BRIEFING

Towards climate neutrality

European Parliament

Carbon dioxide removal

Nature-based and technological solutions

SUMMARY

As a party to the Paris Agreement, the European Union has committed to implementing climate mitigation policies to keep the average temperature rise to well below 2°C, while pursuing efforts to limit it to 1.5°C. Meeting the more ambitious goal of 1.5°C requires bringing the level of global net greenhouse gas emissions to zero by around 2050, according to the Intergovernmental Panel on Climate Change (IPCC). Following this scientific consensus, the European Commission presented in 2019 the European Green Deal as the strategy towards a climate-neutral Europe by 2050, and proposed a European climate law in 2020 to make this target legally binding.

The IPCC scenarios consistent with limiting the temperature rise to 1.5°C show that removing CO_2 from the atmosphere is essential and complements the implementation of emissions reduction policies. In line with this, the European science academies recommend prioritising deep emissions cuts, but also to start developing a portfolio of carbon dioxide removal (CDR) options immediately.

Various options are being discussed in light of the growing consensus that meeting the established targets is dependent on CDR. These range from nature-based practices – such as forestation, soil carbon sequestration and wetland restoration – to technological alternatives such as enhanced weathering, bioenergy with carbon capture and storage, and direct air capture and storage. Nature-based solutions stand out as more cost-effective and viable in the short run, while some technological alternatives have potential to become more relevant later this century.

The European Commission recognises the crucial role of CDR, and intends to focus on nature-based options. An extensive revision of the EU climate mitigation legislation, planned for 2021, will provide an opportunity to set a regulatory framework for CDR.

The European Parliament has repeatedly called for prioritising emissions reductions over CDR, and stressed the importance of conserving biodiversity and enhancing natural sinks and reservoirs. Its position on the proposed European climate law involves removing GHGs that exceed manmade emissions in the EU and each Member State from 2051.

In this Briefing

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Climate action commitments and targets

Adopted in 2015, the Paris Agreement is the first legally binding climate change agreement with a universal scope. By ratifying it in 2016, the European Union (EU) and its Member States committed to taking action to hold the increase in global average temperature compared to pre-industrial levels well below 2°C, and to making efforts to limit the temperature increase to 1.5°C. To this end, the contracting parties agreed to reach net-zero greenhouse gas (GHG) emissions in the second half of the 21st century at the latest, that is, balancing GHG emissions with removals resulting from human activities, which are described in this briefing. The parties shall periodically submit nationally determined contributions (NDCs), which set out their emission reduction targets and plans.

In 2019, the European Commission presented a growth strategy – the European Green Deal – that set out a comprehensive roadmap for making the economy sustainable and climate-neutral by 2050, i.e. achieving net-zero GHG emissions by 2050. To make this target legally binding, in March 2020 the Commission submitted a legislative proposal on a European climate law, which it then amended in September, raising the EU's GHG emissions reduction target for 2030 from the current 40 % to at least 55 % reduction of net emissions compared with 1990 levels. This amendment was based on an impact assessment that evaluated a number of policy options to ensure a smooth transition towards the climate neutrality target of 2050.

In October 2020, the European Parliament adopted amendments to the proposal, including a motion to raise the ambition to a 60 % reduction in total emissions by 2030. In December, the European Council endorsed the 55 % net target, which was subsequently supported by the Environment Council and submitted to the UNFCCC as the EU's updated NDC.

Net emissions: Status and pathways

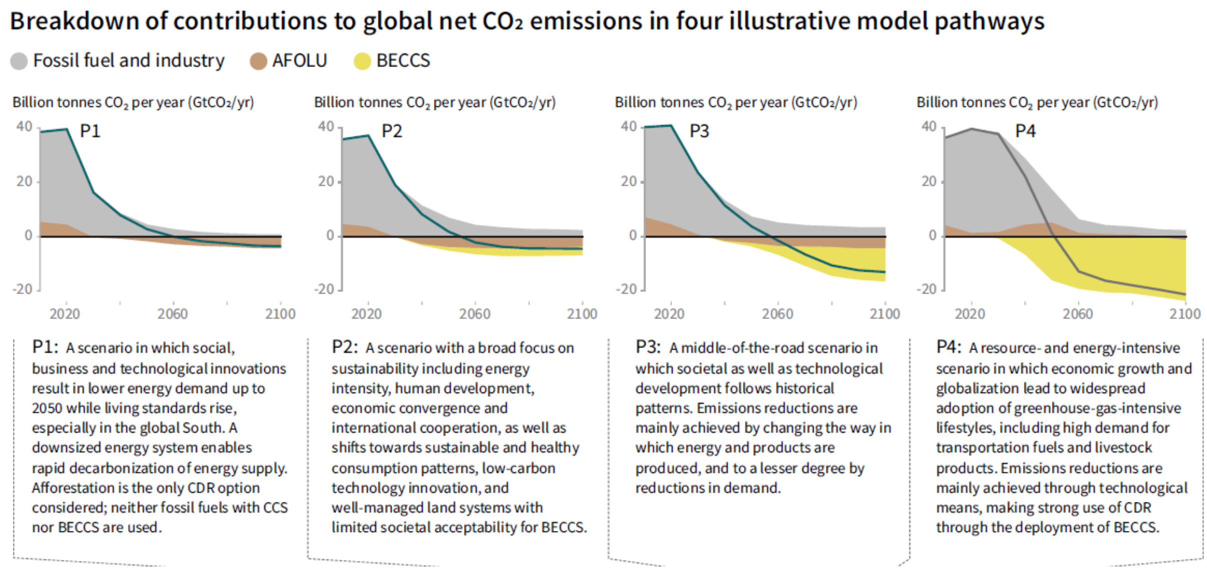
According to the IPCC Special Report on 1.5°C, anthropogenic global warming reached 1°C above pre-industrial levels in 2017. At the current global annual emissions of 42 billion tonnes (Gt) CO_2, the report states the temperature is likely to reach 1.5°C of warming between 2030 and 2052.

Given the quasi-linear relationship between the cumulative amount of CO_2 emissions and global mean temperature rise, achieving the Paris Agreement targets requires staying within the carbon budget (the amount of CO_2 emissions permitted to keep within the temperature thresholds set by the agreement). The IPCC report provides estimates on the remaining carbon budget from 2018, saying that 1 500 Gt CO_2 could be emitted from 2018 onwards for a 50 % probability of limiting warming to 2°C, and around 1 170 Gt CO_2 for a 66 % probability. The remaining carbon budget for 1.5°C is estimated to be 580 Gt CO_2 and 420 Gt CO_2 for probabilities of 50 % and 66 % respectively. The NDCs submitted under the agreement (up to 2018) would result in emissions that already exhaust between 70 % and 130 % of the remaining 1.5°C carbon budget by 2030.

The IPCC report maps four pathways that are consistent with limiting the temperature rise to 1.5°C (see Figure 1 below). These pathways show the evolution of annual net emissions under different assumptions and mitigation approaches, and allow two important conclusions to be drawn. Firstly, limiting global warming to 1.5°C requires that global anthropogenic net emissions should be zero by around 2050. Secondly, meeting this goal requires the deployment of CDR, which, as suggested in Figure 1, can happen by means of bioenergy with carbon capture and storage (BECCS) and removals in the agriculture, forestry and other land use (AFOLU) sector.[1]

The IPCC defines CDR as 'anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products'. The present document distinguishes CDR practices, which refer to nature-based solutions including forestation, soil management, biochar and wetland restoration, from CDR technologies such as enhanced weathering, bioenergy with carbon capture and storage (BECCS) and direct air capture with CCS (DACCS). In the literature, the full set of alternatives is also referred to as CDR technologies or greenhouse gas removal/negative emissions technologies.

Figure 1: IPCC emissions pathways compatible with 1.5°C of warming



Source: Summary for policymakers of the IPCC Special Report on Global Warming of 1.5°C (2018).

The four scenarios in Figure 1 above show different mitigation portfolios with varied decarbonisation rates, energy and resource intensity and reliance on CDR. The figure and the literature clearly show that the less rapid and stringent the GHG emissions reductions are, the stronger the dependence on CDR for meeting the targets of the Paris Agreement grows. Depending on when CDR is deployed, it can serve two different purposes: i) either accelerate the achievement of net-zero emissions by compensating those from harder-to-abate sectors and thus increase the likelihood of staying within the temperature thresholds; or ii) bring global warming below the thresholds following a temperature peak over them (an overshoot).

Climate models suggest that limiting global warming to 1.5°C or 2°C is only feasible with an extensive deployment of CDR after 2030 if the NDCs submitted until 2018 are fully implemented. Thus, according to the European science academies (EASAC), NDCs should be strengthened, and emissions reductions should have priority. However, they stress that emissions reductions should be accompanied by applying feasible CDR approaches now, not later. This would increase the probability of meeting the Paris Agreement, prevent some of the catastrophic impacts of global warming, and limit further dependence on CDR to achieve the targets.

The following sections review the leading alternatives for CDR in terms of abatement potential and cost, side effects and state of development.[2] A final discussion summarises the main conclusions from the literature.

Emissions in the EU

GHG emissions in the EU-27 declined by 24 % between 1990 and 2019, implying that the EU will largely exceed its 2020 target of 20 % emissions reduction. However, according to the European Commission's impact assessment of the climate target plan, the average reduction rate observed in the past is not enough to reach the current 40 % target by 2030, let alone the more ambitious targets recently agreed. The current and planned policies and measures will boost the emissions reduction rate, but not sufficiently. The European Commission estimates that, by 2030, only a 41 % reduction will be achieved. Thus, there is a wide gap between existing and planned measures and the 55 % target. Given the potential challenges of meeting the targets through emissions reductions alone, CDR alternatives need to be assessed for informing the design of EU mitigation strategies. This message has been forcefully conveyed in a SWP research paper: 'since the EU claims to base its climate policy on the climate science consensus developed in IPCC reports, it will no longer be concerned with whether to use CDR or not, but only how'.

Nature-based solutions

Forestation. This term refers to the planting of trees in currently non-forested areas and comprises reforestation of land that previously contained forest, and afforestation of land that did not contain forests. In the new forest, CO_2 sequestration will mainly occur through photosynthesis, resulting in carbon storage in above- and below-ground biomass. In addition, carbon will be sequestered in soils by the transfer from biomass through litter fall, dead roots and leaching from roots. The magnitude of carbon sequestration in the new ecosystem will depend considerably on the type of soil, tree species chosen and forest management practices, but also on characteristics such as climate and moisture.

A 2018 assessment report[3] (Fuss et al.) provides estimates on the potential of forestation for CDR up to 2050, which is in the range of 0.5-3.6 Gt CO_2 per year. Regarding costs, the report calculates that removing one tonne of CO_2 costs US$5-50. However, the cost-effectiveness of forestation varies across regions due to diverse factors such as those mentioned in the previous paragraph.

Regarding side effects, potential positive impacts could relate to employment and local livelihood. Furthermore, improvements of soil quality and nutrients and water cycles are also expected. Potential impacts on biodiversity are case-specific but can be positive when using native and diverse species. Concerns arise regarding the effect of forestation on the albedo, i.e. the capability of a surface to reflect or absorb solar radiation. Forestation lowers the albedo, increasing the temperature of the surface. The change in albedo in some forests could offset the mitigation impact of this CDR practice. Additional shortcomings include the saturation of forest sinks in older forests and forests' vulnerability to disturbances. Consequently, forest management is required long after forestation occurs. A strength of this alternative is that it is already available for large-scale deployment.

Soil carbon sequestration. This is the increase in soil organic carbon content. This can occur by adding carbon inputs to the soil in the form of litter, residues, root or manure; or reducing carbon losses from soil respiration. Introducing changes to agricultural practices, for example, reducing or eliminating tillage (such as overturning of soil), introducing crop rotation, leaving crop residues to decay, or applying compost or manure, enhances this carbon sink, which has the potential to sequester 2-5 Gt CO_2 per year. Each tonne of CO_2 sequestered in the soil could cost US$0-100.

Enhancing carbon sequestration in soils can result in co-benefits in terms of soil quality and crop yields. Some management practices have no adverse side effects, while others can increase other GHG emissions and water pollution. The significant drawbacks of this CDR practice are related to saturation and reversibility, while an advantage is that it can be applied immediately at a large scale.

Biochar. A carbon-rich type of charcoal obtained from heating biomass (for instance, agricultural residues) in the absence of oxygen. It has the potential to sequester carbon when added to the soil. This potential is estimated to be in the range of 0.3-2 Gt CO_2 per year, at the cost of US$90-120/t$CO_2$. The benefits of biochar include positive side effects on soil quality, nutrients and water cycles; reduction of non-CO_2 GHGs release from soils; and its stability in the soil allowing the storage of CO_2 for centuries under the right conditions. Potential adverse effects relate to plant defences and albedo changes. As biochar has not been applied on a large enough scale, there are large uncertainties regarding the above estimates and expected side effects.

Wetland restoration. Most wetlands are considered net carbon sinks in the long run; moreover, they present high carbon stocks per unit area compared to other ecosystems.[4] The primary reason for these effects is the absence of free oxygen in the soil and hence reduced decomposition rates, allowing a significant part of the CO_2 entering the ecosystems to remain stored in the soil. However, wetlands are also a source of methane. Given the high warming potential of this GHG relative to CO_2, some restored wetlands could need up to a century to balance CO_2 uptake and methane release, and thus become net GHG sinks. This concern, together with the uncertainties regarding the net effects of wetlands on climate and the metrics to use, might be the main reason why wetlands are ignored in a considerable part of the CDR literature.

Nevertheless, the 2019 IPCC Special Report on Climate Change and Land presents estimates on the CDR potential of coastal wetlands restoration in the range of 0.2-0.84 Gt CO_2 equivalent (CO_2e) per year, and peatland restoration of 0.15-0.81 Gt CO_2e per year. Some authors conclude that some types of wetlands, especially coastal ones, such as mangroves, can be effective for CDR.[5] Mangroves emit only a limited amount of methane, yet take in considerable amounts of CO_2 immediately after restoration. The cost of mangrove restoration has been estimated at US$510 per t$CO_2$. The higher cost of wetland restoration compared to other CDR methods can be offset by the larger co-benefits in terms of, for instance, flood protection and mitigation, habitat creation and water quality improvements. Another advantage of wetland restoration is that carbon stocks do not saturate during millennial time-scales.

Technological solutions

Enhanced weathering. Weathering is the natural process through which rocks and minerals break down or dissolve. An input to this process is CO_2 from the atmosphere. Therefore, artificially accelerated weathering can help to remove larger amounts of CO_2 from the atmosphere in shorter timescales. This effect can be accomplished by enhancing one of the factors that control the weathering process. For instance, the reactive surface area can be increased by spreading powdered silicate or carbonate minerals over land, coastal areas or ocean waters.

This technology has an estimated potential of 2-4 Gt CO_2 per year, at a cost ranging between US$50/t$CO_2$ and US$200/t$CO_2$. However, there are large uncertainties regarding these estimates. Real-scale field experiments would be needed to understand the full impact of implementing this technology. Potential side effects of this option could include an increase in water pH, a release of heavy metals, impacts on health in case of particles of respirable size, and improvements as regards nutrient availability and soil hydrological properties. A significant shortcoming of enhanced weathering relates to its demand for energy and infrastructure. Overall, the knowledge gaps and uncertainties lead to doubts regarding its desirability and technological readiness.

Bioenergy with carbon capture and storage (BECCS). In this process, biomass that has captured CO_2 from the atmosphere during growth is used to produce energy. The CO_2 resulting from the energy conversion process is captured and stored in geological sinks. Thus, by storing CO_2 that has been captured from the atmosphere, BECCS technology effectively removes CO_2.

According to Fuss et al., BECCS could remove between 0.5 Gt CO_2 and 5 Gt CO_2 per year, at a cost of US$100-200 per tonne. Compared to the rest of the available literature, these estimates are conservative as they reflect sustainability concerns related to bioenergy production. Competition for land is a significant issue, which could potentially impact food prices and food security. Other downsides of bioenergy production relate to GHG emissions associated with land-use changes, adverse effects on biodiversity, changes in albedo, the water footprint, and fertiliser application with side effects on water quality and non-CO_2 GHG emissions. Additionally, potential risks of carbon capture and storage (CCS) might include water pollution, enhanced seismic activity, and health and environmental impacts associated with leakage. A strength of CCS is that geological storage (e.g. in depleted oil and gas reservoirs, coal beds and saline aquifers), has a large capacity and low vulnerability and therefore, unlike other CDR alternatives, has no issues associated with saturation and permanence. Yet, there are doubts about the feasibility of upscaling BECCS in the appropriate timeframe, given its limited social and political acceptability and required infrastructure.

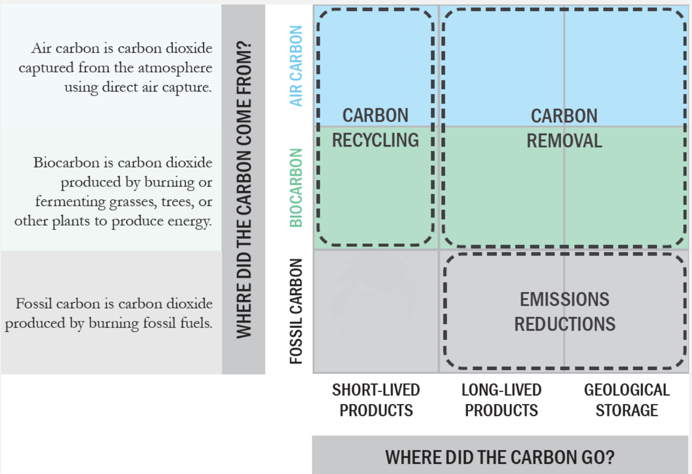
Direct air capture and storage (DACCS). Direct air capture encompasses different technologies used to extract CO_2 from ambient air. Most technologies use large fans to move atmospheric air to a contactor device where CO_2 molecules are separated by contact with a liquid or solid sorbent, resulting in a concentrated stream of CO_2. The sorbent is re-used in the process, while the cleaned air is released in the atmosphere. The resulting CO_2 stream can be used or stored. However, utilisation of CO_2 does not result in negative emissions and, hence, the focus here is on the storage.

The potential of DACCS is uncertain and debatable. The Fuss et al. 2018 assessment provide an estimate in the range of 0.5-5 Gt CO_2 per year by 2050, at a possible cost of US$100-300/t$CO_2$, assuming the presence of economies of scale. The high costs associated with DACCS compared to other CDR alternatives (DACCS requires large capital investments, a substantial input of energy, and carbon transport and storage) might limit its deployment. The energy source chosen is vital for the effectiveness and cost-efficiency of DACCS, because any emissions associated with the use of fossil fuels offset the accomplished CDR. Using cheap renewable energy and positioning the facility close to the storage site could improve the viability of DACCS. The potential side effects of direct air capture are largely unknown. The above-mentioned advantages and drawbacks of CCS as regards side effects, permanence and saturation, also apply to DACCS.

Distinguishing CDR from carbon recycling and emissions reductions

The role of climate policies and CDR alternatives can be understood by analysing where the carbon comes from and where it goes. If a process involves capturing carbon from the atmosphere and storing it for a long term (more than 100 years), the process removes carbon and causes a drop in atmospheric CO_2 concentration (e.g. DACCS and BECCS).

However, when carbon derived from fossil fuels is captured from point sources, it is prevented from reaching the atmosphere, but there is no CO_2 removal. In the best case, emissions reductions will result if the carbon from fossil fuels is stored (CCS) or used in long-lived products.

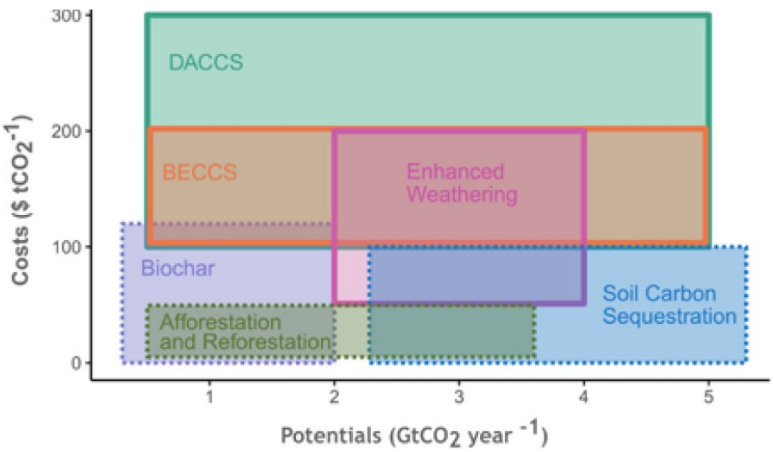


Source: Reduce, Remove, Recycle: Clarifying the Overlap between Carbon Removal and CCUS, American University, 2020.

Comparing the options

Some authors consider the nature-based alternatives in Figure 2 as the lowest-cost options ('no regrets' options). The European science academies include wetland restoration in this group, characterised as the most cost-effective, currently viable, and less uncertain set of options that avoid dependence on CCS. Also, if properly implemented, these options provide co-benefits in terms of flood control, water filtration, biodiversity, soil quality and climate resilience. However, they have limited long-term potential, and their marginal abatement costs – at least for

Figure 2. Estimated costs and 2050 potentials of CDR alternatives



Source: Chapter 4 of Special Report Global Warming of 1.5°, IPCC, 2018 forestation and soil carbon sequestration, are expected to rise after 2050. As shown in Figure 2, technological solutions present the largest potential, but they are also the most expensive options up to 2050. Yet, BECCS and DACCS – once developed – are easier to scale up and provide more permanent carbon pools due to geological storage. Besides, costs associated with DACCS are estimated to decrease with learning and deployment, positioning this technology as a promising option after 2050.

Regardless of the alternative chosen, large-scale deployment of CDR solutions could significantly impact land, water, energy or nutrients. The effect of increased land competition on agricultural and food systems is of particular concern. Thus, the IPCC recommends implementing a portfolio of options deployed at a smaller scale, to enhance sustainability and feasibility.

Apart from the CDR options assessed here, several other alternatives are being studied; these include ocean fertilisation, building with biomass, mineral carbonation, ocean alkalinity, and spreading volcanic ash onto the ocean floor.

EU policy related to carbon dioxide removal

The European Green Deal, the proposed tightened climate targets, and the subsequent revision of EU climate legislation planned in 2021, provide a unique opportunity to create a regulatory framework for CDR.[6] The Commission focuses on using ecosystems for CDR in the short term, although it recognises the need for both nature-based and technological options.

The Parliament has repeatedly called for prioritising emissions reductions over CDR and stressed the importance of conserving biodiversity and enhancing natural sinks and reservoirs, especially forests. It amended the proposal for the European climate law to include the requirement that removals of GHGs by sinks should exceed anthropogenic emissions in the EU and each Member State from 2051.

Under the current framework, the most relevant legislation concerning nature-based CDR is Regulation (EU) 2018/841 for including GHG emissions and removals from land use, land-use change and forestry (LULUCF) in the 2030 climate and energy framework. This regulation extends emissions- and removals-related accounting obligations to all types of land use from 2021 – except wetlands, which will be included from 2026. The regulation commits Member States to ensure that accounted LULUCF emissions do not exceed removals over 2021-2030 and the sector contributes to enhancing the carbon sinks in the long term. The regulation includes certain flexibilities. For instance, if the LULUCF sector in a given Member State results in net removals, the exceeding removals can be transferred to other Member States or used to meet the targets under the Effort-sharing Regulation (EU) 2018/842 (ESR). A Member State with net emissions can meet its commitments by buying removals from another Member State or using emissions allocations under the ESR.

The Commission recognises that this regulation does not sufficiently enhance carbon sinks, and hence intends to propose amendments in June 2021. This, along with a review of the ESR, should provide stronger policy incentives. For the review, the Commission is considering the following policy options: making the regulation more ambitious, strengthening the flexibility with ESR, and combining agriculture and LULUCF in one sector with a separate target. In the climate target plan, the Commission proposes creating a robust CDR certification system by 2023, to incentivise carbon sequestration and facilitate substantial removals from LULUCF, whose certificates could compensate for hard-to-abate emissions across the economy. Other relevant policies include the 2030 biodiversity strategy with the nature restoration plan at the core; the current and upcoming soil strategy; the Farm to Fork strategy, particularly the forthcoming carbon farming initiative; the forest strategy and its planned revision; the adaptation strategy and its expected new version; and the new common agricultural policy with the creation of eco-schemes as crucial in this context.

Regarding CDR technologies, BECCS and DACCS are dependent on CCS development. The CCS Directive 2009/31/EC establishes a legal framework for the safe selection of storage sites and regulates the concession of storage permits. Moreover, it includes provisions on CO_2 capture and transport, further developed in the Industrial Emissions Directive 2010/75/EU. Bioenergy production is primarily regulated in the Renewable Energy Directive (EU) 2018/2001 – also to be reviewed in 2021. However, the legal framework affecting biomass goes beyond energy regulation and includes other policy areas such as environment, climate and agriculture. There is currently no EU legislation that specifically concerns DAC or enhanced weathering.

Concerning EU support for research and innovation on CDR, relevant projects (for instance, the NEGEM project) are funded by Horizon 2020 and Horizon Europe. Besides, the Innovation Fund (2020-2030) has allocated €10 billion to commercial demonstration of low-carbon technologies including CDR and CCS.

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ENDNOTES

[1] According to the IPCC terminology, the term AFOLU encompasses emissions and removals from the LULUCF sectors (land use, land-use change and forestry) and the sector of agriculture. LULUCF covers anthropogenic emissions and removals from forests, croplands, grasslands, wetlands, settlements and other land uses, but excludes non-CO_2 emissions from agriculture. Those are covered by the sector of agriculture, including methane and nitrous oxide emissions mainly from agricultural soils, livestock, and manure management.

[2] All potential and cost estimates but wetlands are taken from Fuss et al., 2018.

[3] Fuss S. et al., Negative emissions – Part 2: Costs, potentials and side effects, Environmental Research Letters, 13(6), 2018.

[4] Scientific papers supporting this statement include Mitsch et al., (2013); Griscom et al., (2017); Taillardat et al., (2020).

[5] Taillardat et al., (2020) and Mitsch & Mander (2018).

[6] Some interesting studies providing recommendations for the design of the framework include: Meyer-Ohlendorf (2020), Geden & Schenuit (2020), and Geden, Scott & Palmer (2018).

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