the more generalised categorisation above.

Placing the emphasis on the type of storage could be another way to differentiate between NETs. With this approach, technologies could be categorised between terrestrial, geological, or oceanic storage, or between more specific types of storage such as biomass on land, soil, geological reservoirs, minerals, or marine sediments and calcifiers.[24] These categories provide information on where the CO_2 is stored, while the permanence can vary with the technology in question.[25] Where the CO_2 is used (but not re-emitted), however, may not easily fit into these categories, and may require its own category. For example, the Royal Society includes the built environment as a separate storage mechanism category.[26]

Another potential categorisation could be between NETs and CDR technology that can solely be used for the purpose of achieving negative emissions, and that technology that can also be utilised for conventional mitigation. Examples of the latter would most notably include those that incorporate geological storage, such as DACCS and BECCS. Some industry stakeholders have suggested further ways to differentiate between NETs. This includes focusing on certain trade-offs, such as energy consumption or land use, or by focusing on co-benefits.

Permanence is another way of categorising different types of negative emissions technologies. The stability or reversibility of the emissions stored - meaning the degree to which they are at risk of being released, and the time frame in which they are likely to remain stored - has a crucial importance in this context, as it affects the permanence of any option. Geological

[22] See R. Bellamy and S. Osaka, S. (2020), "Unnatural climate solutions?", *Nature Climate Change*.

[23] IPCC (2018), Special Report on Global Warming of 1.5C, Annex I: Glossary, p. 394.

[24] See https://iopscience.iop.org/article/10.1088/1748-9326/aabf9b/pdf, p. 6.

[25] See footnote 16, p. 14.

[26] The Royal Society (2018), *Greenhouse Gas Removal*.

storage[27] such as BECCS and DACS is, for example, generally considered to have a high degree of permanence. The same goes for enhanced weathering and many biochar applications. Storage in forests and organic soil matter is, on the other hand, considered more reversible due to risks from natural and human disturbances. Fires, drought, soil degradation, pests, or changes in land management and human activity could for example all risk (partial) release back into the atmosphere.[28] Permanence also affects carbon accounting, for which the time the emissions are likely to remain stored will be crucial. Differentiating between NETs on the basis of permanence could thus be a useful way to group negative emissions technologies, though deciding on clear lines between categories remains an open question.

In the end, different categories provide different information about negative emissions technologies. A combination of different categories may therefore be useful to inform debate and policy. Permanence will inevitably be important, however, and the type of storage may also provide information about this.

3. Differences within NETs

Negative emissions technologies have the potential to deliver simultaneously on multiple dimensions of sustainable growth. The opposite however is also possible and these trade-offs therefore require political choices.

3.1 Risks and timeline

For mitigation policies beyond emissions reduction policies such as negative emissions and CDR, time horizons are not the same and may be insufficient or inappropriate. Negative emissions are intrinsically linked to the concentration of CO_2 in the atmosphere and may need to continue long beyond 2050, either to compensate for residual emissions, or because the atmospheric concentration of CO_2 as such is considered too high.[29]

Another reason why policy time horizons are different for negative emissions concerns consistency. Unlike with emissions reduction, where a tonne of CO_2 reduced will have a benefit both in the short, medium and long term, certain negative emissions technologies can have negative impacts on the atmospheric concentration of CO_2 in the short-term, but positive in the long-term (i.e., a "carbon debt"). The opposite is possible as well: positive short-term impacts but neutral or negative long-term, for example due to a lack of permanence.

[27] There are different approaches to geological storage. Some lead to mineralisation of CO2 (on different time-scales) which in turn supports permanence.

[28] IPCC (2018), Global Warming of 1.5°C p. 125; https://iopscience.iop.org/article/10.1088/1748-9326/aabf9b/pdf, p. 14-16.

[29] It is conceivable that a certain level of CO2 concentration would be targeted globally in the future (expressed in parts per million – ppm). This would create transparent demand for future negative emissions volumes. The pre-industrial CO2 concentration was 280 ppm. In 2021 the concentration reached 419 ppm.

Timelines are also relevant from a technology readiness and availability perspective, as many NETs are still at an immature stage. To scale up the supply of carbon removal, negative emissions technologies may need to be incentivised before the demand is there because of the need to reach (net-zero) climate targets. Similarly, to emissions reductions technologies, learning effects and economies of scale can drive down the costs of a technology. As there is a need to remove large volumes of CO_2 from the atmosphere, technologies that can achieve this should be incentivised in the short term so that they can deliver at the requisite volumes in the longer term, and especially when emissions reductions are exhausted, or net-negative emissions targets need to be reached.

The overshoot of temperature targets is one specific scenario where the role of negative emissions would become critical. Removal of carbon from the atmosphere would then be the (only) means of bringing global temperatures back down. Doing so would require net-negative emissions, i.e., a greater volume of removals than what remains in GHG emissions. "The larger and longer an overshoot, the greater the reliance on practices that remove CO_2 from the atmosphere."[30]

There is also some debate on the equivalence of emissions reductions and negative emissions. The IPCC notes that CO_2 removals have a non-linear impact on global temperatures. While this could mean that greater negative emissions would be needed to compensate for one tonne of emissions, it could also provide further justification for prioritising emissions reductions over negative emissions.[31]

3.2 Trade-offs and co-benefits

3.2.1 Land

The most significant potential trade-offs with negative emissions involve land. "Land is a critical resource and plays an important role in the climate system,"[32] according to the IPCC's special report on land; for both good and bad reasons. Land-use through forestry and agriculture accounts for nearly a quarter of global GHG emissions but can equally play a large role in providing biomass for renewable energy and contributing to climate change mitigation through carbon dioxide removal.

Even in global mitigation scenarios that the IPCC considers to be limiting the use of bioenergy and BECCS, the global land area used for bioenergy would be nearly 1 million square kilometres, which is roughly the size of Egypt's or Tanzania's landmass. However, biomass is not a homogenous category. Agricultural and food waste have different land-use implications than do crops or woody biomass grown for bioenergy. For afforestation and reforestation, the land

[30] See https://www.ipcc.ch/sr15/faq/faq-chapter-4/.

[31] See https://www.carbonbrief.org/guest-post-why-co2-removal-is-not-equal-and-opposite-to-reducing-emissions.

[32] See https://www.ipcc.ch/2019/08/08/land-is-a-critical-resource_srccl/.

footprint per tonne of CO_2 removed is higher than for BECCS.[33] Other NETs that may require land to some extent include soil carbon sequestration, biochar, and enhanced weathering.

Beyond climate mitigation, land is critical for food security and biodiversity. For negative emissions technologies that require significant arable land, trade-offs with food production and security may arise. With regards to bioenergy, competition for land could lead to shortages and increased food prices, though not all bioenergy is necessarily in direct competition with food production.[34] Similarly, an expansion of bioenergy can threaten biodiversity if it displaces or disrupts land ecosystems with high biodiversity. This may limit the scale of the potential contribution of land-intensive negative emissions approaches involving bioenergy or afforestation and reforestation.

Nevertheless, potential benefits beyond carbon removal might also arise from different negative emissions technologies, though these are often conditional and depend on how and where they are deployed. Enhanced weathering, soil carbon sequestration, and biochar could provide co-benefits in terms of soil nutrients and N_2O emissions reductions. With regards to biodiversity, reforestation could have positive effects on biodiversity if it restores natural ecosystems.[35] If deployed on degraded land, bioenergy may also provide benefits in terms of soil restoration and protection from erosion.[36] Food security is also threatened by climate impacts, and as such, efforts to mitigate climate change, including CDR, could also indirectly help improve food security.

3.2.2 Energy

Some negative emissions technologies require energy for their operations, in addition to any energy that may be needed to produce, transport, and install the negative emissions capacity. These energy penalties can undermine the efficiency of different carbon removal technologies, depending on amounts required and whether the energy is low-carbon. While negative emissions are still possible even if fossil fuels are used, this would reduce the economic efficiency of removing carbon from the atmosphere. From an emissions perspective, any energy needed for NETs would ideally be provided by renewable sources, although any emissions from fossil fuels used could also be captured.

On the other hand, if significant volumes of renewables are needed, the question of optimal use of scarce resources that can also be deployed to reduce emissions becomes relevant. Virtually every sector of the economy requires increased volumes of renewables due to electrification as a principal decarbonisation route. Therefore, combining emissions reductions and negative emissions involve trade-offs (see also section 4.1) for the deployment of resources, in particular while lower cost emissions reductions have not been exhausted. A

[33] See https://www.ipcc.ch/sr15/chapter/chapter-4/ - section 4.3.7.

[34] S. Fuss et al. (2018), "Negative emissions—Part 2: Costs, potentials and side effects", *Environmental Research Letters*, p. 13.

[35] IPCC (2018), Special Report on Global Warming of 1.5C, p. 266.

[36] See footnote 34.

specific example is Direct Air Capture with geological storage. Direct Air Capture directly affects the atmospheric concentration of carbon dioxide by removing CO_2 from the atmosphere. To achieve this, vast volumes of energy (both electricity and heat) are required.

If public financing is involved, policymakers will have an interest in ensuring that scarce resources such as renewables are deployed where they have the greatest impact in mitigating climate change. If there are sufficient market signals for both emissions reductions and negative emissions, and the technologies to provide for either are competitive, such trade-offs will automatically resolve themselves. Before that stage is reached, however, policymakers may not be able to evade making explicit choices on the extent of financial and regulatory support.

3.2.3 Geological storage

Captured CO_2 requires storage space, irrespective of whether it is captured directly from the atmosphere, or if it is captured from industrial processes before it is emitted. This also applies to certain negative emissions technologies such as DACCS and BECCS, which need to store the emissions captured from the atmosphere (DACCS) or from bioenergy plants (BECCS).

In principle, the potential availability of geological storage is not expected to be a constraint.[37] On a global scale, estimates range between 8 000 to 55 000 $GtCO_2$.[38] Nevertheless, available storage space may in reality be scarcer. To "turn technical geological storage capacity into economical storage capacity, the storage project must be economically viable, technically feasible, safe, environmentally and socially sustainable and acceptable to the community."[39] Particularly for storage options on land, public perception may also play a more notable role in limiting the availability of storage options. In this case, while CCS infrastructure can serve both, a question for policymakers might be whether to prioritise the deployment of CCS for emissions reductions in industry, or prioritise the deployment of CCS for negative emissions, e.g., through BECCS or DACCS. In addition, operationalisation of sites may also come with a time lag. The fact that a geological site could in theory be used for storage does not mean CO_2 storage could practically start. This affects the planning and business case of carbon capture projects.

3.2.4 Use of CO_2

Captured CO_2 does not necessarily have to be stored in geological sites. It is also possible to use the CO_2 as an input for other products. In cases where CO_2 is first absorbed from the atmosphere (e.g., through direct air capture or through biomass) and subsequently used in products where the CO_2 is stored permanently, carbon capture and use (CCU) can also be considered as contributing to negative emissions. However, in some cases of use, the emissions of CO_2 are simply deferred and not avoided. Indeed, most cases of CCU to date are not permanent. One prominent example is synthetic fuels. While synthetic fuels could decarbonise hard-to-abate sectors such as aviation, they are at best carbon-neutral, as the CO_2 re-enters

[37] See footnote 34, p. 11.

[38] IEA (2021), "The world has vast capacity to store CO2: Net zero means we'll need it".

[39] IPCC (2005), *IPCC Special Report on Carbon Dioxide Capture and Storage*, p. 200.

the atmosphere once used. This illustrates the potential for overlaps between mitigation technologies for carbon removal and emissions reductions.

3.3 Readiness and costs

Not all negative emissions technologies are readily available as of today. Beyond afforestation and reforestation, whose deployment is primarily limited by trade-offs, other negative emissions technologies may be at earlier stages of development. These include, among others, BECCS, biochar, DACS, enhanced weathering, and ocean alkalinisation. So far, BECCS is the only technology that has been included in the IPCC's pathways to 1.5°C alongside afforestation and reforestation. Nevertheless, lack of scale and uncertainties remain also for the availability of this option. For many of the other technologies, uncertainty remains regarding the potential and the desired scale of deployment, relating to trade-offs and the availability of resources (see section 2.2).

Just as the availability and maturity of different negative emissions technologies vary widely, so does cost. Due to learning effects and scale, costs can be both high and uncertain, especially where a technology is new and may decrease in cost as it matures and is scaled up. For example, cost estimates range from around US$100–300/t$CO_2$ for DACS though some estimates can reach up to US$1000/t$CO_2$ and are expected to decrease in the long term. Cost estimates also vary between liquid solvent and solid sorbent DACS technologies, today with the latter at a higher cost than the former.[40] While starting at a lower level of US$30–120/t$CO_2$, modest cost decreases for biochar may also come as the technology matures. Afforestation and reforestation, on the other hand, tend to be among the cheaper options, with estimates at around US$5-50/t$CO_2$.[41]

However, costs could also increase with scarcity, especially for those technologies that may compete for or be constrained by limited resources, such as land and available storage. Afforestation and reforestation, while among the cheaper options, may for example see increasing costs as the opportunity costs for land use increase (i.e., when suitable land becomes scarcer). This could also become the case for BECCS, due to trade-offs for both land and biomass, as well as enhanced weathering due to decreasing availability of nearby mining and deployment sites.[42] Should regulation or public concern limit the availability of geological storage sites, or should their operationalisation when needed be delayed, this could potentially also affect the costs of technologies relying on these sites for storage.

To scale up and ensure the availability of different negative emissions technologies, policy support is needed sooner rather than later. Investments are needed long before the various options can contribute significant volumes of negative emissions and will need to be

[40] Current range of 450-900 £/tonne for solid sorbent, while 180-270 £/tonne for liquid solvent (https://coalitionfornegativeemissions.org/the-case-for-negative-emissions-executive-summary/).

[41] See footnote 34, p. 33.

[42] Ibid.

encouraged through appropriate policy measures. Nevertheless, already-existing options could be further deployed. Considerations about trade-offs, co-benefits, permanence, and costs will all need to be considered in policy development.

3.4 Accounting issues

Permanence is a key criterion by which to compare and assess negative emissions and carbon removal approaches. While lack of permanence does not have to imply that negative emissions technologies with limited permanence cannot contribute to mitigation, the carbon accounting becomes more important. Additionally, depending on the time scale, it may have implications for the scale at which these limited options should be pursued.

The IPCC states in its Land report that "Land-based options that deliver carbon sequestration in soil or vegetation [...] do not continue to sequester carbon indefinitely". In addition, "accumulated carbon in vegetation and soils is at risk from future loss (or sink reversal) triggered by disturbances such as flood, drought, fire, or pest outbreaks, or future poor management."[43] Therefore, negative emissions options that are not permanent may tend to have more complicated accounting to reflect potential future perturbations. Conversely, with options that are considered permanent, the accounting would only need to reflect the balance of emissions once the carbon removal process has been completed.

A complicating factor could be associated emissions; those that may result from the process itself, or also from the production of technology installations or transport. For example, certain technologies are energy intensive, which – depending on whether renewable energy or carbon-capture is used – could lead to additional emissions. Transportation of materials or even CO_2 may also be envisaged, which could also lead to emissions depending on transportation mode. From an accounting perspective, it would be important to take the entire lifecycle emissions into account to ensure that net negative emissions are achieved for each activity. This would however make accounting more challenging.

If negative emissions are not expressed as an absolute volume (tonnes of CO_2e), a reference to baseline years may be necessary, as is the case for emissions reductions. The common baseline year is 1990. To illustrate: if the EU should want to compensate for 5% of residual emissions with negative emissions, the annual volume of negative emissions would be around 250 million tonnes. If the EU should adopt a net-negative target of -20% at some point, this would amount to 1 billion tonnes of carbon removed annually. In 2019, EU27 GHG emissions amounted to 3.5 billion tonnes, including the net sink from LULUCF.[44]

[43] Section {6.4.1} of the IPCC Special Report on Climate Change and Land.

[44] See https://ec.europa.eu/clima/sites/clima/files/strategies/progress/docs/com_2020_777_en.pdf.

4. Discussion: political choices and potential concerns

4.1 Flexibility or separate targets

Negative emissions can compensate for residual emissions, or they can help deliver net-negative emissions. The removal of CO_2 from the atmosphere can also compensate for other greenhouse gases that are virtually impossible to reduce to zero (e.g., N_2O or CH_4). Until the point where emissions reductions are deemed exhausted, any volume of negative emissions still offsets greenhouse gases that continue to be emitted. This can be seen as desirable or undesirable, depending on the perspective taken.

Negative emissions compensating for emissions can in one way create flexibility for countries in meeting their emissions reductions targets. If the costs of additional negative emissions are lower than the abatement costs of emissions, focusing climate policy on NETs could be more cost effective compared to conventional mitigation options. On the other hand, it could arguably also lead to decreased pressure to invest further in reducing emissions and could discourage and displace investment in conventional emission reduction technology. There is therefore a risk that an expectation of large volumes of negative emissions could defer efforts to reduce emissions, particularly in sectors that are considered hard-to-abate. Should it then prove unfeasible to deliver the requisite volume of negative emissions, the achievements of climate neutrality goals – and ultimately the Paris Agreement temperature targets – may be at risk. This can be seen as a form of moral hazard.

Political decisions are therefore needed, which can take the form of separate targets for negative emissions, or explicit choices about net emissions targets. With the updated 2030 target of "at least net -55%", the EU has already made such a choice. Furthermore, the legal text of the newly adopted European Climate Law states that "In order to ensure that sufficient mitigation efforts are deployed until 2030, it is appropriate to limit the contribution of net removals to the Union 2030 climate target to that level."[45] This only covers natural carbon sinks however, and the potential contribution of other negative emissions technologies is still to be decided.

Flexibility between policy frameworks is another dimension that may become relevant in the EU policy debate in the short term. Currently, just under 2/5th of GHG emissions in the EU are covered by the EU ETS, with the remaining 3/5th covered by the Effort-Sharing Regulation. GHG emissions and removals (i.e., sinks) from the forestry and land-use sector are covered separately in the LULUCF Regulation. As part of the Green Deal, a separate ETS for road transport and buildings may be introduced, with integration into the main EU ETS being an option for a later stage.

Regardless of whether a sector is included in an ETS, the Effort-Sharing approach could continue to allow differentiation between member state's targets. Such targets could include separate negative emissions targets or be expressed as net targets. Flexibility between the different

[45] See https://data.consilium.europa.eu/doc/document/PE-27-2021-INIT/en/pdf.

frameworks already exists between the ETS and Effort Sharing, as well as Effort Sharing and LULUCF frameworks. Allowing negative emissions of a certain type could facilitate more flexibility between the frameworks, by allowing transfers, but can also be a reason to constrain it.

Moral hazard can remain an issue even with separate targets, as the setting of emissions reduction and carbon removal targets is an iterative political process. The knowledge that there will be some volume of removals may affect the incentives for policymakers to accept a given emissions reductions target. Any combination of emissions reduction and removals targets can also be expressed as a net target.

4.2 Public acceptance

Despite their potential to contribute to mitigating climate chance, negative emissions technologies may run into public perception and acceptance problems. Some of this may be related to the concept of negative emissions as such, and whether it is perceived as a legitimate form of mitigation or climate policy. This relates to public concern that it may displace investment in and focus on conventional mitigation options, as well as concerns over permanence. The categorisation of negative emissions technologies can similarly affect public opinion, with 'natural' solutions being perceived as more desirable.[46] The specific technology to deliver negative emissions may also affect acceptance. Indeed, some forms of carbon removal make use of technologies that are themselves facing public acceptance issues, irrespective of whether or not they are able to deliver negative emissions.

Bioenergy has been a source of political controversy in the EU through debate concerning biofuels and adverse impacts on land-use and food security (see section 2.2.1). The combustion of woody biomass (which contributes to the share of renewable energy in final energy consumption), meanwhile, has also led to controversy in some member states. Both the carbon accounting dimension – with the biomass harvest being accounted for under the forestry and land-use (AFOLU) sector of the country producing the biomass while being considered zero-carbon when combusted – as well as the alternative uses of wood and land play into this.

CCS applied as a conventional emissions reduction technology has also faced public acceptance challenges. CCS has long been discussed as an emissions abatement technology, although initial projects often focused on the power sector. With the increasing competitiveness of renewables, alternatives to CCS were often seen as more attractive and investment in CCS less desirable. Nevertheless, for hard to abate industrial sectors there may be fewer alternatives to reduce emissions. Hence, several projects focusing on industrial CCS have recently found support in the Netherlands, Norway, and the UK. Even so, the use of CCS may be controversial from a political point of view if there are public concerns about safety and permanence.

[46] See https://www.nature.com/articles/s41558-019-0661-z?proof=t.

5. Policy conclusions

Clarity and consensus on the basic terms, definitions, and categorisations around negative emissions is important when discussing policy framework and market incentives. Both emissions reductions and negative emissions are climate change mitigation. It is important however, to clearly differentiate between the two concepts. Furthermore, certain technologies can also contribute to both. For instance, CCS is an emissions reductions technology, but if combined with bioenergy (BECCS) or direct air capture (DACS), it becomes a negative emissions technology.

Pursuing negative emissions should not deter or replace emissions reductions. Given the difficulty of meeting the 1.5C target of the Paris Agreement, both are needed. Political choices are required to resolve the trade-offs between negative emissions compensating for emissions, and to deliver net-negative emissions. These choices need to be made for different time horizons, as the EU has already done for 2030. Separate targets may be one way of addressing this. However, in some cases, flexibility and cost-effectiveness may be reasons to allow negative emissions to offset continued emissions. One key question would be about the fungibility of negative emissions credits with other accounting units under various policy instruments (e.g., EUAs under the ETS, or AEAs under Effort Sharing).

To scale up negative emissions technologies in time to deliver negative emissions (for either residual emissions or for net-negative emissions after 2050) at the scale required, policy efforts need to start today. Clarity on demand for negative emissions (credits) can be important in establishing a positive business case for investment in negative emissions technologies. For instance, the year in which the EU ETS cap will reach zero, which will be well before 2050, with the more rapid reduction of the emissions ceiling proposed as part of the Fit-for-55 package will determine when no new regular ETS allowances would be issued. Negative emissions credits, however, could in theory be used for compliance for residual ETS emissions.

Deployment ahead of commercialization could achieve cost reductions through learning effects. An open question is if NETs should be eligible for public support using existing instruments to support emissions reductions, or if new targeted support mechanisms would be better placed.

Nevertheless, the EU is not starting from a blank slate. Existing policy frameworks already account for some NETs, such as natural carbon sinks under LULUCF. The same goes for flexibilities between policy frameworks, such as between the ETS and Effort Sharing. This is an additional reason to advance quickly with a general negative emissions framework, to ensure that other (technological and hybrid) types of negative emissions can also be pursued.

While an all-encompassing framework could be attractive, the differences between options also matter. Different types of negative emissions may need to be pursued simultaneously, though maintaining complete technology neutrality could be difficult. The categories used to group NETs may have an important role to play. For different policy frameworks such as ETS, ESR, and LULUCF, specific types of NETs could for example be allowed, excluding others. Whether or not there should be open categories or closed lists of technologies annexed to relevant legislation would need to be determined. A regulatory framework that is flexible enough to adapt to new emerging technologies, and changing economic incentives, will be needed to scale up negative emissions. The EU certification system currently being developed will play a role here.

In the future, the EU will need to clarify policy targets for negative emissions. Whether to have separate negative emissions targets, or to what extent negative emissions can contribute to regular emissions reductions targets requires a political choice. Another element is whether differentiation between different categories of negative emissions is desirable. For incentives, options are numerous and may include direct procurement of negative emissions volumes; issuance of credits for compliance with existing climate policies; carbon take-back obligations or carbon removal obligations[47]; and the use of discount rates to address permanence or moral hazard concerns.[48]

Policy conclusions

- **Start today:** To scale up negative emissions technologies to deliver the negative emissions needed in the future, clarity, policy, and incentives need to be in place sooner rather than later.
- **Policy coherence**: Co-benefits, side-effects, and trade-offs matter and vary between NETs. These should be accounted for in policymaking, in addition to permanence.
- **Pursue negative emissions in addition to emissions reductions**: Pursuing negative emissions should not deter or replace emissions reductions, as both mitigation categories will be needed.

[47] See https://www.nature.com/articles/s41586-021-03723-9.

[48] These will be discussed in an upcoming CEPS policy paper, to be released in autumn 2021, which will be informed by this Scoping Paper.

References

Bellamy, R. and S. Osaka (2020), "Unnatural climate solutions?", *Nature Climate Change,* 10, 98–99 (https://doi.org/10.1038/s41558-019-0661-z).

European Commission (2018), In-Depth Analysis in Support of the Commission Communication, COM(2018) 773.

European Commission (2020), "Circular Economy Action Plan: For a cleaner and more competitive Europe" (https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf).

European Commission (2020), "Farm to Fork Stratgey: For a fair, healthy and environmentally-friendly food system" (https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf).

Fuss, S. et al. (2018), "Negative emissions—Part 2: Costs, potentials and side effects", *Environmental Research Letters*, *13*(6), 063002.

Honegger, M, W. Burns, D.R. Morrow (2021), "Is carbon dioxide removal 'mitigation of climate change'?", *RECIEL*. 2021; 00: 1– 9 (https://doi.org/10.1111/reel.12401).

IEA (2021), *"*The world has vast capacity to store CO2: Net zero means we'll need it"*, IEA, Paris (https://www.iea.org/commentaries/the-world-has-vast-capacity-to-store-co2-net-zero-means-we-ll-need-it).*

IPCC (2005), *IPCC Special Report on Carbon Dioxide Capture and Storage,* Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)], Cambridge University Press.

IPCC (2018), "Annex I: Glossary" [Matthews, J.B.R. (ed.)] in Masson-Delmotte, V. et al. (eds.) *Global Warming of 1.5°C,* An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf).

Minx, J. C. et al. (2018), "Negative emissions—Part 1: Research landscape and synthesis", *Environmental Research Letters*, 13(6) 063001.

Sandalow, D., R. Aines, J. Friedmann, C. McCormick and D.L. Sanchez (2021), Biomass Carbon Removal and Storage (BiRCS) Roadmap, ICEF, January (https://www.icef.go.jp/pdf/2020/roadmap/roadmap.pdf).

Tanzer, S. E. and A. Ramirez (2019), "When are negative emissions negative emissions?", *Energy and Environmental Science*, 12(4), 1210-1218.

The Royal Society (2018), *Greenhouse Gas Removal* (https://royalsociety.org/-/media/policy/projects/greenhouse-gas-removal/royal-society-greenhouse-gas-removal-report-2018.pdf).

UNFCCC (1992), *United Nations Framework Convention on Climate Change*. United Nations, FCCC/INFORMAL/84 GE.05-62220 (E) 200705, Secretariat of the United Nations Framework Convention on Climate Change (https://unfccc.int/resource/docs/convkp/conveng.pdf).