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Atmospheric CO_2 as a resource for renewable energy production: A European energy law appraisal of direct air capture fuels

Romina Schaller[1] | Till Markus[1] | Klaas Korte[2] | Erik Gawel[2]

[1]Department of Environmental and Planning Law, Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany

[2]Department of Economics, Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany

Correspondence
Romina Schaller, Department of Environmental and Planning Law, Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany.
Email: romina.schaller@ufz.de

Abstract

The high concentration of carbon dioxide (CO_2) in the atmosphere is considered the root cause of climate change. However, in the future atmospheric CO_2 could play a strategic role towards a renewable energy transition due to its use as a carbon source for the production of goods. Notably, direct air capture (DAC) technology, by removing CO_2 from the atmosphere, could support and improve the carbon footprint of the transport and building sector, both of which are responsible for a large part of the world's greenhouse gas emissions. Once the CO_2 is removed, it can be used to produce synthetic fuels for the transport sector, where there are few low-carbon alternatives, such as aviation and shipping. In this article, we examine European Union legislation, focusing on the Renewable Energy Directive, and conclude that DAC fuels can be considered as renewable energy for the transport sector. Moreover, we highlight that the Directive does not yet regulate the methodology that defines the renewable character of DAC fuels and examine relevant criteria to be considered. In addition, because DAC can possibly be operated in buildings, we examine whether the Energy Performance of Buildings Directive is a legal instrument to be considered for deploying this technology.

1 | INTRODUCTION

The Paris Agreement[1] aims to keep the global temperature increase below 1.5°C. To achieve this, many scientists and governments agree that climate neutrality needs to be achieved by 2050, that is, creating a balance between greenhouse gases emitted and the absorption of greenhouse gas emissions by sinks.[2] This objective reflects a broad consensus in the scientific community about what is necessary to prevent dangerous anthropogenic interference in the climate system.[3] Attaining climate neutrality requires drastic measures. The use of fossil fuels for energy production must be phased out, and emissions from activities that are difficult to avoid (e.g. in the chemical industry, the cement industry or in the transport sector) must be reduced as far as possible. An option for this is the use of technologies or measures to remove CO_2 from the atmosphere (carbon dioxide removal [CDR]). To date, different technologies are being researched

[1]Paris Agreement (adopted 12 December 2015, entered into force 4 November 2016) 55 ILM 740.
[2]ibid art 4(1).

[3]V Masson-Delmotte et al (eds), *Global Warming of 1.5°C* (Intergovernmental Panel on Climate Change 2018) 17; J Rogelj et al, 'Scenarios Towards Limiting Global Mean Temperature Increase Below 1.5 °C' (2018) 8 Nature Climate Change 325.

and developed, including so-called direct air capture (DAC) technologies.[4]

DAC not only allows removing CO_2 from the atmosphere but also through certain processes could generate energy carriers. For example, the removed carbon can be used in the production of synthetic fuels (direct air carbon capture and use [DACCU]). These synthetic fuels can be used in for instance the transport sector, especially in the aviation and shipping sector, for which there are few low-carbon alternatives.[5] This article aims to assess whether synthetic fuels derived from CO_2 removed through DAC (DACCU fuels) can be considered as renewable energy for the transport sector under European Union (EU) law, especially in the aviation and shipping sector, and to what extent they are covered by EU energy legislation.

To this end, this contribution briefly introduces CO_2 as a resource for energy production (Section 2). It then explains different characteristics of DAC (Section 3). This is followed by an analysis of the circular use of carbon through DAC technology, as a specific application of DAC. Its possible strategic role in the energy transition is analysed, focusing on the transport sector. That is, DACCU fuels are discussed as an alternative to the use of fossil fuels derived from oil or gas (Section 4). Next, to find out which requirements must be met by DACCU fuels to qualify as renewable energy and what challenges must be overcome for its use, we will examine, mainly for illustrative purposes, Directive 2018/2001/EU on the promotion of the use of energy from renewable sources (RED II).[6] Furthermore, because DAC may operate in the future in urban buildings and can possibly contribute to improving their carbon footprint, we examine whether Directive 2010/31/EU on the energy performance of buildings (EPBD)[7] is a legal instrument to consider for deploying DACCU (Section 5). In the last section, we present our conclusions and an outlook on the consideration of DACCU fuels as a renewable energy and on their regulation for a potential future deployment (Section 6).

[4]R Hanna et al, 'Emergency Deployment of Direct Air Capture as a Response to the Climate Crisis' (2021) 12 Nature Communications 368; National Academies of Sciences, Engineering, and Medicine, 'Negative Emissions Technologies and Reliable Sequestration' (The National Academies Press 2019); European Academies Science Advisory Council, 'Negative Emission Technologies: What Role in Meeting Paris Agreement Targets?' (European Academies' Science Advisory Council 2018); JC Minx et al, 'Negative Emissions—Part 1: Research Landscape and Synthesis' (2018) 13, Environmental Research Letters 063001; S Fuss et al, 'Negative Emissions—Part 2: Costs, Potentials and Side Effects' (2018) 13 Environmental Research Letters 063002.

[5]C Beuttler, L Charles and J Wurzbacher, 'The Role of Direct Air Capture in Mitigation of Anthropogenic Greenhouse Gas Emissions' (2019) 1 Frontiers in Climate 1, 4; C Breyer et al, 'Direct Air Capture of CO_2: A Key Technology for Ambitious Climate Change Mitigation' (2019) 3 Joule 2053.

[6]Parliament and Council Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (recast) [2018] OJ L328/82 (RED II).

[7]Parliament and Council Directive (EU) 2010/31/EU on the energy performance of buildings (recast) [2010] OJ L153/13.

2 | ATMOSPHERIC CO_2 REVOLUTION: FROM WASTE TO RESOURCE FOR ENERGY PRODUCTION?

The global average atmospheric carbon dioxide concentration is currently 416 parts per million CO_2 (NASA, latest measurement: February 2021).[8] In 2019, it was estimated that most of the total energy (about 84%) came from carbon-based fossil sources (such as coal, oil and gas) which are mainly used in the electricity, transport, heating and industry sectors and, as a result of this use, increased CO_2 emissions into the atmosphere.[9] In light of anthropogenic climate change and the international efforts to avert it, we are used to seeing CO_2 concentrations in the atmosphere as an excessively available waste product. Accordingly, any further CO_2 emissions constitute a threat to the climate system stability—and therefore to humans. Arguably, the development of technologies for CDR may fundamentally change this perspective by potentially allowing for the consideration of atmospheric CO_2 as a resource.

While research on climate change has been focusing for a long time on means and ways to avoid further emissions, an increasing number of processes are being developed to remove high concentrations of CO_2 from the atmosphere and either store it or put it to use.[10] This is because those who seek to make use of atmospheric CO_2 realize its relevance as a *feedstock* or *resource* that, through its capture and use, provides carbon, which is needed to produce synthetic fuels, plastics and building materials.[11] It can also be used chemically to accelerate biological processes, for example, to improve plant growth in greenhouses and in the production of food and feed.[12] This means that, using capture technologies, atmospheric CO_2 would become a resource that can be used to produce fuels and a variety of ingredients for different products, such as basic chemicals.[13] In this article, we will focus on fuels produced by deploying DACCU and examine the legal aspects that must be considered to qualify them as renewable in the context of EU law.

[8]NASA, 'Global Climate Change Website' (March 2021) <https://climate.nasa.gov/vital-signs/carbon-dioxide/>.

[9]H Ritchie and M Roser, 'Fossil Fuels' (Our World in Data, 2017) <https://ourworldindata.org/energy-mix?country=#energy-mix-what-sources-do-we-get-our-energy-from>.

[10]C Hepburn et al, 'The Technological and Economic Prospects for CO_2 Utilization and Removal' (2019) 575 Nature 87; F Nocito and A Dibenedetto, 'Atmospheric CO_2 Mitigation Technologies: Carbon Capture Utilization and Storage' (2020) 21 Current Opinion in Green and Sustainable Chemistry 34; J Artz et al, 'Sustainable Conversion of Carbon Dioxide: An Integrated Review of Catalysis and Life Cycle' (2018) 118 Chemical Reviews 434, 435.

[11]DW Keith et al, 'A Process for Capturing CO_2 from the Atmosphere' (2018) 2 Joule 1573; Artz et al (n 10); M Marchese et al, 'CO_2 from Direct Air Capture as Carbon Feedstock for Fischer-Tropsch Chemicals and Fuels: Energy and Economic Analysis' (2021) 46 Journal of CO_2 Utilization 101487; A Kätelhön et al, 'Climate Change Mitigation Potential of Carbon Capture and Utilization in the Chemical Industry' (2019) 116 Proceedings of the National Academy of Sciences of the United States of America 11187; H Ostovari, A Sternberg and A Bardow, 'Rock 'n' Use of CO_2: Carbon Footprint of Carbon Capture and Utilization by Mineralization' (2020) 4 Sustainable Energy and Fuels 4482; Z Yi, T Wang and R Guo, 'Sustainable Building Material from CO_2 Mineralization Slag: Aggregate for Concretes and Effect of CO_2 Curing' (2020) 40 Journal of CO_2 Utilization 101196; Nocito and Dibenedetto (n 10).

[12]J Bao et al, 'Greenhouses for CO_2 Sequestration from Atmosphere' (2018) 1 Carbon Resources Conversion 183, 184.

[13]S Davis et al, 'Net-Zero Emissions Energy Systems' (2018) 360 Science 6396; D Heß, M Klumpp and R Dittmeyer, 'Nutzung von CO_2 aus Luft als Rohstoff für synthetische Kraftstoffe und Chemikalien' (Karlsruhe Institute of Technology 2021).

3 | DAC: CONCEPTS, FUNCTIONS AND CHARACTERISTICS

DAC can be described as the technical processes through which CO_2 is separated directly from the ambient air by chemical processes. The retrieved CO_2 can have two applications:

- It can be stored long term, either geologically or through mineralization,[14] also known as direct air carbon capture and storage (DACCS).
- It can be used as an input for the manufacturing of goods, known as DACCU. Through DACCU, the integration of the retrieved CO_2 into the process chain of (combined) technologies (referred to as Power-to-X) can produce synthetic materials and fuels such as diesel, gasoline and kerosene.[15]

It has been pointed out that DAC could eventually achieve negative emissions under the condition that the storage is indeed permanent. In the case of DACCU, the permanence of the sequestration will be affected by the fact that DACCU products are put into use and the captured CO_2 will be fully or partially reintroduced into the atmosphere.[16] Accordingly, in the long term, this approach is, at best, climate neutral and is also referred to as a 'circular carbon' approach.[17]

To understand the process of CO_2 separation from the ambient air, we first briefly explain the chemical processes involved, followed by an example of a specific Power-to-Liquid (PtL) process[18] to obtain hydrocarbon fuel called 'crowd oil'.[19]

The separation of CO_2 from the air can be achieved, for example, by the following chemical processes: *absorption* and *adsorption*. Absorption is a physicochemical process in which compounds are dissolved in a liquid phase and retained in the liquid volume. In the context of DAC, aqueous hydroxide sorbents such as alkaline and alkaline-earth hydroxides—sodium hydroxide (NaOH) and calcium hydroxide ($Ca(OH)_2$), respectively—are used. The use of this type of sorbents can be low cost but leads to high water loss. In addition, high-temperature heat is required because only in this way is the reaction for regeneration possible.[20] In contrast to absorption, with adsorption, the compounds are retained on the surface of a solid sorbent. In the case of DAC, chemical adsorption is applied, for instance, the use of solid (poly)amines directly as sorbents or the use of (poly)amines chemically bound to solids. Here, CO_2 is mainly regenerated by heat at low temperature and vacuum.[21]

Both approaches described include the use of electricity. Both processes, however, may also be described based on the use of heat.[22] That is, based on their thermal energy demand: *high temperature* (HT-DAC) and *low temperature* (LT-DAC). The use of HT-DAC (>850°C) is required to perform the regeneration process to obtain a pure CO_2 stream. After the absorption process, in which potassium hydroxide (KOH) or NaOH can be used as aqueous solution, the next step is regeneration. In this step, the aqueous potassium carbonate (K_2CO_3) is mixed with calcium hydroxide ($Ca(OH)_2$) in a causticizer unit to obtain solid calcium carbonate ($CaCO_3$) and regenerated NaOH. Finally, a calcination process of $CaCO_3$ is performed, obtaining calcium oxide (CaO) and CO_2 as products. An interesting aspect of this type of solution is that instead of using electricity-based gas (Power-to-Gas [PtG])—where its production would be very high in energy consumption—the possibility of using concentrated solar power plants for high-temperature heat generation could be considered.[23] LT-DAC (<100°C) is used in those technologies in which the adsorption and desorption processes operate one after the other (regeneration) in the solid sorbent unit. Here, a temperature-vacuum swing process is applied in a low-temperature heat range. For example, amine compounds bound to dry porous granulates can be used as filter material in connection with the use of air humidity.[24]

There are also other approaches by which CO_2 can be filtered out of the atmosphere without using thermal energy, for example,

[14] J Matter et al, 'Rapid Carbon Mineralization for Permanent Disposal of Anthropogenic Carbon Dioxide Emissions' (2016) 352 Science 1312; I Gunnarsson et al, 'The Rapid and Cost-Effective Capture and Subsurface Mineral Storage of Carbon and Sulfur at the CarbFix2 Site' (2018) 79 International Journal of Greenhouse Gas Control 117.

[15] Breyer et al (n 5); P Viebahn, A Scholz and O Zelt, 'The Potential Role of Direct Air Capture in the German Energy Research Program—Results of a Multi-Dimensional Analysis' (2019) 12 Energies 3443; JC Koj, C Wulf and P Zapp, 'Environmental Impacts of Power-to-X Systems—A Review of Technological and Methodological Choices in Life Cycle Assessments' (2019) 112 Renewable and Sustainable Energy Reviews 865, 867; C Panzone et al, 'Power-to-Liquid Catalytic CO_2 Valorization into Fuels and Chemicals: Focus on the Fischer-Tropsch Route' (2020) 38 Journal of CO_2 Utilization 314, 315; Beuttler et al (n 5).

[16] T Markus et al, 'Negativemissionstechnologien als neues Instrument der Klimapolitik: Charakterisiken und klimapolitische Hintergründe' (2021) 43 Natur und Recht 90, 94; R Dittmeyer et al, 'Crowd Oil not Crude Oil' (2019) 10 Nature Communications 1818.

[17] Hepburn et al (n 10); Dittmeyer et al (n 16); D Deutz and A Bardow, 'Life-Cycle Assessment of an Industrial Direct Air Capture Process Based on Temperature–Vacuum Swing Adsorption' (2021) 6 Nature Energy 207.

[18] PtL refers to processes in which liquid fuel is generated from electricity, water and CO_2 or CO. See Heß et al (n 13) III.

[19] Dittmeyer et al (n 16).

[20] JC Pires, 'Negative Emissions Technologies: A Complementary Solution for Climate Change Mitigation' (2019) 672 Science of The Total Environment 502, 504; MMJ de Jonge et al, 'Life Cycle Carbon Efficiency of Direct Air Capture Systems With Strong Hydroxide Sorbents' (2019) 89 International Journal of Greenhouse Gas Control 25, 27; Deutz and Bardow (n 17) 203.

[21] Deutz and Bardow (n 17) 203; Viebahn et al (n 15); JA Wurzbacher, C Gebald and A Steinfeld, 'Separation of CO_2 from Air by Temperature-Vacuum Swing Adsorption Using Diamine-Functionalized Silica Gel' (2011) 4 Energy and Environmental Science 3584; Keith et al (n 11).

[22] Viebahn et al (n 15); M Fasihi, O Efimova and C Breyer, 'Techno-Economic Assessment of CO_2 Direct Air Capture Plants' (2019) 224 Journal of Cleaner Production 957, 961; Heß et al (n 13) 3.

[23] E Koepf et al, 'Liquid Fuels from Concentrated Sunlight: An Overview on Development and Integration of a 50 kW Solar Thermochemical Reactor and High Concentration Solar Field for the SUN-to-LIQUID Project' (2019) 2126 AIP Conference Proceedings 180012; S Zoller et al, 'Heat Transfer Model of a 50 kW Solar Receiver–Reactor for Thermochemical Redox Cycling Using Cerium Dioxide' (2019) 141 Journal of Solar Energy Engineering 021014; S Hu et al, 'Thin-Film Materials for the Protection of Semiconducting Photoelectrodes in Solar-Fuel Generators' (2015) 119 Journal of Physical Chemistry C 24201.

[24] Viebahn et al (n 15); Wurzbacher et al (n 21); JA Wurzbacher et al, 'Concurrent Separation of CO_2 and H_2O from Air by a Temperature-Vacuum Swing' (2012) 46 Environmental Science and Technology 9191.

through electrochemical processes. However, to date, there is no commercial application.[25]

One process for obtaining hydrocarbon fuels by using CO_2 from DAC ('crowd oil'),[26] for example, is through the adaptation of air conditioning (AC) systems. First, the ambient air is sucked in and passed through a special filter material. The CO_2 molecules in the air are captured in the filter. When this filter is fully loaded, it is heated to 95°C. This causes the molecules to desorb again, and pure CO_2 is obtained; CO_2 is then converted together with water vapour into synthesis gas by means of the high-temperature electrolysis system. As a third step, the Fischer–Tropsch process is used, whereby long-chain hydrocarbon molecules are formed from the synthesis gas. In this way, these molecules serve as the raw product for renewable synthetic fuels. Finally, for the transformation of this raw product into liquid fuel, these long-chain hydrocarbons will be split into shorter fragments in a further reaction stage (use of hydrocracking and isomerization methods). Kerosene, gasoline or diesel is then obtained by subsequent distillation.[27]

The global potential CO_2 reduction through DAC is estimated to lie between 0.5 and 5 gigatons of carbon dioxide ($GtCO_2$) per year.[28] However, DAC also faces several challenges and generates several questions regarding its realization and effectiveness. DAC requires the capture of large amounts of air, because air contains only about 415 parts per million CO_2. This means that, depending on the case, DAC units will need to be physically large, may require large amounts of materials for their construction and are permanently dependent on the use of substantial amounts of absorbent chemicals or catalysts.[29] Likewise, water consumption will depend on the use of the processes described above to separate CO_2 from the ambient air. For example, the use of the adsorption process combined with the use of HT-DAC leads to high water loss, whereas in adsorption processes coupled with the use of LT-DAC, not only CO_2 can be obtained, but also, water can be captured as a by-product.[30] In addition, and perhaps the most important obstacle to overcome for the deployment of this technology, is the requirement of large amounts of energy, in the form of heat and/or electrical energy.[31] For all these reasons, DAC is currently considered the most expensive of all CDR technologies (US$200–600 per ton of CO_2).[32] Compared with other CDR technologies, however, DAC also presents an important advantage. In principle, its installations can be built practically anywhere (e.g. on non-arable land) where cleanly generated electricity is sufficiently available for its operation. In this way, it is assumed not to put pressure on ecosystems or food systems.[33] However, for the potential large-scale deployment of DAC, all requirements related to plant construction materials and chemicals, as well as the demand for water, energy and land, are essential aspects that are still being intensely debated.[34]

Last but not least, CO_2 can not only be captured directly from the atmosphere but can also be extracted from point sources, such as combustion or fermentation processes (e.g. from cement or steel factories and biogas plants).[35] Well-developed technologies are already available for this process, and even synthetic fuels can be produced using, for example, the Fischer–Tropsch approach. The question then arises why DAC is needed.[36] Among the advantages offered by these point sources of carbon capture is not only the high concentration of CO_2 in the gas mixture, but also the fact that CO_2 extraction requires, for example, low energy consumption and less solvents, as well as the use of existing and correspondingly cheap industrial process technologies, which has a positive effect on costs.[37] With regard to the latter, DAC would be at a disadvantage compared with existing cheaper technologies, which can be implemented in these plants. However, from an environmental point of view, the CO_2 capture rate is never total in all processes. This means that when fossil sources are used, a part of the greenhouse gas is always released into the atmosphere, and to recapture this CO_2, DAC would have to be used.[38] Furthermore, this would mean prolonging the operation of fossil power plants, which is not viable in the face of climate neutrality policies. Only in cases where CO_2 comes from biogenic sources (e.g. biogas plants) or from waste incineration plants or where emissions from fossil processes are unavoidable could they be considered as valid point sources for carbon capture (e.g. emissions from burning lime for cement production).[39] In this sense, DAC could play a strategic role here.

4 | CIRCULAR CARBON: CAN DACCU CONTRIBUTE TO THE RENEWABLE ENERGY TRANSITION?

The drastic increase in atmospheric CO_2[40] and its impacts on the climate system led all world's countries to establish legally binding

[25]M Eisaman et al, 'Energy-Efficient Electrochemical CO_2 Capture from the Atmosphere' in M Laudon, D Laird and B Romanowicz (eds), *Technical Proceedings of the 2009 CTSI Clean TechConnect Briefs, Technology Conference and Trade Show* (CRC Press 2009) 175; Fasihi et al (n 22) 963.

[26]Dittmeyer et al (n 16).

[27]This type of DAC technology is being developed by a research project formed by KIT, Climeworks, Sunfire and INERATEC. See ibid.

[28]Minx et al (n 4); Fuss et al (n 4).

[29]Deutz and Bardow (n 17), 207; Keith et al (n 11) 1573ff.

[30]Viebahn et al (n 15); Fasihi et al (n 22) 961ff, 971. About managing and disposing of residues that may involve DAC, see T Hester, 'Negative Emissions Technologies and Direct Air Capture' in M Gerrard and J Dernbach (eds), *Legal Pathways to Deep Decarbonization in the United States* (ELI Press 2019) 749, 765.

[31]For more detailed information, see Heß et al (n 13); Hanna et al (n 4).

[32]Keith et al (n 11) 1588; National Academies of Sciences, Engineering, and Medicine (n 4) 190; F Creutzig et al, 'The Mutual Dependence of Negative Emission Technologies and Energy Systems' (2019) 12 Energy and Environmental Science 1805, 1811; Royal Society and Royal Academy of Engineering, 'Greenhouse Gas Removal' (Royal Society and Royal Academy of Engineering 2018).

[33]Beuttler et al (n 5); Heß et al (n 13) 21; P Smith et al, 'Biophysical and Economic Limits to Negative CO_2 Emissions' (2015) 6 Nature Climate Change 42, 43–44.

[34]J Fuhrman et al, 'Food-Energy-Water Implications of Negative Emissions Technologies in a +1.5°C Future' (2020) 10 Nature Climate Change 920; S Chatterjee and KW Huang, 'Unrealistic Energy and Material Requirement for Direct Air capture in Deep Mitigation Pathways' (2020) 11 Nature Communications 3287; G Realmonte et al, 'Reply to "High Energy and Materials Requirement for Direct Air Capture Calls for Further Analysis and R&D"' (2020) 11 Nature Communications 3286; Deutz and Bardow (n 17) 203.

[35]A Goeppert et al, 'Air as the Renewable Carbon Source of the Future: An Overview of CO_2 Capture from the Atmosphere' (2012) 5 Energy and Environmental Science 7833, 7836.

[36]Fasihi et al (n 22) 959; Goeppert et al (n 35) 7836.

[37]Fasihi et al (n 22) 975ff; Heß et al (n 13) 19ff.

[38]Heß et al (n 13) 19.

[39]ibid.

[40]The concentration of CO_2 in the atmosphere has increased from approximately 277 parts per million (ppm) in 1750, the beginning of the Industrial Age, to approximately 409.85 ppm in 2019. See P Friedlingstein et al, 'Global Carbon Budget 2020' (2020) 12 Earth System Science Data 3269, 3272.

instruments to put in place measures to protect the climate. In 1992, the parties to the United Nations Framework Convention on Climate Change[41] agreed to stabilize greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system.[42] In this regard and through the 2015 Paris Agreement, parties agreed to peak global greenhouse gas emissions as soon as possible and then reach a balance between emissions and removals by sinks (net zero) in the second half of the century.[43] In addition, it was agreed to keep the global average temperature increase well below 2°C above preindustrial levels and to strive to limit this increase to 1.5°C.[44] However, unlike the Kyoto Protocol,[45] the Paris Agreement does not set specific emission targets for the parties but requires parties to submit five-yearly nationally determined contributions, meaning that parties themselves define their own reduction targets.[46]

To achieve the 1.5°C goal, according to the Intergovernmental Panel on Climate Change (IPCC) 2018 Special Report on 1.5°C, a global CO_2 budget has been determined, which estimates that only 420 GtCO_2 (for a 66% probability, medium confidence) can be emitted into the atmosphere,[47] and, if these emissions remain constant (42 GtCO_2 per year), this budget would be depleted in 10 years. The same IPCC report points out the importance of CO_2 removal to offset residual emissions and achieve net negative emissions to return to 1.5°C.[48] This requires rapid and far-reaching transitions in energy, land, industrial and urban systems and infrastructure, including transport and buildings.[49] However, considering that 36.8 gigatons per year of CO_2 were released in 2019,[50] achieving the Paris Agreement temperature goal under the abovementioned circumstances is a major challenge. To date, worldwide one fifth of CO_2 emissions come from transport sector (24%), if we only consider CO_2 emissions from energy.[51] At the same time, energy use from fossil sources (84.3%) still plays an important role globally.[52] Global transportation demand (measured in passenger-kilometres) is expected to double and passenger aviation demand is expected to triple by 2070.[53]

Therefore, technologies such as DACCU could play a strategic role in addressing this global mitigation challenge. Not only could it contribute to mitigating climate change by replacing products from traditional fossil carbon sources, but it could also contribute to a renewable energy transition through providing an input for the generation of energy carriers from renewable energy sources that can be used as fuels and feedstocks for the chemical industry.[54] For example, DACCU fuels can be used in sectors for which there are few low-carbon alternatives, such as aviation[55] and shipping.[56] In this way, additional fossil energy carriers (such as oil or gas) would no longer be required, but the carbon for producing energy carriers could be drawn from the atmosphere. Even if CO_2, at some point, would re-enter the atmosphere, it would not add additional atmospheric CO_2 but re-emit what had already been emitted once.

This is why countries such as Japan,[57] Australia,[58] the United Kingdom[59] and the United States[60] have incorporated circular carbon use through DAC into their climate strategies as part of their renewable energy transition, while in other countries such as Switzerland, Finland, Germany and Canada, among others, studies on synthetic fuels using DAC technology are being carried out.[61]

Several questions regarding the deployment of DACCU fuels, however, still have to be resolved. They range from, for instance, the amount of energy it requires or how to carry out its conversion processes and potential rebound effects to the assessment of the economic reasonableness of DACCU fuels vis-à-vis their fossil equivalents (which would require considering the full economic costs including external ones like environmental damages that might accrue from both production and use). Being a possible low-carbon alternative to traditional fossil fuels, one crucial issue is indeed the design of the regulatory framework under which the deployment of DACCU fuels would take place. It will be the legal framework that will determine whether DACCU fuels qualify as renewable energy. For illustrative purposes, the following section will examine whether, under current EU legislation, DACCU fuels would qualify as renewable energy, and which open questions remain in this regard.

5 | DACCU FUELS IN THE EUROPEAN LEGAL FRAMEWORK

The economy in particular and society in general still depend on energy based predominantly on fossil fuels. For example, the EU's energy sector was responsible in 2019 for the emission of 3.9 GtCO_2, with the main source being the power sector (32%), followed by the

[41]United Nations Framework Convention on Climate Change (adopted 29 May 1992, entered in force 21 March 1994) 1771 UNTS 107 (UNFCCC).
[42]ibid art 2(1).
[43]Paris Agreement (n 1) art 4(1).
[44]ibid art 2(1)(a).
[45]Kyoto Protocol to the United Nations Framework Convention on Climate Change (adopted 11 December 1997, entered into force 16 February 2005) 2303 UNTS 148.
[46]Paris Agreement (n 1) art 3.
[47]Masson-Delmotte et al (n 3) 12.
[48]ibid 17.
[49]ibid 15.
[50]Deutz and Bardow (n 17) 203.
[51]International Energy Agency (IEA), 'Energy Technology Perspectives 2020—Special Report on Carbon Capture Utilisation and Storage. CCUS in Clean Energy Transitions' (IEA 2020) 22.
[52]Ritchie and Roser (n 9).
[53]International Energy Agency, 'Energy Technology Perspectives 2020' (International Energy Agency 2020), 292.
[54]Davis et al (n 13); Heß et al (n 13).
[55]J Scheelhaase, S Maartens and W Grimme, 'Synthetic Fuels in Aviation—Current Barriers and Potential Political Measures' (2019) 43 Transportation Research Procedia 21.
[56]E Fridell, 'Emissions and Fuel Use in the Shipping Sector' in R Bergqvist and J Monios (eds), *Green Ports*, (Elsevier 2019) 19; P Balcombe et al, 'How to Decarbonise International Shipping: Options for Fuels, Technologies and Policies' (2019) 182 Energy Conversion and Management 72.
[57]The Government of Japan, 'The Long-Term Strategy under the Paris Agreement' (June 2019) <https://unfccc.int/process/the-paris-agreement/long-term-strategies>.
[58]Australian Government Department of Industry, Science, Energy and Resources, 'Australia's Long-Term Emissions Reduction Plan—A whole-of-economy Plan to achieve net zero emissions by 2050' (October 2021) <https://unfccc.int/sites/default/files/resource/Australias_LTS_WEB.pdf>.
[59]HM Government, 'Net Zero Strategy: Build Back Greener' (October 2021) <https://unfccc.int/process/the-paris-agreement/long-term-strategies>.
[60]'The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050' (November 2021) <https://unfccc.int/process/the-paris-agreement/long-term-strategies>.
[61]Fasihi et al (n 22) 960; Dittmeyer et al (n 16).

transport sector (25%) and manufacturing industries (20%).[62] Added to this is the fact that only 8% of the total energy used in transport comes from renewable sources.[63] It is not only the use of fossil fuels for energy production that must be avoided. Emissions from activities that are difficult to avoid (in the chemical industry, the cement industry or the transport sector) must also be reduced as much as possible. In this regard, Article 194(1)(c) of the Treaty on the Functioning of the European Union (TFEU)[64] establishes that the Union's energy policy shall aim to promote energy efficiency and energy saving and the development of new and renewable forms of energy, although the same Treaty also states in Article 194(2) TFEU that EU legislation shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply, without prejudice to Article 192(2)(c).[65]

In this context, the EU has developed and adopted several instruments to support the energy transition. The European Commission, in its Communication on the European Green Deal,[66] sets out to achieve a 55% of greenhouse gas emission reduction by 2030 and achieve a carbon-neutral economy by 2050. The European Green Deal also points out that renewable energy sources will play an essential role towards a clean energy transition.[67] Because achieving climate neutrality requires a 90% reduction in emissions from transport by 2050, the Commission has expressed its willingness to consider legislative options to boost the production and uptake of sustainable alternative fuels for the different transport modes.[68] Further, to achieve the target of reducing emissions by at least 55% compared with 1990 by 2030, the Commission presented a package of legislative proposals ('Fit for 55').[69] In the energy sector, the updated Renewable Energy Directive proposes to increase the binding target from the current 32% to 40% of renewables in the EU energy mix.[70] The aim is to make the energy system cleaner and more efficient not only by fostering renewable-based electrification but also by promoting the uptake of renewable fuels in sectors such as industry and transport where this is more difficult.[71] The Commission has also proposed two initiatives to regulate the use of sustainable fuels in both aviation and maritime transport. The ReFuelEU Aviation regulation, for example, will oblige fuel suppliers to ensure that all aviation fuel made available to aircraft operators at EU airports contains a minimum share of sustainable aviation fuel, including synthetic fuels.[72] The ReFuelEU Maritime regulation also proposes the use of sustainable fuels and zero-emission technologies, setting standards to reduce the greenhouse gas emissions of energy used by ships calling at European ports.[73]

Against this backdrop, DACCU fuels could be strategically positioned as a sustainable alternative for the energy transition in the transport sector, especially the aviation and shipping sectors. However, for the potential deployment of this technology, the design of the regulatory framework is crucial. The energy policy being adopted in the EU demands the use of renewable energy sources to continue the decarbonization process to achieve climate targets by 2030 and 2050. Therefore, there are two central issues that need to be assessed. First, whether DACCU fuels (synthetic fuels) qualify as energy and/or fuels from renewable sources. Second, whether DACCU fuels can be mainstreamed into any obligation to comply with a renewable energy share in transport sector. To this end, the definition of renewable energy under European legislation will be addressed. Also, because there is the possibility of DAC operating in urban buildings in the future, it needs to be determined whether capturing CO_2 through AC systems can also be considered as another way to improve the carbon footprint of buildings.

To answer these issues and in line with the approach of this article, we now focus on the analysis of the following directives:

- Directive 2018/2001/EU[74] on the promotion of the use of energy from renewable sources (RED II), a key instrument for the deployment of DACCU for the transport sector;
- Directive 2010/31/EU[75] on the EPBD linked to the building sector.

Both instruments are part of the legislative package called 'Clean Energy for All Europeans' that was launched by the European Commission at the end of 2016, with the aim of creating a new legal framework for the European energy system.

5.1 | RED II: Decarbonizing the transport sector through DACCU fuels?

RED II sets a new binding renewable energy target for the EU for 2030 of at least 32% of final energy consumption, with a clause for a possible review of the increase by 2023.[76] Member States have leeway in determining their own contribution to the target according to

[62] IEA (n 51) 135.
[63] Eurostat, 'Energy for Transport: 8% from Renewable Sources' (2018) <https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/DDN-20200123-2>.
[64] Consolidated version of the Treaty on the Functioning of the European Union [2012] OJ C326/47 (TFEU).
[65] ibid art 192(2): 'By way of derogation from the decision-making procedure provided for in paragraph 1 and without prejudice to Article 114, the Council acting unanimously in accordance with a special legislative procedure and after consulting the European Parliament, the Economic and Social Committee and the Committee of the Regions, shall adopt: … (c) measures significantly affecting a Member State's choice between different energy sources and the general structure of its energy supply.'
[66] Commission (EU) 'The European Green Deal' (Communication) COM(2019) 640 final, 11 December 2019.
[67] ibid para 2.1.2.
[68] ibid para 2.1.5.
[69] Commission (EU) 'Fit for 55': Delivering the EU's 2030 Climate Target on the Way to Climate Neutrality (Communication) COM(2021) 550 final, 14 July 2021.
[70] Commission (EU) Proposal for a Directive amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and of the Council and Directive 98/70/EC as Regards the Promotion of Energy from Renewable Sources, and Repealing Council Directive (EU) 2015/652, COM (2021) 557 final, 14 July 2021.
[71] Commission (EU) (n 66) para 2.2.3; Commission (EU) (n 69).
[72] Commission (EU) 'Proposal for a Regulation on Ensuring a Level Playing field for Sustainable Air Transport' COM(2021) 561 final, 14 July 2021.
[73] Commission (EU) Proposal for a Regulation on the Use of Renewable and Low-Carbon Fuels in Maritime Transport and Amending Directive 2009/16/EC, COM(2021) 562 final, 14 July 2021, 4.
[74] RED II (n 6).
[75] EPBD (n 7).
[76] RED II (n 6) art 3(1).

their national circumstances.[77] However, a more specific measure for the integration of renewable energy in the transport sector, where the legally binding target is at Member State level, is outlined in Article 25(1) RED II, which states that

> in order to mainstream the use of renewable energy in the transport sector, each Member State shall set an obligation on fuel suppliers to ensure that the share of renewable energy within the final consumption of energy in the transport sector is at least 14 percent by 2030 (minimum share) in accordance with an indicative trajectory set by the Member State and calculated in accordance with the methodology set out in this Article and in Articles 26 and 27.[78]

The Directive states that the ‘transport sector’ here only refers to road and rail transport.[79] Member States can opt to contribute to this share in the aviation and maritime sectors, but are not subject to this obligation.[80]

If DACCU fuels were to be regarded as a source of renewable energy in the sense of RED II, they could play a strategic role in the EU's efforts to achieve climate neutrality by 2050, as well as the Commission's proposals for regulation in the transport sector.[81] In particular, these fuel types would allow fuel suppliers to comply with the obligation imposed by Member States to ensure that the share of renewable energy in final energy consumption in the transport sector is at least 14% by 2030 at the latest.[82] Moreover, RED II also states that the Commission will subsequently assess this obligation with a view to increasing it where necessary to meet the Union's international commitments to decarbonization. If this type of fuel would fall within the ambit of RED II, it would not only be a strong incentive for the deployment of DACCU, but it would also benefit its use as renewable energy.

To assess whether DACCU fuels qualify as energy and/or fuels from renewable sources, the definition of renewable energy must be addressed. Article 2(1) RED II defines renewable energy as ‘energy from renewable non-fossil fuels, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas’.[83] At first blush, CO_2 does not qualify as a renewable energy under this definition. As mentioned in Section 2, CO_2 is a resource or feedstock that provides carbon for the production of synthetic fuels, among other goods. Furthermore, synthetic fuels do not qualify as renewable energy under the definition of Article 2(1) RED II. However, Article 25(1) RED II extends this qualification through the obligation to ensure the minimum share of renewable energy. For the calculation of this minimum share, Article 25(1) RED II states that the following fuels will be taken into account: *renewable liquid and gaseous fuels of non-biological origin (RFNBO)* and *recycled carbon fuels*. The RFNBO are those liquid or gaseous fuels used in the transport sector other than biofuels and biogas and whose energy content comes from renewable sources other than biomass.[84] The recycled carbon fuels, unlike the previous one, are those liquid and gaseous fuels produced from liquid or solid waste streams of non-renewable origin … and from process waste gases and exhaust gases of non-renewable origin produced as an unavoidable and unintended consequence of the production process in industrial installations.[85]

Of these two types of fuels, the RFNBO definition is appropriate for DACCU fuels. As long as the energy content of DACCU fuels comes from renewable sources (e.g. wind, solar or geothermal) and they are neither biofuels nor biogas, they qualify as a RFNBO. Therefore, as a RFNBO fuel and within the meaning of Article 25(1) RED II, DACCU fuels qualify as renewable energy. Arguably, the origin of the CO_2 used, as resource or feedstock, for the production of DACCU fuels is not an issue. That is, CO_2 can come from the atmosphere or from waste gas streams, such as from power plants.[86] Accordingly, as a RFNBO, DACCU fuels can be mainstreamed into the renewable energy share obligation under Article 25(1) RED II.

The recognition of a DACCU fuel as a RFNBO is not the only a requirement for the qualification as a renewable energy under RED II. Many CO_2 conversion processes require energy that may come from fossil sources, such as natural gas (methane). Therefore, the sustainability criterion is key in DACCU processes for CO_2 transformation: The energy required for fuel conversion must be based on renewable energy sources. In this regard, Article 27(3)(6) RED II states that ‘electricity taken from the grid may be fully counted as renewable, provided that it is produced exclusively from renewable sources and the renewable properties and other appropriate criteria have been demonstrated, ensuring that the renewable properties of such electricity are declared only once and only in one end-use sector’.[87] It is then established in Article 27(3)(8) that the Commission shall establish, by means of a delegated act no later than 31 December 2021, a methodology to comply with these requirements.[88] It should also be noted that to demonstrate this ‘renewable’ character, the application of Article 19 RED II is key, because it deals precisely with guarantees of origin of energy from renewable sources. Article 19 RED II requires the Member States to ensure the issue of a Guarantee of Origin (GO) at the request of producers of electricity, gas, hydrogen, heating or cooling from eligible renewable energy sources. The system is voluntary, and individual producers can decide whether to submit such a

77 ibid art 3. See A Monti and B Martinez Romera, ‘Fifty Shades of Binding: Appraising the Enforcement Toolkit for the EU's 2030 Renewable Energy Targets’ (2020) 29 Review of European, Comparative and International Environmental Law 221, 222.

78 RED II (n 6) art 25(1).

79 ibid art 27(1).

80 Commission (EU), ‘Renewable Energy—Recast 2030 (RED II)’ <https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii>.

81 Commission (EU) (n 70); Commission (EU) (n 72); Commission (EU) (n 73).

82 RED II (n 6) art 25(1).

83 ibid art 2(1).

84 ibid art 2(36).

85 ibid art 2(35).

86 L Dammer et al, ‘Support for the revision of the Monitoring and Reporting Regulation for the 4th Trading Period (Focus: Carbon Capture and Utilisation (CCU))’ (Umweltbundesamt 2019) 25.

87 RED II (n 6) art 27(3)(6).

88 Recital 90 of the Directive RED II, ibid, also states that this methodology should ensure the existence of a temporal and geographical correlation between the electricity production unit with which the producer has a bilateral contract for the purchase of electricity from renewable sources and the production of fuel.

request. The main provisions of Article 19 define and limit the purpose of a GO, establish the conditions under which they are issued, specify the conditions for using a GO and specify the content of the GO. They also establish the conditions for designating supervisory bodies for national GO systems, among others.

Another criterion that DACCU fuels have to meet for being eligible to qualify as a renewable energy share (minimum share, Article 25(1) RED II) is 'additionality'. This means that the expected increase in electricity demand in the transport sector above the current reference value is achieved with additional renewable generation capacity (Article 27(3) RED II). In the case of RFNBO fuels, and therefore DACCU fuels, recital 90 RED II states that 'the fuel producer contributes to the use or financing of renewable energies'.[89] This new additional renewable energy generation capacity thus needs to be provided by the producer of the DACCU fuels. This requirement could place them at a competitive disadvantage compared with other types of fuels, such as biofuels. Although Recital 90 itself offers some guidance on how to determine this 'additionality', the rules in the Directive are not clear on the matter. Therefore, the methodology will need to establish how to distinguish between additional renewable energy and non-renewable energy.

Finally, another pending challenge of RED II for the deployment of DACCU fuels is to avoid double counting in the calculation of emission savings, especially with respect to credits under the EU emissions trading system. In this regard, Article 28(5) RED II states that through a delegated act by December 2021, the methodology for assessing greenhouse gas emission savings from RFNBO shall be specified to ensure that no avoided emissions credits are granted for CO_2 whose capture has already received emission reduction credits under other legal provisions.[90]

5.2 | The EPBD: Improving the carbon footprint of buildings?

The EPBD is a binding legal instrument that promotes the improvement of the energy efficiency of buildings within the Union.[91] It sets minimum requirements with regard to the energy performance of technical building systems whenever they are installed, replaced or upgraded.[92] The EPBD was adopted in 2010 and later amended in 2018.

The analysis of this legal instrument is relevant due to its linkage to the production of DACCU fuels, among other energy carriers. It is likely that DAC could be operated on farms, but it is also possible that in the future, DAC could be carried out in urban buildings by retrofitting AC systems to capture CO_2 from ambient air.[93]

If we consider that buildings are responsible for emissions for approximately 36% of all CO_2 emissions in the EU[94] and that almost half of its energy (50%) is consumed for heating and cooling purposes in buildings and industry, of which 80% is used in buildings,[95] the requirement for measures to help reduce these emissions is clear. Moreover, the majority of this energy is produced by fossil fuels (66%).[96]

Considering these aspects, DAC could contribute to improving the carbon footprint in buildings where operational processes emit CO_2 (preferably of non-fossil origin or unavoidable), particularly in larger office buildings.[97] However, this will only be effective if the DACCU operations fulfil sustainability criteria, such as that the energy used comes from renewable sources and the energy demand for its operations is optimized. This is in line with the Union's energy policy objective of promoting energy efficiency and energy savings (Article 194(1)(c) TFEU).

Article 2bis(1) EPBD states that each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy-efficient and decarbonized building stock by 2050. Although to date it is not possible to affirm the increase of energy efficiency through DAC, CO_2 capture through AC systems in buildings could be recognized as a way to contribute to lowering the carbon footprint of buildings, as long as the energy used fulfils sustainability criteria as outlined above. This approach could be introduced in the EPBD, not only for the renovation of buildings[98] but also for new buildings.[99]

To date, the Commission's proposal for the modification of RED II promotes the production and use of renewable energy in the building sector (Article 15a).[100] For this, Member States shall set an indicative target for the share of renewables in final energy consumption in their buildings sector in 2030. Both approaches, namely, the renovation of buildings that would allow the installation of AC systems with DAC technology and the promotion of the use of renewable energy in the buildings sector, could be beneficial as a cross-sectoral solution to achieve climate neutrality. This statement is supported also by the Commission's communication on 'A Renovation Wave for Europe', which highlights that decarbonization and integration of renewable energy is a key principle for the renovation of buildings towards the 2030 and 2050 targets. It states that energy systems should be integrated at the local and regional level to help decarbonize transport, as well as heating and cooling.[101]

However, even though DACCU may be attractive in regions with underdeveloped infrastructures due to the possibility of generating energy carriers,[102] this should not encourage the indiscriminate

[89] ibid.
[90] Dammer et al (n 86).
[91] EPBD (n 7) art 1(1).
[92] ibid art 1(2)(c)(iii).
[93] Dittmeyer et al (n 16).
[94] Parliament and Council Directive (EU) 2018/844 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency [2018] OJ L156/75, recital 6.
[95] ibid recital 7.
[96] Heat Roadmap Europe, 'Heating and Cooling: Facts and Figures' (2017) <https://heatroadmap.eu/heating-and-cooling-energy-demand-profiles/> 3.
[97] Dittmeyer et al (n 16).
[98] EPBD (n 7) art 2bis.
[99] ibid art 6.
[100] Commission (EU) (n 70).
[101] Commission (EU) 'A Renovation Wave for Europe—Greening Our Buildings, Creating Jobs, Improving Lives' (Communication) COM(2020) 662 final, 14 October 2020.
[102] Dittmeyer et al (n 16).

installation of AC systems in every building, because this would imply a high energy demand with respective environmental costs and might even lead to an increase in CO_2 emissions.[103] Even so, rising global temperature will make people try to cool their spaces to maintain their productivity and well-being,[104] especially if we consider that the demand for AC systems will increase in southern European countries.[105]

6 | CONCLUSIONS AND OUTLOOK

To stabilize the global average temperature, we need to change our living and production conditions. Essentially, an energy transition is required in the electricity, transport and industry sectors. High concentrations of CO_2 in the atmosphere are considered as a problem with a view to climate change, but it can possibly also be viewed as a carbon source for the production of synthetic fuels, thus supporting an energy transition. In this way DACCU could support and improve the carbon footprint of the transport and building sectors, which are responsible for a large share of global greenhouse gas emissions. However, a big challenge for the deployment of this technology is the optimization of the energy consumption required to carry out the capturing and conversion processes. To date, there is no specific legal framework to properly regulate this technology, but it is already being incorporated in climate strategies such as those of Japan, Australia and the United Kingdom. With the aim of assessing whether DACCU fuels can be considered as renewable energy for the transport sector under the EU's legal framework and what challenges remain, we have examined European legislation, focusing on RED II. As a result, we concluded that DACCU fuels can be qualified as RFNBO according to the definition established in the Directive, as they are neither biofuel nor biogas. However, this is not the only requirement DACCU fuels need to fulfil to be eligible to qualify as renewable energy, but also, the energy with which DACCU fuels are produced must come from renewable sources. RED II does not yet regulate the methodology to be considered to demonstrate this ‘renewable’ character. However, this methodology must establish criteria linked to the calculation of the electricity used for the production of this type of fuel. Another aspect to be clarified is the type of additionality applied to RFNBO, which places it at a competitive disadvantage compared with, for example, biofuels. It is necessary to establish features that allow distinguishing when renewable energy is additional and when it is not.

We also conclude that in the future, both the aviation and maritime transport sectors should be subject to the renewable energy (minimum) share requirement if the EU's 2030 and 2050 climate targets are to be achieved. It is also necessary to establish criteria to avoid double counting in the calculation of emissions savings. Although it is not yet possible to establish the ‘renewable’ character according to the criteria to be established in the methodology under RED II, DACCU fuels do qualify as RFNBO. Therefore, it is possible to conclude that DACCU fuels can be considered as a potential option for a renewable energy transition. Likewise, because DACCU could contribute to the improvement of the carbon footprint of buildings, the recognition of this approach in the EPBD could be an option. However, our analysis also highlights that this will only be effective if the DACCU operations fulfil sustainability criteria, such as that the energy used comes from renewable sources and the energy demand for its operations is optimized (energy efficiency).

Finally, while we conclude that European legislation allows DACCU fuels to qualify under certain criteria as renewable energy, there are issues that need to be resolved as this technology emerges, such as improving and extending the terminology and certification of these types of fuels.

ORCID

Romina Schaller https://orcid.org/0000-0003-2245-046X

AUTHOR BIOGRAPHIES

Romina Schaller is a postdoctoral researcher at the Helmholtz Centre for Environmental Research, Department of Environmental and Planning Law (Germany), where she focuses on international and European environmental law in the fields of climate change mitigation (e.g. forest protection through REDD+) as well as on ecosystem services and sustainable development. Her current research explores the legal aspects for the regulation of CDR technologies and the emerging challenges linked to their governance.

Till Markus currently works as a senior legal researcher at the Department for Environmental and Planning Law at the Helmholtz Centre for Environmental Research in Leipzig and as a senior lecturer at the University of Bremen. He is also chief editor of the leading German environmental law journal (Zeitschrift für Umweltrecht [ZUR]) and has published and taught extensively in different areas of international and European Union law, environmental law, the law of the sea, comparative law and legal theory.

Klaas Korte is a researcher at the Department of Economics of the Helmholtz Centre for Environmental Research—UFZ, Leipzig, Germany. He holds a diploma in economics and business administration with a focus on environmental economics and public finance from the Leibniz-Universität Hannover, Germany. The main emphasis of his research is on the economic analysis and assessment of policy instruments and regulation in the fields of climate, energy and environmental policy.

Erik Gawel graduated from Cologne University with a diploma and PhD in economics. He was a visiting professor in the Postgraduate Programme of the German Research Foundation (DFG)

[103]‘Air-Conditioners Do Great Good, But at a High Environmental Cost’ (The Economist, 25 August 2018); IEA, ‘The Future of Cooling—Opportunities for Energy-Efficient Air Conditioning’ (IEA 2018) 11.
[104]L Wenz, A Levermann and M Auffhammer, ‘North-South Polarization of European Electricity Consumption Under Future Warming’ (2017) 114 Proceedings of the National Academy of Sciences of the United States of America E7910.
[105]IEA (n 103); Wenz et al (n 104).

'Risk Regulation and System of Civil Law' (Bremen University) and habilitated at Augsburg University. He was a scholarship holder of the German National Academic Foundation, the DFG and Max Planck Society. Today, he is Full Professor of Institutional Environmental Economics and Director of the Institute for Infrastructure and Resources Management at Leipzig University as well as Head of the Economics Department of the Helmholtz Centre for Environmental Research—UFZ, Leipzig. He is, among others, a member of the European Academy of Sciences and Arts.

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