Industrial Removals' Resource Use in the 2040 Climate Target Impact Assessment

An analysis of biomass, electricity, and water needs for Bioenergy and Direct Air Carbon Capture and Storage (BECCS and DACCS) in the EU Commission's Impact Assessment of the 2040 target

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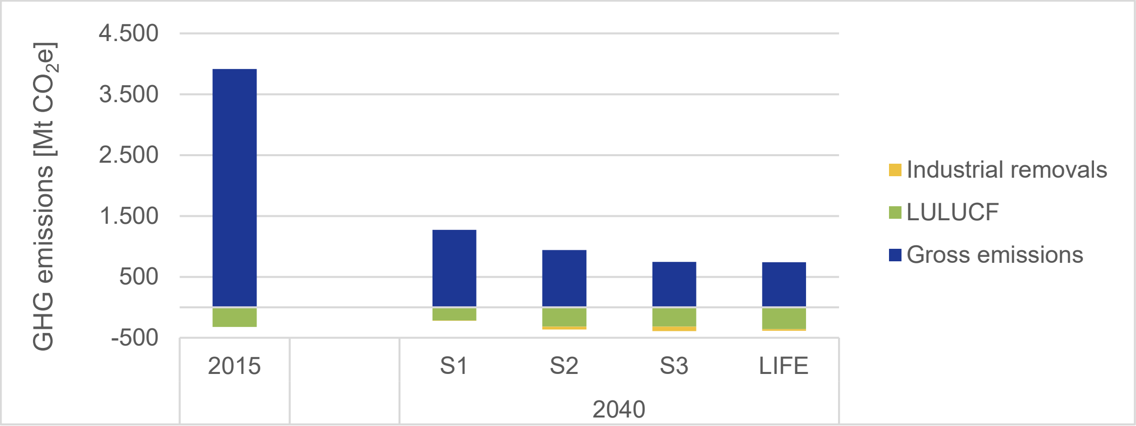
Summary

Resource use and related impacts of industrial carbon removals are critical factors to consider when assessing the role of these removals in achieving net greenhouse gas (GHG) emission reductions. This report therefore analyses the projected scale of deployment and the associated biomass, electricity, and water needs by 2040, based on the Impact Assessment (IA) underlying the EU Commission's Communication on the EU's 2040 climate target.

Scale and resource requirements of industrial removals in the impact assessment

The IA projects that industrial removals, specifically Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS), will play a minor role in net GHG emission reductions by 2040. **These technologies are expected to remove between 27 and 75 Mt CO_2 in 2040, which is lower than natural removals of around 300 Mt CO_2 in that year or the gross GHG emission reduction of around 2,500 Mt CO_2e that is projected between 2022 and 2040.** This means that, without industrial removals, the net GHG emission reduction in 2040 would decrease by no more than 1%.

Figure 1: GHG emissions and removals in 2005 and 2040 across the IA scenarios



Source: Own representation based on EC (2024).

Despite the minor role of industrial removals, the IA fails to take a cautious approach concerning biomass availability (and thus for BECCS) as well as for the electricity consumption of DACCS: it uses rather optimistic biomass availability estimates and assumes DACCS specific electricity consumption at the lower end of other projections, potentially underestimating resource needs. However, due to the low reliance on industrial removals by 2040, the overall impact on biomass and electricity consumption is projected to be low. This creates an opportunity for further technological advancements beyond 2040, improving DACCS efficiency and ensuring carefully planned and sustainable BECCS implementation.

Finally, it is important to note that the IA does not examine CO_2 transport and storage for industrial removals in detail – thus, this report focuses on CO_2 capture. Additionally, the IA shows no absolute figures for biomass, electricity and water needs. These could only be derived by own calculations based on the 'technology assumptions' sheets and complementary sources. This makes it difficult to assess the EU's climate plan.

Biomass needs for Bioenergy with Carbon Capture and Storage (BECCS)

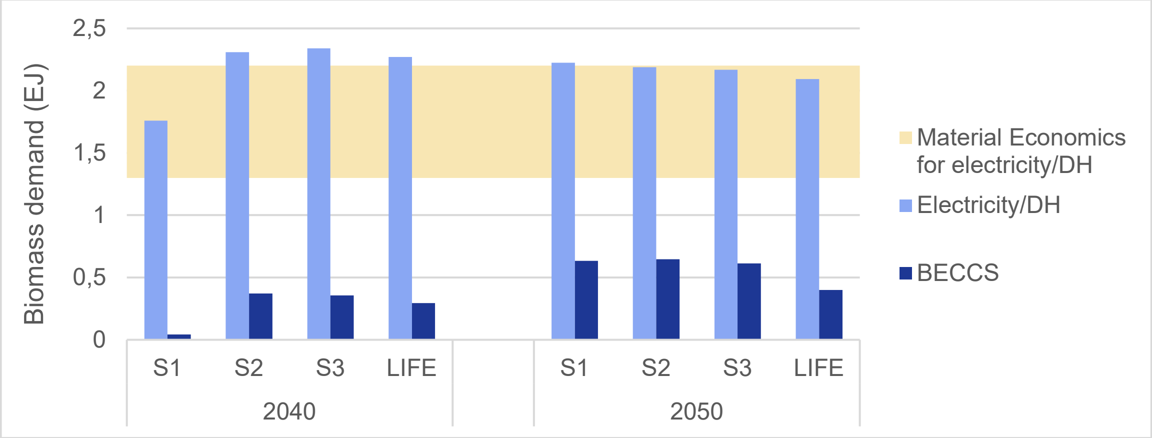
The delivery of BECCS as a negative emissions technology depends on biomass sourcing and (in)direct impacts on existing carbon sinks. Sustainability issues associated with the sourcing of biomass, particularly regarding food production and biodiversity, limit the availability of biomass for materials and energy purposes, especially when using stemwood or dedicated energy crops. The IA does not sufficiently address these risks related to BECCS.

The IA projects BECCS to remove between 27 Mt and 34 Mt of CO_2 in 2040 (LIFE, S3, S2). This amount is at the lower end of what is outlined in the scenarios from the ESABCC and would not require the construction of new facilities, as it could be implemented at existing bioenergy plants.

To remove 34 Mt CO_2 in 2040, the biomass input required for BECCS is around 0.4 EJ. This is roughly 16% of the projected biomass demand for electricity and district heating in 2040. This means that the IA leaves more than 80% of the projected biomass for e.g. flexible bioenergy electricity generation without CCS.

While there is no estimate for biomass availability for BECCS in 2040, Material Economics estimates that available sustainable biomass is around 1.3-2.2 EJ for electricity and district heating. This range depends on how much sustainable biomass is available overall and how much is required for materials and other energy purposes. **The IA projects 2.3 EJ in the scenarios S2, S3 and LIFE in 2040 – this is slightly less than the 2022 biomass use of 2.6 EJ and slightly above estimated availability constraints of 2.2 EJ, but considerably too high for the case where only 1.3 EJ is available. This would most likely also impact the availability of biomass for BECCS.**

Figure 2: Biomass demand of centralised electricity and heat generation and of BECCS in the IA



Source: Own calculation based on EC (2024), Material Economics (2021).

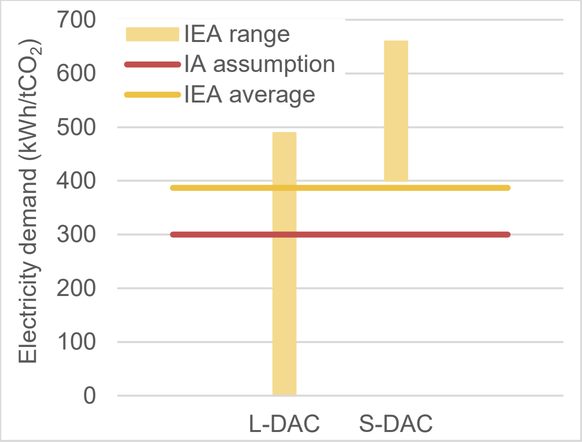
These findings remain consistent when looking at the overall biomass consumption for all energy purposes. The IA projects a small increase to 7 EJ in 2040, which is close to exceeding, but still within the range of 4–8 EJ of estimated biomass to be sustainably available. However, if only 4 EJ of biomass can be used for energy purposes, the IA's projected biomass demand could exceed sustainable supply, limiting the availability for all energy purposes below the IA's projections.

Electricity demand of Direct Air Carbon Capture and Storage (DACCS)

The IA projects DACCS to remove around 15 Mt CO_2 in S2 and 42 Mt CO_2 in S3. In addition, DACC is not only used for underground storage (DACCS) but also for e-fuels production as part of DACCU (carbon capture and utilisation). If both are considered, DACCUS (carbon capture, utilisation, and storage) captures between 20 Mt and 121 Mt CO_2 in 2040 (S2 and S3). The IA projects that DACCS is significantly higher than in other available scenarios.

Despite these higher projections, DACCS will require a minor share of total electricity and energy supply. The IA assumes an electricity consumption of 300 kWh/tCO_2, which is lower than the IEA's average of 387 kWh/tCO_2 and well below the upper estimate of 600 kWh/tCO_2. **Based on the IA assumption, DACCS electricity demand is 12.6 TWh in 2040 (S3). If the IEA average is applied, this demand increases to 16 TWh, and with the upper estimate, it reaches 27 TWh.** Compared to the energy sector's electricity demand and total electricity demand, consumption of DACCS is limited equalling less than 1.4% and 0.6%, respectively.

Figure 3: Specific electricity demand of different DACCS technologies and assumption in the IA



Source: EC (2024), IEA (2022).

When considering DACCUS, the increased capture rate leads to a higher electricity demand of up to 36 TWh in the IA's S3 (which assumes more DACC for e-fuels than for storage). With the higher IEA estimates, the demand could rise to 47 TWh or 77 TWh. The corresponding shares equal 1.9% of the EUs energy sector electricity demand with the IA's assumption, 2.5% with the IEA average and up to 4.1% in the upper IEA estimate. Compared to the total electricity generation, this would imply a share of 0.7% with the IA assumption, and 0.9% and 1.5% with the IEA average and upper estimate.

For energy consumption overall findings show that DACCS has a limited impact on energy consumption in 2040, with CO_2 capture for e-fuel production (DACCU) making up the larger part of the energy needs in S3. In general, it should be noted that for CO_2 removal through DACCS to be effective, the energy used must come from renewable sources.

Water demand of Direct Air Carbon Capture and Storage (DACCS)

Water use for DACCS depends on the technology employed. Liquid solvent DACCS (L-DACC) requires significant amounts of water, making water availability a critical factor in site selection, especially in generally water scarce regions. The IA does not provide specific data on water consumption for DACCUS, but external sources suggest that DACCUS could use up to 2,100 Mm^3. This is a substantial amount. Comparably, the water consumption of the energy sector in 2020 was around 3,500 Mm^3. Local water availability will therefore be a key factor in deciding the location of L-DACC units.

Contents

1 Introduction 7

2 Options of industrial carbon dioxide removals 8

2.1 What are carbon dioxide removals? 8

2.2 Bioenergy with Carbon Capture and Storage 8

2.3 Direct Air Carbon Capture and Storage 9

2.4 Storage sites for BECCS and DACCS 10

3 Industrial carbon removals in 2040 12

4 Bioenergy with Carbon Capture and Storage (BECCS) 15

4.1 Biomass demand in the EU in 2040 15

4.2 Biomass demand for BECCS in the EU in 2040 18

4.3 Conclusion 20

5 Direct Air Carbon Capture and Storage (DACCS) 21

5.1 Electricity demand in the EU in 2040 21

5.2 Electricity consumption of DACCS and DACCUS in 2040 22

5.3 Conclusions 27

6 Index of figures, tables, abbreviations 29

List of Figures 29

List of Tables 29

Abbreviations 30

7 References 31

Ecologic Institute: Science and policy for a sustainable world 36

1 Introduction

The EU is set to adopt a climate target for 2040 in the coming years, as mandated by the European Climate Law (ECL). This target is a crucial milestone on the EU's journey towards climate neutrality by 2050 and achieving net negative emissions thereafter.

On February 6, 2024, the Commission published its communication regarding the EU's climate target for 2040. In this document, the Commission recommends a 90% reduction in net greenhouse gas (GHG) emissions by 2040 compared to 1990 levels.

Carbon removals are an important component in achieving the proposed climate target of net 90% reduction in GHG emissions. However, the gross GHG emission reduction and net removals from land use, land-use change, and forestry (LULUCF) are projected to make the largest contribution to achieving the target, with industrial removals becoming more relevant towards 2050 (see Table 2).

The technologies for industrial removals in the Impact Assessment (IA) are Bioenergy Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS). While other methods exist, such as biochar and enhanced rock weathering, the IA focuses exclusively on BECCS and DACCS.

The use of industrial removals raises important questions that will become more pressing as the importance of industrial removals grows and as other sectors demand green electricity and sustainable biomass to decarbonise:

- **Biomass consumption:** BECCS depends on a reliable supply of biomass, raising questions about the availability of sustainable biomass for such facilities and about related (in)direct impacts on land use, human rights, and nature and biodiversity conservation.
- **Energy consumption:** DACCS requires electricity and heat, raising questions about the availability of green electricity and clean heat.
- **Water use:** DACCS uses water in the capture process, raising questions about water availability for such facilities and their location.

This report examines the assumptions and outcomes related to industrial removals, specifically BECCS and DACCS, as outlined in the IA. It focuses on analysing the IA's assumptions regarding their biomass, electricity, and water requirements in 2040 across various scenarios.

More specifically, the report defines what carbon removals are, describes very briefly the technologies used for BECCS and DACCS and gives a short overview of CO_2 storage sites (chapter 2). Chapter 3 provides an overview of industrial removals by 2040. In chapter 4, the report analyses overall biomass demand for centralised electricity and heat generation as well as for BECCS. Chapter 5 provides an assessment of DACCS' electricity and water demand.

2 Options of industrial carbon dioxide removals

2.1 What are carbon dioxide removals?

According to the IPCC, carbon removals describe human activities "*removing CO_2 from the atmosphere and* <u>*durably*</u> *storing it in geological, terrestrial, or ocean reservoirs, or in products*" (emphasis partly added). This definition includes "*existing and potential anthropogenic enhancement of biological, geochemical or chemical CO_2 sinks, but excludes natural CO_2 uptake not directly caused by human activities […]. CCS and CCU can only be part of CDR methods if the CO_2 is biogenic or directly captured from ambient air, and stored durably in geological reservoirs or products*" (IPCC, 2022b). This is a direct allusion to BECCS and DACCS and it also excludes any CO_2 use for non-durable options such as e-fuels from being a removal option.

Importantly, the IPCC does not define the crucial adjective "durable". To address this ambiguity and to take account of the atmospheric lifetime of CO_2, permanent storage should be defined by the time that carbon stays in the atmosphere, which is in large parts more than 1000 years (see e.g. Meyer-Ohlendorf, 2023; BioNET & CDRterra, 2023; Frontier Initiative, 2024). In its information note on carbon removal mechanisms, however, the Supervisory Body of the Article 6.4 Mechanism of the Paris Agreement only vaguely states that 100 years is a commonly used period and a "*commonly accepted normative choice*" (Supervisory Body, 2022). It does not define durable storage.

According to the EU's Carbon Removals and Carbon Farming Regulation (CRCF, 2024), permanent carbon removals are defined as "any practice or process that, under normal circumstances and using appropriate management practices, captures and stores atmospheric or biogenic carbon for several centuries".

2.2 Bioenergy with Carbon Capture and Storage

Bioenergy with Carbon Capture and Storage (BECCS) generally refers to biomass **thermal power and/or heat generation** (while BioCCS is the umbrella term for CO_2 capture and storage from any biogenic source)**.** In BECCS, CO_2 emitted from biomass combustion is separated from the boiler flue gas and then captured and stored, for example, in underground formations. This means that BECCS integrates electricity and/or heat production from biomass with a downstream CCS unit to capture CO_2. Therefore, it can be considered a sub-category of CCS (for more info see e.g., Fajardy et al., 2018; Hajian and Sedighi, 2022; IEA Bioenergy, 2020). CCS comes with energy losses of around 15-29%, though some studies suggest it could be reduced to 2-4% (EC, 2022; Gustafsson et al., 2021).

Inputs into bioenergy power and heat plants include wet and dry or pulverised biomass, biogas, or biofuels from different biomass feedstocks such as wood, crops, biogenic residues from the agricultural sector, or organic wastes from households and services (Consoli, 2019). The IA outlines a Technology Readiness Level (TRL) of 5.5, which means that BECCS has undergone testing in relevant environments but requires further demonstration to fully validate its performance in real-world conditions. Therefore, the technology is only expected to become operational between 2030 and 2040 (EC, 2024).

CO_2 can not only be captured during biomass combustion, but also during **biofuel production**, using methods such as gasification, digestion, Fischer-Tropsch synthesis, and fermentation. In these processes, 15% (fermentation) to 55% (gasification) of the biomass carbon is released as high-purity CO_2, which can be captured directly for the most part (Fajardy et al., 2018). The primary fuel used is bioethanol, which generates an almost pure stream of CO_2 as a byproduct of fermentation (Consoli, 2019).

CO_2 can also be captured during the **upgrading of biogas to biomethane**, which the IA refers to as ‘biogenic carbon’ (EC, 2024) and which can only be indirectly considered as BECCS as it does not involve capture during bioenergy generation. In the upgrading process of biogas to biomethane, biogas composed of 60% CH_4 and 40% CO_2 is transformed to biomethane consisting of 97% CH_4 which is a renewable gas with almost identical properties to natural gas (IEA Bioenergy, 2022). As the CO_2 in biogas is one of the cheapest sources of pure CO_2, it is also being used for other purposes, such as the production of synthetic methane (IEA Bioenergy, 2022).

2.3 Direct Air Carbon Capture and Storage

Direct Air Carbon Capture and Storage (DACCS) refers to chemical processes that extract CO_2 from the ambient air and store it in certain structures such as underground formations (Breitschopf et al., 2023; IPCC, 2022a). In more detail, the basic Direct Air Carbon Capture (DACC) process is as follows: Ambient air is drawn in with fans and passed past a sorbent, which binds the CO_2 present in the air. The CO_2 is then separated from the sorbent during the desorption or regeneration process, and can be recovered in a concentrated form. The sorbent can be reused after, depending on the specific technical process (Breitschopf et al., 2023; Hanson et al., 2021; IEA, 2022). Currently, there are two main DACC technology approaches for capturing CO_2 from the air: solid and liquid DACC. Solid DACC (S-DACC) employs solid sorbent filters that chemically bind the CO_2. Liquid DACC (L-DACC) uses chemical solutions such as a hydroxide solution (see Figure 4).

Table 1: Technological options for DACC – general assumptions

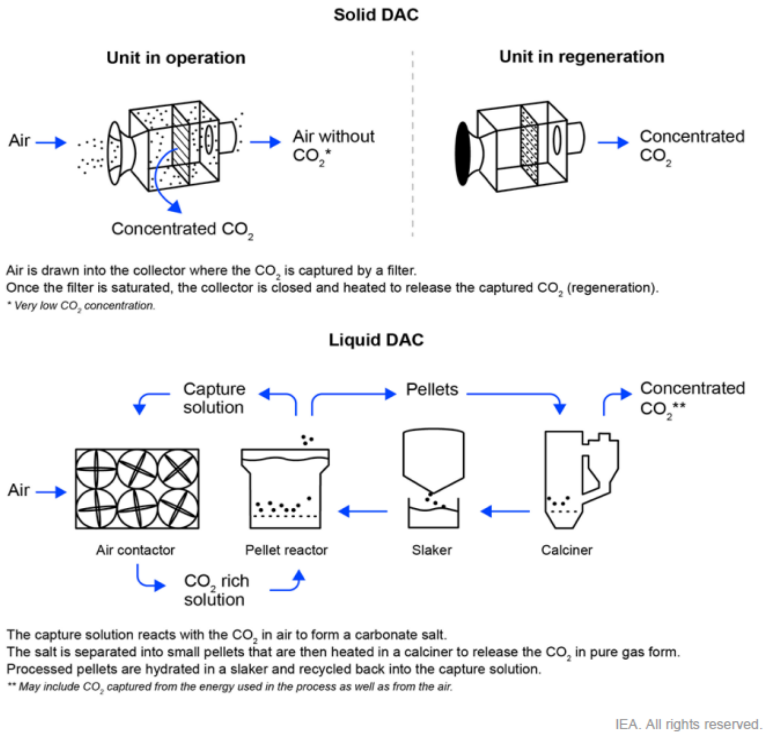
	L-DACC	S-DACC
Sorbent	Liquid	Solid
Scale	Large	Small to medium
Temperature	High	Low
Electricity consumption	Low	High
Water consumption	High	Low
Geographical suitability	Arid or remote	Abundant renewables available

Source: Own representation based on IEA (2022).

The sorbent regeneration process requires heat to release the CO_2 bound to the sorbent. In general, L-DACC works with higher temperatures than S-DACC, needs water, and regeneration pressure is at ambient level. S-DACC systems use vacuum or pressure swing adsorption to separate the CO_2 from the solid sorbent, making them more electricity-intensive. Both systems require electricity for fans and blowers, pumps (in case of L-DACC), compressors for the captured CO_2 as well as control systems and ancillary equipment (IEA, 2022; Terlouw et al., 2021). For L-DACC systems, optimal capture rates are primarily attainable in hot and humid climates due to favourable absorption kinetics. In contrast, S-DACC systems exhibit lower capture costs in cold and humid environments, where temperature is a crucial factor (An et al., 2023). L-DACC is designed for large-scale operations, while S-DACC is better suited for small to medium-sized units (IEA, 2022) (see also Table 1).

In general, captured CO_2 can either be stored underground (DACCS) or the captured CO_2 can be used in fuels or products (DACCU: Direct Air Carbon Capture and Utilisation). While DACCU temporarily delays the release of CO_2 back into the atmosphere by reusing it, this approach does not generally result in the permanent removal of CO_2.

Figure 4: Typical S-DACC (top) and L-DACC (bottom) configurations



Air is drawn into the collector where the CO_2 is captured by a filter.
Once the filter is saturated, the collector is closed and heated to release the captured CO_2 (regeneration).
** Very low CO_2 concentration.*

The capture solution reacts with the CO_2 in air to form a carbonate salt.
The salt is separated into small pellets that are then heated in a calciner to release the CO_2 in pure gas form.
Processed pellets are hydrated in a slaker and recycled back into the capture solution.
*** May include CO_2 captured from the energy used in the process as well as from the air.*

Source: IEA (2022).

2.4 Storage sites for BECCS and DACCS

In order to effectively remove CO_2 from the atmosphere, the captured CO_2 needs to be isolated long-term from the atmosphere. Such storage options include pressing CO_2 into geological formations, such as saline aquifers where CO_2 is dissolved in brine, disused oil and gas fields, and mineralisation in sandstone or alkaline rock on the sea ground. These solutions are expected to store CO_2 for thousands of years. The transport of CO_2 to such storage sites is facilitated via road and rail networks, but also offshore and onshore pipelines, as well as transport ships (Breitschopf et al., 2023; IPCC, 2022a).

The IA emphasises the importance of "strategic storage sites" but does not go into further detail (EC, 2024). There are theoretical geological CO_2 storage resources of 507 Gt in Europe, both onshore and offshore, but further studies are needed to determine whether and how much CO_2 can in fact be safely stored there (Simon et al., 2022). Despite this seemingly high potential, its practical implementation is hindered by several factors, including technical constraints, insufficient infrastructure, high capital requirements, policy hurdles, and challenges in market integration (IEA, 2019). A shortage of permanent geological storage capacity is expected in the short to medium term, with less than 60% of announced captured emissions projected to be able to be stored in 2032 (Simon et al., 2022). This mismatch is also highlighted in the EU Net Zero Industry Act (EC, 2023).

Under normal conditions, carbon storage technology presents minimal risks to human health. However, risks can arise from the escape of CO_2 as a result of an accident or the gradual release of the gas from the storage complex. Risks to groundwater and soil arise from leaks, which can lead to the release of salty groundwater from deep aquifers and thus to the contamination of near-surface fresh groundwater, soil, and surface water. Most of the storage sites under discussion are offshore, where leakages could directly harm marine biodiversity and where the development of surface and subsurface infrastructure could indirectly affect flora and fauna, landscapes, and biodiversity. In addition, long-term CO_2 storage may conflict with other underground uses, such as geothermal energy, natural gas storage, offshore wind energy and nature protection reserves (Cames et al., 2024; UBA, 2023).

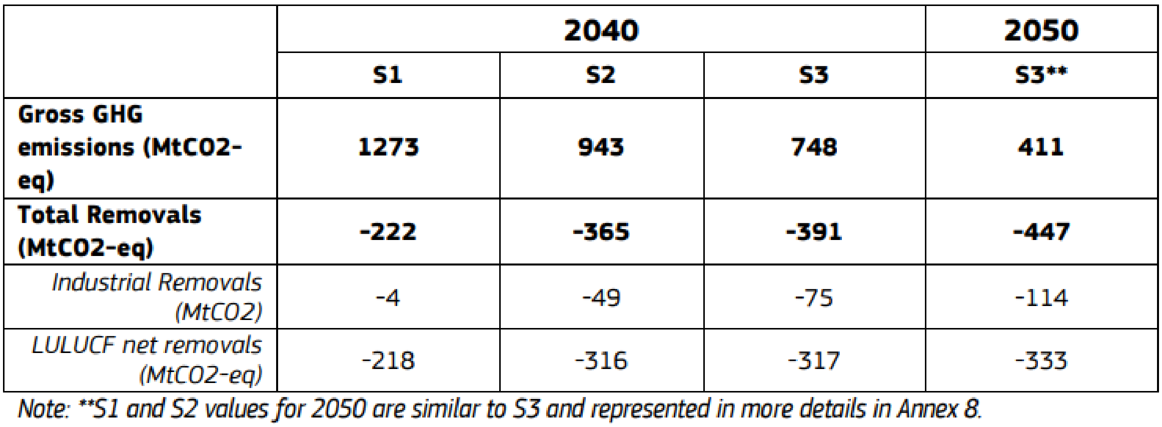
Around 30% of the European BECCS potential is located within 300 km of prospective carbon sites under development (Rosa, Sanchez, & Mazzotti, 2021). However, in the North Sea region, where there is significant offshore storage potential and where most of the planned storage projects are concentrated, Norway and the UK are relevant first movers. At EU level, the Netherlands and Denmark are leading the way (Simon et al., 2022). In 2024, Sweden, Denmark, Belgium and the Netherlands agreed with Norway on the cross-border transport of CO_2 to establish a CCS-market in the North Sea region (Swedish Ministry of Climate and Enterprise, 2024).

Currently, the demand for operational carbon storage sites in Europe exceeds capacity. The Global CCS Institute identifies three operational CCS projects and four under construction in Europe. Stockholm Exergi is negotiating with the Norwegian Northern Lights project to store the CO_2 captured from its BECCS plant. The project, operated by Shell, Total, and Equinor, and funded mainly by the Norwegian government and the EU, aims to inject liquefied CO_2 into a saline aquifer in the North Sea starting in 2024. Storage costs for such offshore aquifers range between EUR 6 and 20 per tonne of CO_2 in a mature industry scenario. However, the transport of CO_2 in ships poses challenges, including the risk of boil-off gas emissions during storage, loading and transit, potentially leading to economic losses and environmental pollution (Abraham et al., 2024).

3 Industrial carbon removals in 2040

The IA accompanying the EU Commission's Communication on a 2040 climate target includes four different scenarios – S1, S2, S3 and the LIFE variant (1). While S1 is projected to achieve a net reduction of 78%, S2 reduces net emissions by 88%, S3 by 92% and LIFE also by 92% by 2040 (compared to 1990). The Commission's recommended net reductions of 90% fall between the reductions projected in S2 and S3, and LIFE.

Table 2: Projected industrial removals and net LULUCF removals in 2040 and 2050



	2040			2050
	S1	**S2**	**S3**	**S3****
Gross GHG emissions (MtCO2-eq)	**1273**	**943**	**748**	**411**
Total Removals (MtCO2-eq)	**-222**	**-365**	**-391**	**-447**
Industrial Removals (MtCO2)	-4	-49	-75	-114
LULUCF net removals (MtCO2-eq)	-218	-316	-317	-333

*Note: **S1 and S2 values for 2050 are similar to S3 and represented in more details in Annex 8.*

Source: EC (2024).

To reach the proposed target, the IA indicates that gross emissions would have to decrease by 75% to 85% by 2040 compared to 1990 (S2/S3) to around 850 MtCO$_2$e. This is an absolute emission reduction of around 2,500 Mt CO$_2$e between 2022 and 2040. Carbon removals should total up to 390 MtCO$_2$ in 2040, with net removals from land use, land-use change, and forestry (LULUCF) expected to contribute most to target achievement, with estimated net removals of around -320 MtCO$_2$e (see Figure 5).

While industrial removals play a limited role until 2040, they become more significant by 2050. The IA projects industrial removals to reach up to 75 MtCO$_2$ in S3 in 2040, accounting for only up to 19% of the total carbon removal (see Figure 5). Current projections of industrial removals show their small impact on the overall target – the net GHG reduction would only diminish by 1% in S2, S3 and LIFE if industrial removals were excluded.

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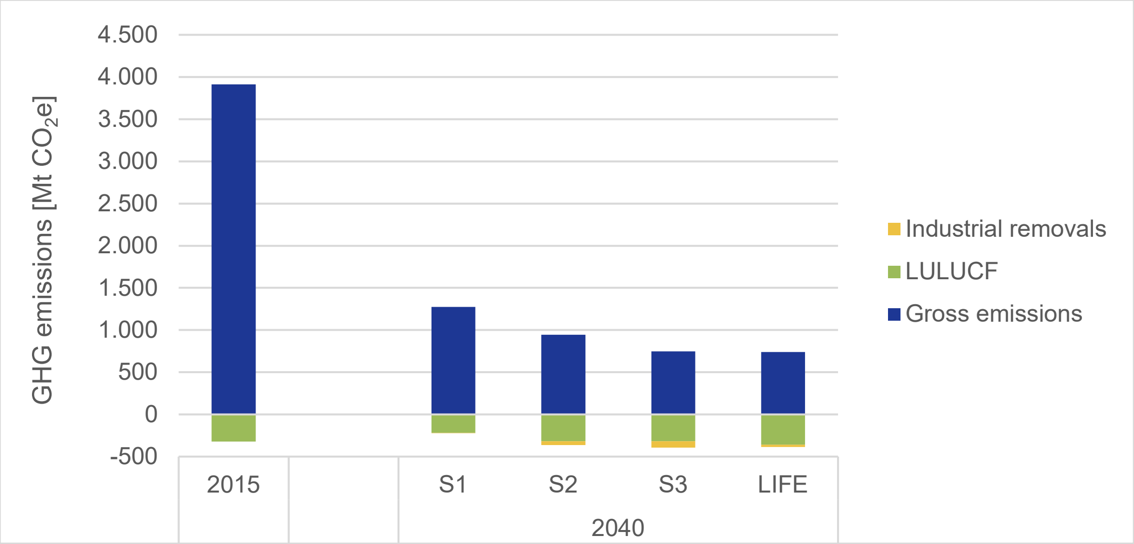
(1) The LIFE variant assesses the sensitivity of the analysis to assumed societal trends towards more sustainable lifestyles taking place in different systems such as food, transport or energy as well as in the field of circular economy. The objective of the LIFE scenario is to demonstrate the potential of demand-side measures to complement the supply-side technology deployment analysed in S1, S2 and S3 (EC, 2024).

Figure 5: GHG emissions and removals in 2005 and 2040 across the IA scenarios

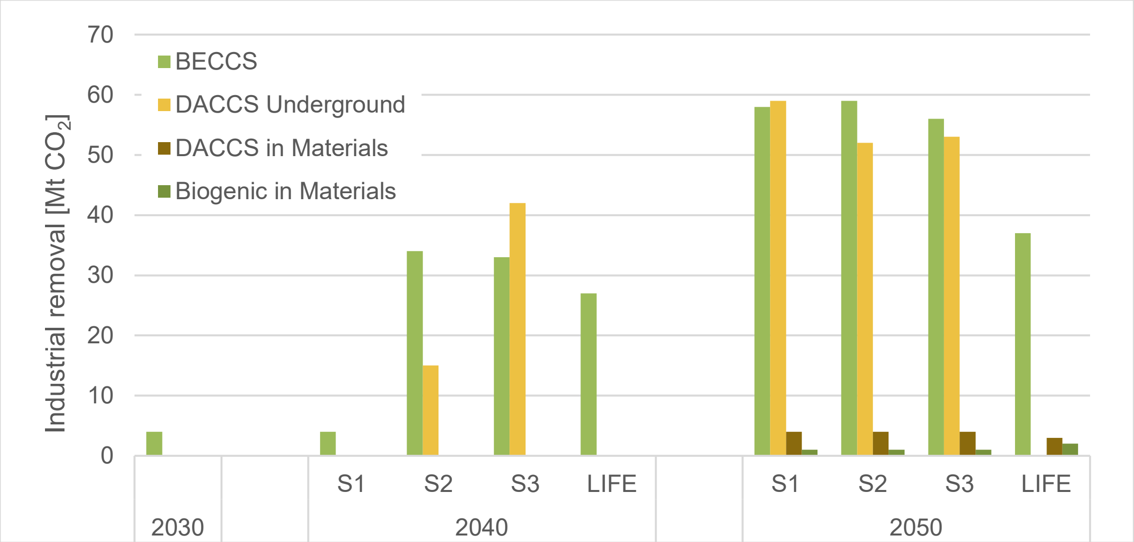


Source: Own representation based on EC (2024).

The contribution of BECCS and DACCS differs significantly across the IA's scenarios. Carbon removal from BECCS ranges from very limited application in S1 to close to 35 Mt CO_2 in S2 and S3. DACCS is not used in S1, removes 15 Mt CO_2 in S2, an amount that more than doubles to 42 Mt CO_2 in S3. The use of industrial removals is then further increased until 2050, when BECCS is projected to remove almost 60 Mt CO_2 and DACCS almost 120 Mt across S1–S3 (see Figure 6).

According to the IA, the captured CO_2 is stored underground or stored in materials to count as removal; however, by 2040, no CO_2 is stored in materials, and it remains only a very small share in 2050. In the LIFE-scenario, industrial removals are comparably lower than in S2 and S3, with BECCS being the dominant method until 2050.

Figure 6: Industrial carbon removals by source in 2030, 2040 and 2050 across the IA scenarios



Source: Own representation based on EC (2024). Note: the IA also considers CO_2 captured from air and stored in materials (DACCS in materials) and CO_2 captured during the upgrading of biogas to biomethane (Biogenic in Materials). Both options only arise by 2050 with a limited amount.

Scenarios from others that meet the net 90% emission reduction project a wide range of BECCS and DACCS contribution from 46 to 207 $MtCO_2$ for BECCS and zero to 7 $MtCO_2$ for DACCS (ESABCC, 2023). A model from Climact (2024) does not assume any contribution from DACCS and BECCS in 2040, and the POTEnCIA scenario predicts a high contribution from BECCS of over 77.6 $MtCO_2$ but hardly any DACCS (POTEnCIA in EC, 2024). Thus, the IA’s BECCS estimates are on the lower end of the range, while its DACCS projections are much higher in comparison to the other scenarios. This suggests that scenarios either compensate DACCS with BECCS or focus on deeper GHG emission reductions and/or enhancing natural sinks.

The differences across scenarios are significant and reflect the uncertainty around the two technologies, as the future development of BECCS and DACCS largely depends on technological advancements, cost developments, and social acceptance (IPCC, 2023).

4 Bioenergy with Carbon Capture and Storage (BECCS)

This section examines the biomass needs for the projected BECSS in the IA. It starts with assumptions on overall biomass availability and on bioenergy use in the IA, then focuses on BECCS deployment in centralised electricity and heating. The section concludes with an analysis on whether the IA assumes BECCS could potentially exceed sustainable biomass limits. The analysis focuses on the input side of biomass installations, excluding a discussion of the projected electricity and heat generation and efficiency of CCS.

4.1 Biomass demand in the EU in 2040

Availability of sustainable biomass for energy purposes

The application of BECCS depends on the availability of sustainable biomass and it leads only to CO_2 removal if it captures and stores more CO_2 than it emits throughout its entire lifecycle. This includes direct and indirect emissions from growing, harvesting, transporting, and converting the biomass, as well as the CCS process (BioNET & CDRterra, 2023; Cobo et al., 2022). The limited availability of biomass creates competition between its use for energy production, material applications (like wood products and pulp), and chemical processing, requiring careful prioritisation to optimise resource efficiency and sustainability outcomes (Popp et al., 2021).

The sustainability of BECCS depends on the type of biomass used. Primary biomass from forests and arable land, in particular energy crops and stemwood, lead to competition for land and water resources and can create serious conflicts with food production, biodiversity conservation, existing carbon sinks, and soil fertility. The IA finds that an increased demand for woody biomass of 0.8 EJ, e.g., in S3, would negatively impact LULUCF net removals, reducing them by approximately 100 Mt CO_2 in 2040 which is about a third of the projected removals of 317 Mt CO2 in that scenario and year (see Table 2). Other studies found BECCS to be among the most harmful removal technologies to ecosystems, with large-scale land conversion threatening both forest ecosystems and agricultural land availability (Cobo et al., 2022; IPCC, 2022c; Werner et al., 2023).

By-products and (formally) waste, are more sustainable. Particularly the use of waste biomass, such as livestock manure, crop residues, organic municipal waste and wastewater, can minimise side effects but faces competition from composting and bio-based products. Other secondary biomass streams, for example by-products of the timber industry, are already in use, potentially creating further competition with BECCS. In addition, the term "forestry residues" refers to any wood that cannot be marketed for purposes such as timber or pulp production which can vary in form and quantity depending on the harvesting system. To limit land use and related impacts, new sources like offshore algae and genetically modified organisms are under research (Feng & Rosa, 2023; Hajian & Sedighi, 2022; Smith et al., 2023; Udali et al., 2024).

Therefore, BECCS can only contribute meaningfully to climate mitigation if implemented with careful consideration of resource streams, using only sustainable sourced biomass particularly from waste-based feedstocks.

Bioenergy in the IA

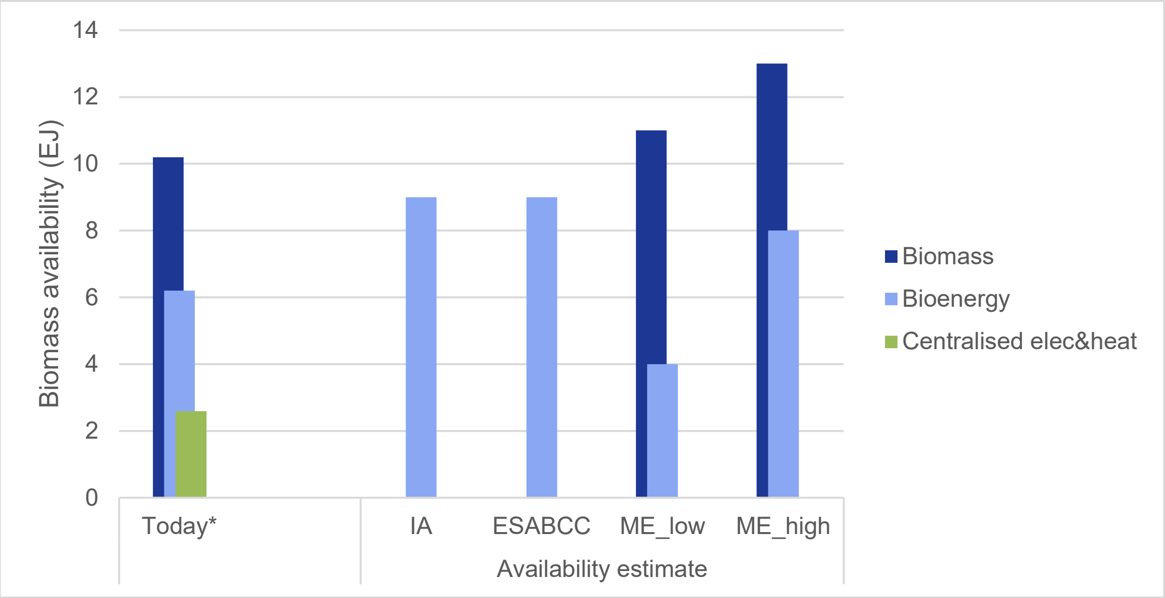
The IA focuses on *bioenergy* demand only and does not estimate overall *biomass* demand, such as for materials and products. It does, however, project wood demand (in cubic meters) for energy and non-energy purposes to estimate the land impact. Changes related to land use are then covered under LULUCF.

The modelling of the IA caps available biomass for energy purposes at 9 EJ overall to stay within sustainability boundaries. The 9 EJ are based on the 'environmental risk level' identified by the ESABCC (2023). Accordingly, the IA states that staying below 9 EJ, coupled with a shift to second-generation biofuels, will help ensure that future bioenergy use does not significantly impact land use and biodiversity. The IA expects that biomass imports are limited to maximum 0.5 EJ in 2040 (EC, 2024).

The overall cap on bioenergy of 9 EJ is just slightly above the upper limit estimated by Material Economics (2021). In its high value scenario, Material Economics estimate the total biomass availability at 11–13 EJ by 2050. This is in between other studies' results summarised by the EEA (2023), particularly of the JRC which provides a range between 8.3–20.3 EJ by 2040, and 7.8–21.2 EJ by 2050 (Ruiz et al., 2019).

According to Material Economics, the available biomass for energy purposes is 4–8 EJ. The total biomass availability is at 11–13 EJ and biomass demand for materials at 5.5–7 EJ by 2050. This is not much more than the current biomass supply of 10.2 EJ of which 6.2 EJ are used for energy purposes. Of these 6.2 EJ, 4.4 EJ are for electricity and (centralised and decentralised) heat generation, with the remainder primarily used for road transport (see Figure 7).

Figure 7: Estimates for available biomass, biomass for energy purposes, and biomass for electricity and centralised heat generation



Source: EC (2024) ESABCC (2023), Material Economics (2021). Note: *data refers to Material Economics and the IA outlining similar values such as the statistics (Eurostat, 2024) with 6.1 EJ for bioenergy demand and 3.0 EJ for centralised electricity and heat generation.

The IA also **caps bioenergy imports**. Generally, imported biomass is connected to similar but more adverse impacts on land systems, food security, and water needs when compared to the EU's own sources. This is due to factors such as less stringent sustainability regulations as well as higher land-use and water competition in exporting regions (see e.g. Welfle et al., 2014; Wu et al., 2023). For example, deforestation, health and human rights issues have been reported for the Drax bioenergy plant in the UK (Sharma, 2023).

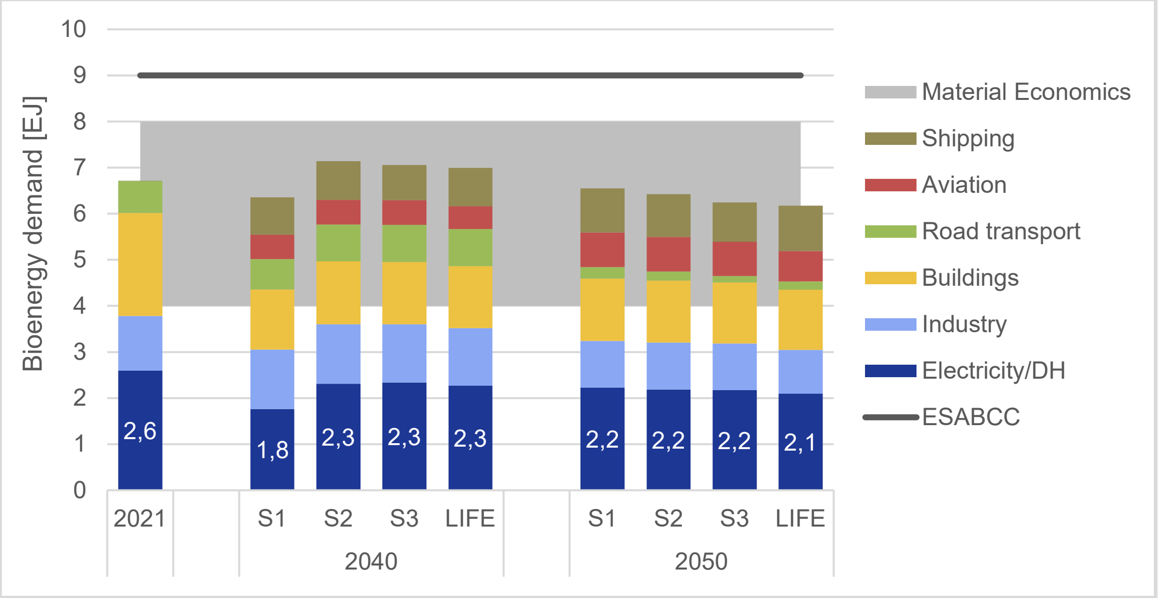
The IA's **cap on bioenergy imports** is at 0.5 EJ. This is above Material Economics' (2021) estimate. Material Economics projects that imports from non-EU countries are unlikely to exceed current levels (2) of around 0.2–0.4 EJ because of sustainability and food security concerns (Material Economics, 2021). However, the difference of 0.3–0.1 EJ is small compared to the 9 EJ overall consumption which means that just a small variation in the EU's own bioenergy generation can compensate for a smaller bioenergy import.

EU bioenergy demand in 2040

The IA projects that biomass consumption for energy purposes will grow to around 7 EJ by 2040 in all scenarios except for S1 (which, however, does not meet the envisaged 90% net emission reduction by that year). This is an increase of 6% in S2 and S3 compared to 2021 and corresponds to about 16% of the EU's gross available energy (GAE) in 2040.

Growth will mainly be driven by the increased need for second-generation biofuels, including advanced liquid biofuels and biomethane, whereas direct use of solid biomass is expected to decline. The demand is expected to be met by a shift away from food crops to lignocellulosic crops and agricultural residues – both being more sustainable sources than the food crops. At the same time, forest stemwood inputs are reduced by around 8–9% while forest residues increase by around 37% (S2 andS3).

Figure 8: Biomass availability and biomass demand for energy purposes in 2021 and in 2040, 2050



Source: Own representation based on EC (2024), Biomass availability for energy purposes according to ESABCC (2023), and Material Economics (2021) for 2050.

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(2) The IA suggests current imports of 10 Mtoe or 0.4 EJ; Material Economics of 0.2 EJ.

As the projected biomass demand for energy purposes equals roughly to 7 EJ in 2040, the IA scenarios do not exceed the critical threshold of a sustainable bioenergy availability of 8–9 EJ estimated by others (see Figure 8). However, **given that the demand for biomass for other purposes than energy (e.g. materials) is expected to grow strongly, Material Economics forecasts that only 4 EJ of sustainable biomass will be available for energy purposes. This is significantly less than the projected 7 EJ of the IA.**

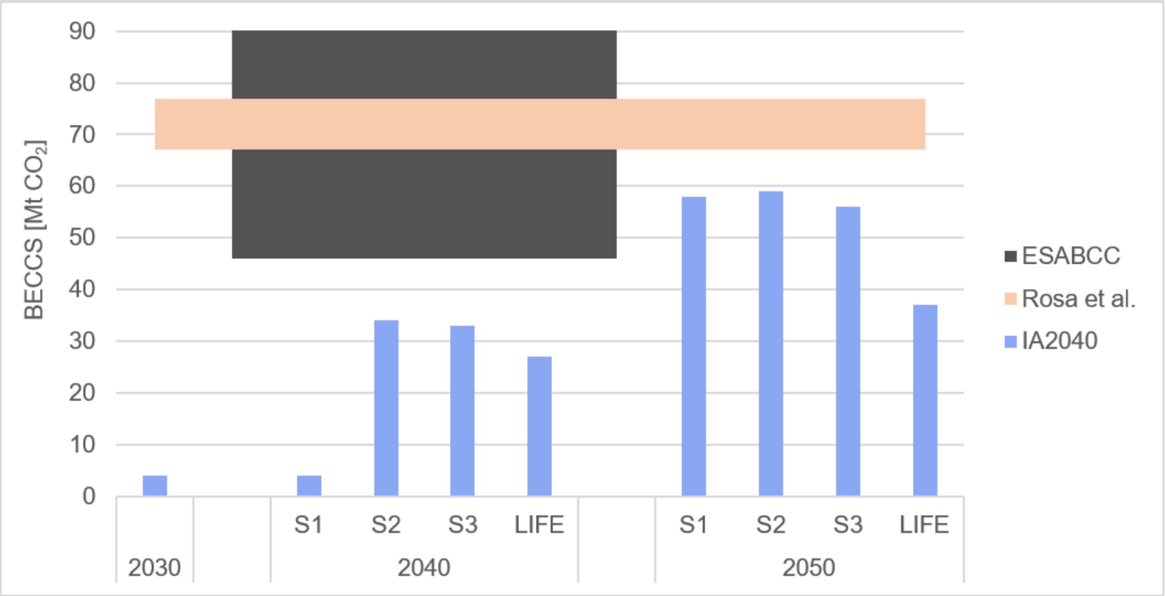
4.2 Biomass demand for BECCS in the EU in 2040

CO_2 removal through BECCS

Biomass demand for BECCS depends on the amount of CO_2 to be removed. The IA projects that BECCS deployment will accelerate after 2030, with removals reaching between 27 Mt and 34 Mt CO_2 in 2040. By 2050, the IA expects removals to increase to between 37 Mt and almost 60 Mt CO_2 (in both years, LIFE provides the lower and S2 the upper end) (see Figure 9). More specifically, the IA outlines the captured and stored CO_2 emissions from the application of BECCS and assumes that all CO_2 captured through BECCS will be permanently stored.

Compared to other studies, the IA's projections for BECCS of maximum 34 Mt CO_2 by 2040 are significantly lower than the scenarios outlined by the ESABCC (2023), which range from 46 to 207 Mt CO_2 per year in 2040. Rosa et al. (2021) estimate the potential for BECCS at existing sites in Europe at 67–77 Mt CO_2 for biomass, including renewable waste energy generation ([3]), suggesting that existing sites could meet the projected BECCS capacity without the need for new bioenergy installations.

Figure 9: CO_2 captured and stored through BECCS



Source: Own representation based on EC (2024), ESABCC (2023), Rosa, Sanchez, & Mazzotti (2021).

([3]) They outline a full potential for removals from use of biomass of around 200 Mt CO_2 per year. Approximately two thirds of this comes from existing point sources, mainly pulp and paper mills, followed by waste-to-energy plants and biomass co-firing plants, while the remaining third is derived from distributed sources, mainly crop residues, followed by livestock manure and household organic food waste (Rosa, Sanchez, & Mazzotti, 2021).

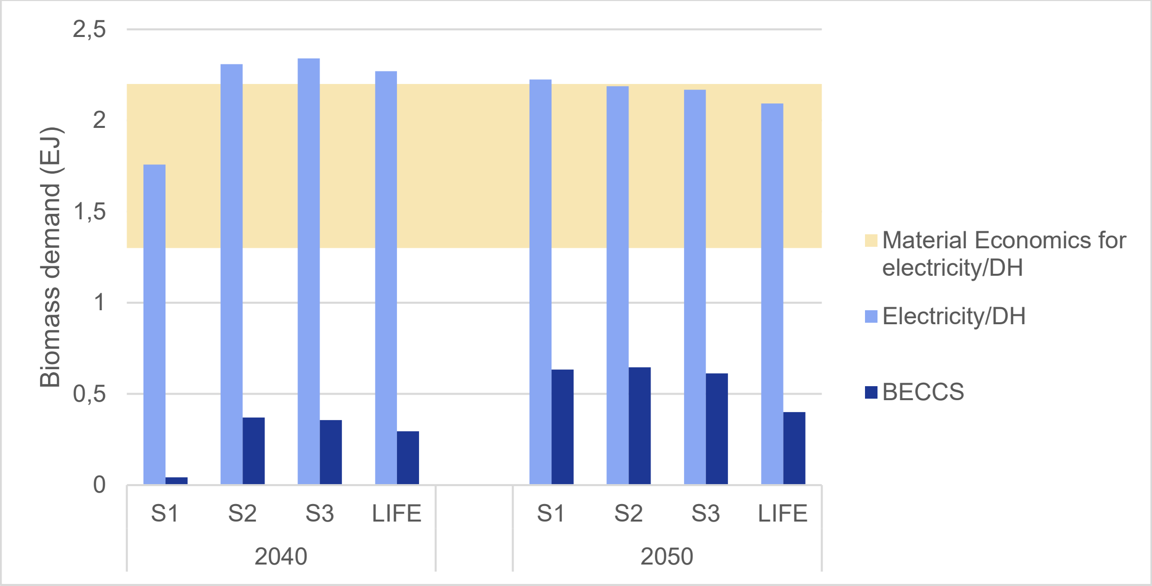
Biomass demand for BECCS in the EU

The IA does not provide specific details on the BECCS biomass demand. As a rough proxy, the IA indicates that the biomass input to BECCS is around 0.4 EJ, based on an average emission factor of approximately 92 t CO_2/TJ (UBA, 2022b) and CO_2 emissions captured with BECCS of around 34 Mt CO_2 (see Figure 9).

BECCS will be deployed in centralised electricity and heat generation, which currently accounts for about 32% of the final bioenergy demand in the EU. According to the IA, the subsector's biomass demand is expected to decrease from 2.6 EJ in 2022 to 2.3 EJ in S2, S3 and LIFE in 2040 and will further decline to 2.2 EJ in 2050 (see Figure 8). The 0.4 EJ for BECCS amount to about 16% of the biomass input into centralised electricity and heat generation (S2) (see Figure 10). As a result, around 16% of CO_2 emissions from biomass electricity and district heating will be captured and stored.

The IA's projected biomass use for centralised electricity and heat generation is slightly above Material Economics' high-value scenario, which estimates that around 1.3 to 2.2 EJ produced by biomass will be used for centralised electricity and heat generation by 2050. Most of the biomass electricity and heat generation is expected to be for backup capacities and flexible generation. As a result, biomass in large-scale baseload power generation with CCS would play only a limited role (4). Material Economics (2021) does not specify what "limited" means.

Figure 10: Biomass demand of centralised electricity and heat generation and of BECCS



Source: Own calculation based on EC (2024), UBA (2022a), Material Economics (2021).

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(4) CCS is technically feasible also for flexible power generation but more efficient and economic viable for stable generation as CCS units are generally designed to run continuously.

4.3 Conclusion

Biomass availability is limited – as is therefore its use for energy purposes. The IA' projected total biomass demand for energy purposes of 7.1 EJ is in line with both the ESABCC bioenergy demand limit of 9 EJ and the Material Economics limit of 4–8 EJ. For centralised electricity and heat generation, the IA projects a biomass demand of roughly 2.3 EJ, which is close to the availability constraints specified by Material Economics of 1.3–2.2 EJ.

The IA's projected biomass demand therefore sits at the upper end of what Material Economics expects to be available. If more biomass is required for other purposes than energy generation (taking the lower end of the suggested range), this would mean that the IA's bioenergy demand – including the specific share for centralised electricity and heat generation – is considerably too high to be supplied by available sustainable biomass sources.

It is unclear how the model would adjust to such a projection, with only 4 EJ of biomass available. This constraint would also affect projected BECCS deployment, requiring careful consideration of whether it can still be achieved with sustainable sources. However, this might be possible due to the limited application of BECCS by 2040: According to the IA, BECCS would require 0.4 EJ of biomass or 16% of the projected biomass for centralised electricity and heat generation to capture the projected 30 Mt CO_2. Achieving this would depend on equipping about half of the existing large-scale facilities with CCS, requiring no new facilities.

For all BECCS, it must be ensured that installations capture and store more CO_2 than they emit throughout the entire lifecycle, considering the impact on existing carbon stocks – both in- and outside the EU. To avoid creating new demand for primary biomass and to reduce existing needs, particularly for stemwood, it is essential that BECCS installations use biomass from waste streams only.

5 Direct Air Carbon Capture and Storage (DACCS)

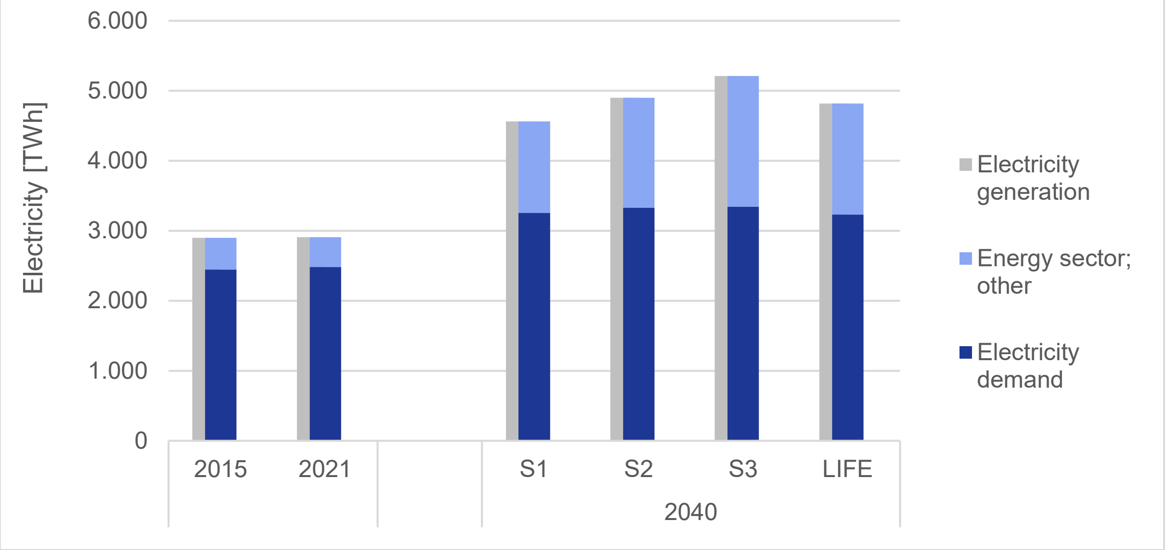
The following section outlines the electricity demand of DACCS by 2040. While this study focuses on removals, DACC is also used to extract clean CO_2 for the production of e-fuels (DACCU) – a relevant factor in the IA; thus, this section also outlines the electricity needs for all DACCUS. In addition, it presents estimates on water demand related to overall water availability.

5.1 Electricity demand in the EU in 2040

The IA projects that electricity generation increases by 57% to 79% between 2021 and 2040, reaching 4,565 TWh to 5,210 TWh across scenarios S1–S3. In contrast, electricity consumption of the end-use sectors (transport, industry, households, services, and agriculture) will increase only by 30% to 34% across the four IA scenarios from around 2,500 TWh in 2021 to around 3,300 TWh in 2040 (see Figure 11). The increase in the end-use sectors is driven by growing electrification such as the adoption of electric vehicles in the transport sector, industries shifting to electric arc furnaces as well as households transitioning to heat pumps. Although all sectors are expected to contribute to the increased electricity demand, the absolute increase is most prevalent in transport.

The difference between electricity generation and final consumption is the electricity consumed by the energy sector itself. Figure 11 shows the required electricity generation, electricity consumption, and the energy sector's self-consumption across scenarios.

Figure 11: Electricity generation, consumption of the energy sector and end-use sectors in 2015, 2021 and 2040



Source: Own representation based on EC (2024). Electricity demand is of end-consuming sectors (transport, industry, households, services and agriculture); Energy sector and other consumption includes own consumption by power plants, RFNBOs production, DACC and transmission and distribution losses.

The energy sector's self-consumption differs between scenarios, with the highest figures in S3. This is due to the much higher production of liquid and gaseous fuels from renewable sources excluding biomass (RFNBO) (5) and from DACCUS. These two fall into this category and are not included in the final electricity demand. Combined, the production of e-fuels and hydrogen, and DACCUS consume approximately 270 TWh (in S2) or 600 TWh (in S3) more electricity than in S1. The consumption of DACCUS is not specifically outlined in the IA (see next section).

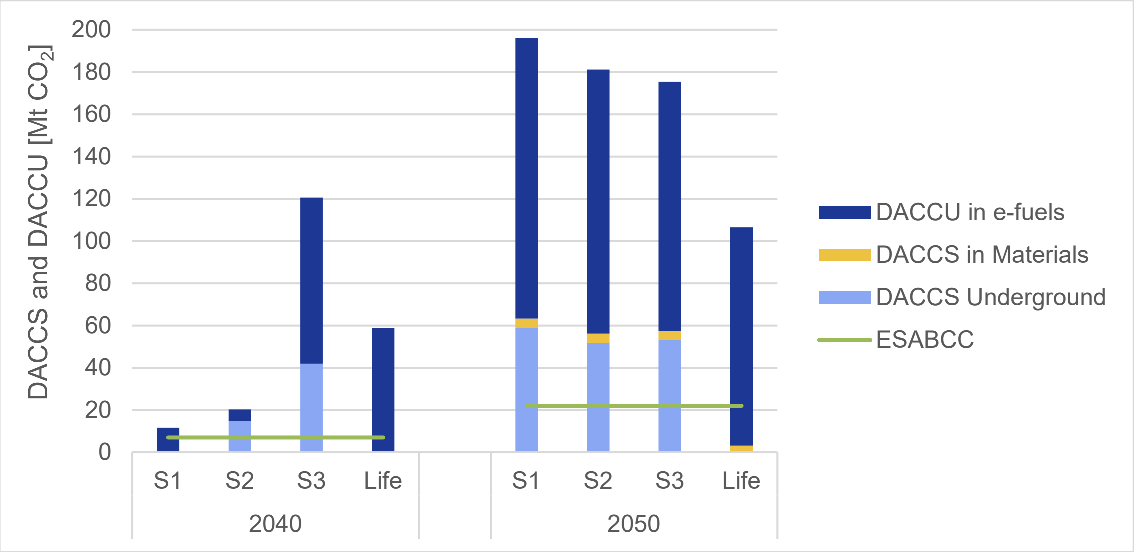
For DACCS to function as a carbon removal technology, it is indispensable that the electricity comes from renewable energy sources and not from fossil fuels (and that the CO_2 is permanently stored in geological reservoirs). The IA assumes that while electricity generation increases, the proportion of fossil fuels is set to decline significantly and be replaced by renewable energy sources. Fossil-fired generation will decrease from 36% in 2021 to as low as 3–8% by 2040, while renewables will increase from 40% in 2021 to up to 81–87% (S1-S3) (EC, 2024).

5.2 Electricity consumption of DACCS and DACCUS in 2040

CO_2 captured, used, and stored

The IA projects a CO_2 capture of 12 Mt to 120 Mt by 2040 across scenarios S1 to S3 for underground storage (DACCS) and for e-fuel production (DACCU) (6) (see Figure 12).

Figure 12: CO_2 capture and use (DACCU) or removal (DACCS) by 2040 and 2050



Source: Own representation based on EC (2024), ESABCC (2023). Note: CO_2 captured for e-fuel production is not considered a removal technology. The IA considers CO_2 captured for underground storage and stored long-term in materials to be removed. The IA does not provide a clear description of what materials are considered.

By 2040, the IA scenarios show different developments depending on the requirement for removals and assumptions on diffusion. In S1, CO_2 capture is minimal and all CO_2 is used for e-fuel production. S2 assumes a 75% higher diffusion of DACCS when compared to S1 with most of the CO_2 being stored underground. S3 assumes the widest diffusion of DACCUS leading to more CO_2 being stored (42 Mt) as well as a significant higher amount being used for

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(5) RFNBOs are gaseous or liquid fuels from renewable hydrogen but also its derivatives. This includes e-fuels when produced from renewable hydrogen.

(6) E-fuels are considered under carbon capture and use (CCU) and do *not* count as carbon removal as the CO_2 is released back into the atmosphere within a couple of years.

e-fuels (79 Mt). By 2050, the captured CO_2 will further increase, with the ratio between storage and use roughly fluctuating around 1/3 for storage and 2/3 for use. The LIFE scenario delivers no DACCS, as natural sinks are assumed to meet the removal requirements (see Figure 12).

According to the ESABCC (2023) scenario comparison, carbon removals through DACCS range from 0 to 7 Mt CO2 by 2040, and reach up to 22 Mt by 2050. The IA's projections on the application of DACCS are therefore considerably higher in S2 and S3. Due to a lack of knowledge about the expected development of technology and costs (ESABCC, 2023), it remains uncertain if these IA levels can be achieved.

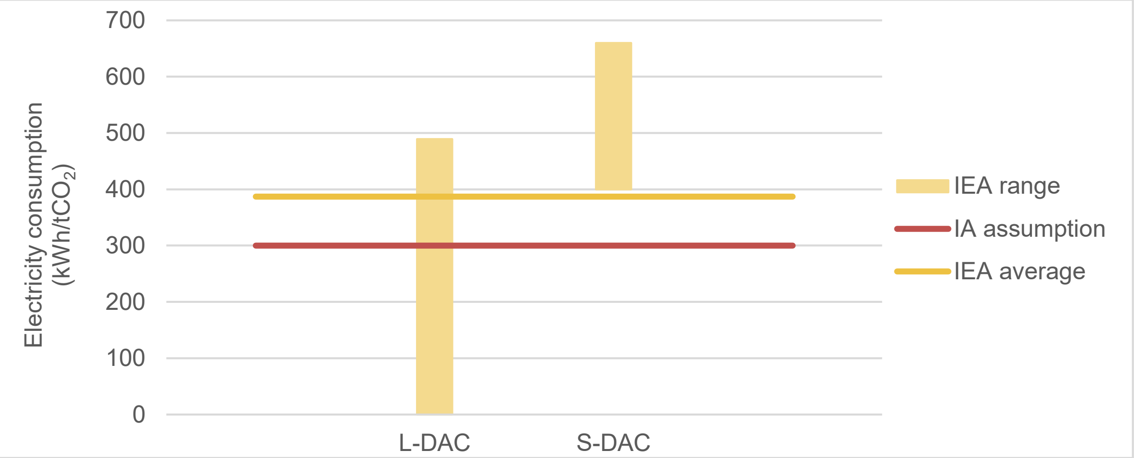
Electricity consumption for DACCUS

DACCUS requires electricity and/or heat for regeneration of the sorbent depending on the type of technology (see section 2.3). This section focuses on the electricity demand while the next give an overview on energy demand (electricity and heat).

The IA does not outline the total electricity consumption of DACC but provides that specific electricity consumption is about 300 kWh/t CO_2 (7).

The IEA (2022) states that S-DACC requires around 400–660 kWh/t CO_2, while L-DACC requires up to 489 kWh/t CO_2 (8). The IEA's standard values for L-DACC and S-DACC, also available on their website (IEA, 2023), are 361 kWh/t CO_2 and 639 kWh/t CO_2, respectively (9). Similar values can also be found in Küng et al. (2023). There is no information available from existing installations. When compared to the IEA, the IA estimate is comparably lower, though still within the range of using only L-DACC and lower than using only S-DACC (see Figure 13).

Figure 13: Specific electricity demand of different DACCS technologies and assumption in the IA



Source: EC (2024), IEA (2022).

Based on the IA's assumptions, we calculated the electricity demand of DACCS to be between 4.5 TWh in S2 and 12.6 TWh in 2040. Considering that DACCS requires more electricity in the

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(7) Attachment: 2040CT_TechnologyAssumptions_Energy; the table presents 0.300 as „input over output ratio" for „Capture CO_2 from air (Adsorption technology) (per 1 tCO_2)". As for all other technologies, the ratio is presented in MWh, we assume that it is also the case for DACC so that the electricity consumption is 0.3MWh/tCO_2 (= 0.3TWh/MtCO_2).

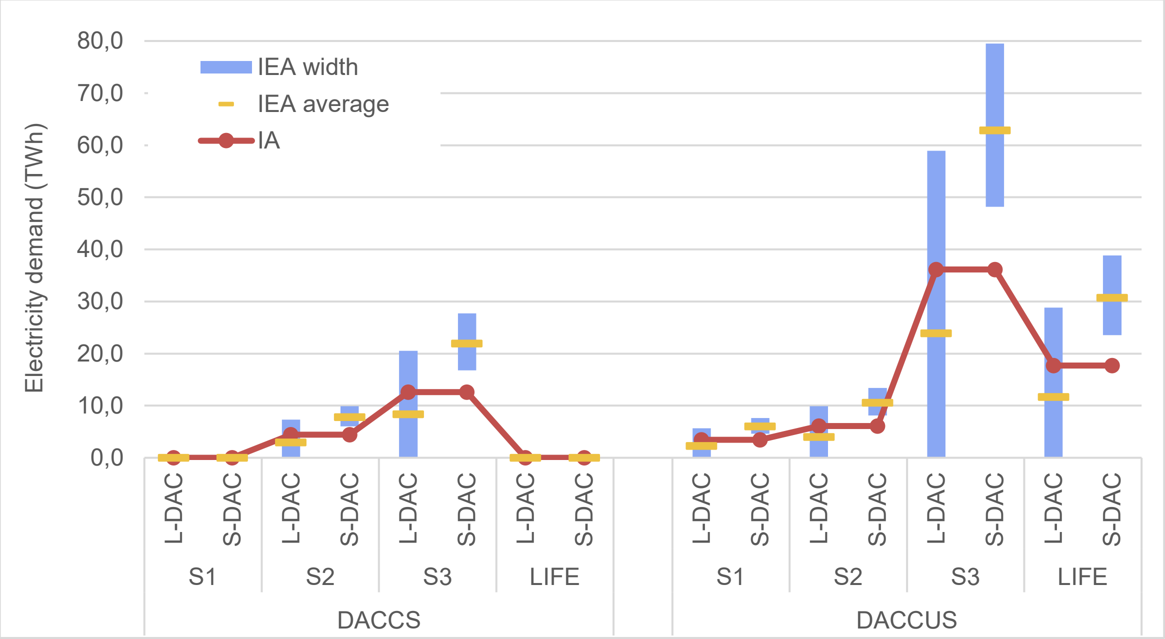
(8) The total *energy* requirements for S-DACC are at around 2,000-2,600 kWh/t CO_2, while L-DACC is around 1,500-2,400 kWh/t CO_2 (=7.2-9.5 GJ/t CO_2, and 5.5-8.8 GJ/t CO_2). The share of *electricity* consumption is 20-25% for S-DACC and 0-20% for L-DACC, while the remaining energy input is for heating (IEA, 2022).

(9) 0.8+0.5 GJ/tCO_2 and 1.8 + 0.5 GJ/tCO_2 for L-DACC and S-DACC, respectively.

IEA estimates (around 387 kWh/t CO_2 on average), the demand may increase to 5.8 TWh in S2 and 16.3 TWh in S3. From a precautionary principle and using the electricity intensity of 639 kWh/tCO_2 (IEA, 2023), the calculated electricity demand would amount to 9.5 TWh and 26.8 TWh for S2 and S3, respectively (see Figure 14).

In addition to storage, CO_2 is also used for e-fuels (see Figure 12). Considering all DACCUS, electricity demand is projected by the IA to be 6.1 TWh in S2 and 36.1 TWh in S3. Again, if DACCUS requires electricity in line with the IEA average, the demand may increase to 7.9 TWh in S2 and 46.7 TWh in S3. In the case of the high electricity intensity, the calculated annual electricity requirements amount to 13 TWh and 77 TWh for S2 and S3.

Figure 14: Electricity demand of DACCUS with underground storage and for use and storage in 2040



Source: Own calculations based on EC (2024), IEA (2022).

When compared to total electricity generation, the share used for DACCS remains below 0.6% for S2 and S3, even under the consideration of the different specific electricity consumption levels. When compared to the energy sector's own consumption (where the IA places DACCUS units), the share increases to around 1% (0.7–1.4 %) in S3, while it remains below 0.6% in S2.

The share of all DACCUS units is also below 0.5% for S2 when compared to total electricity generation; in S3 the share increases to around 1% (0.7%–1.5%). When compared to the energy sector's own consumption the share is around 0.6% (0.4-0.8%) in S2 and around 2–4% (1.9%–4.1%) in S3.

Energy demand of DACC

The IA projects the overall energy demand (including electricity and heating) of DACCS to be between 21–76 TWh in 2040 for S2 and S3, depending on the specific consumption estimates, ranging from 1.4–1.8 TWh/MtCO_2 (10). The IA assumption of the specific energy demand is

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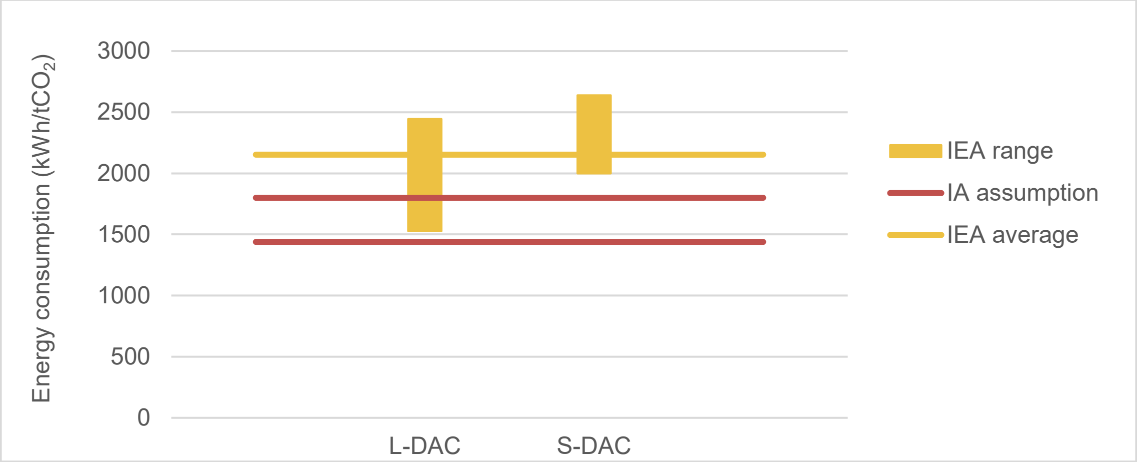
(10) Attachment: 2040CT_TechnologyAssumptions_Energy; the table presents 1.139–1.500 as „input over output ratio for heat" for „Capture CO_2 from air (Adsorption technology) (per 1 tCO_2)". As for all other technologies, the ratio is presented in MWh, we assume that it is also the case for DACC so that the heat consumption is 1.1-1.5 TWh/MtCO_2.

comparably lower than the IEA estimate of around 2.1 TWh/MtCO$_2$ on average based on a range of 1.5–2.6 TWh/ MtCO$_2$ (IEA, 2023) (see Figure 15).

Figure 15: Specific energy demand of different DACC technologies and assumption in the IA

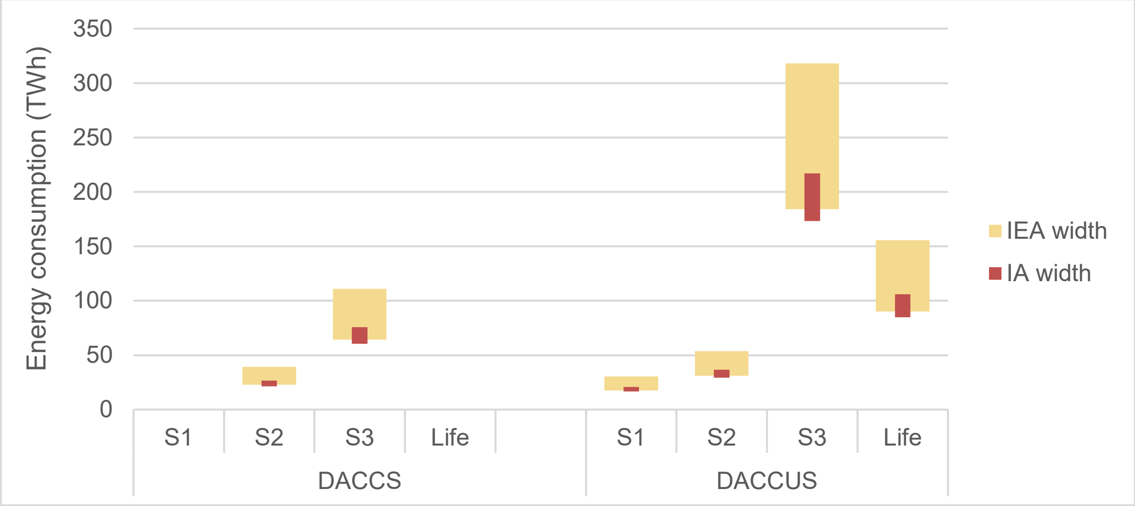


Source: EC (2024), IEA (2022).

This means that with the average IEA estimate, the overall energy input for DACCS would be around 32 TWh and 90 TWh for S2 and S3, respectively. In a conservative approach where energy intensity is at 2.6 TWh/MtCO$_2$, the calculated annual energy requirements amount to 39 TWh and 111 TWh for S2 and S3 (see Figure 16).

The energy consumption of all DACCUS in the IA is projected to be between 29–36 TWh for S2 and 173–217 TWh for S3. Again, based on the average energy consumption estimates of the IEA, this would be higher at 44 TWh and 259 TWh for S2 and S3, respectively. Considering the upper end of the IEA estimate of 2.6 TWh/MtCO$_2$, the energy consumption in S2 could be as high as 54 TWh, and in S3, it could rise to 318 TWh for DACCUS (see Figure 16).

Figure 16: Energy consumption of DACC in 2040



Source: EC (2024), IEA (2022).

When comparing the energy consumption of DACCS and DACCUS with the total energy consumption projected by the IA for 2024 (11,875–11,844 TWh in S2 and S3), the share of

DACCS remains below 1% across the different consumption estimates. The share of DACCUS, however, increases to maximum 2.7% considering S3 (with its additional CO_2 capture for e-fuels) and the different energy consumption estimates.

Water consumption of DACCUS

The IA does not provide any information regarding the water consumption of DACCUS.

How other studies compare to this: The IEA (2022) but also other sources provide a range for the net water consumption of the two main technological approaches (see Table 3). The specific water requirement or extraction is largely influenced by the surrounding temperature and humidity (IEA, 2022); for L-DACC, the water requirement also depends on solvent volatility and water losses during operation (Küng et al., 2023). For L-DACC, the specific consumption ranges from 0 to 50 m^3 water/tCO_2. Other studies narrow it down to 1 to 13 m^3 (Ozkan et al., 2022) (11) and to around 4 m^3 (Küng et al., 2023; Rosa, Sanchez, Realmonte, et al., 2021).

S-DACC, on the other hand, has no net water consumption, but it can produce water as a by-product. The quantity varies based on the adsorption medium and environmental conditions (Block et al., 2024) and ranges from no net consumption to 2 m^3 water/t CO_2 captured. However, minimising water production is advisable due to the additional energy required (IEA, 2022).

DACC relies solely on blue water, meaning freshwater from surface water bodies and aquifers. This may create competition for water resources between other energy, municipal, industrial, and irrigated agricultural water use (Rosa, Sanchez, Realmonte, et al., 2021). The absence of geographical inventories and water risk assessments, particularly regarding scarcity, complicates the understanding and evaluation of potential competition and environmental impacts related to water use (Küng et al., 2023).

Table 3: Water demand in tH_2O/tCO_2 as calculated in different publications

Publication	Water consumption in m^3water/tCO_2	
	S-DACC	L-DACC
IEA (2022)	-2 to 0	0 to 50
Fasihili et al. (2019)	-2 to -0.8	
Ozkan et al. (2022)		1 to 13
Rosa et al. (2021) (12)		4
Küng et al. (2023) (13)		4.4

Source: Own representation.

In the IA's projections, DACCS would therefore have no net water consumption or require up to 2,100 Mm^3 and DACCUS up to ~6,000 Mm^3, considering S3 (with 42 Mt and 121 Mt CO_2 capture, respectively) and the upper estimate for L-DACC of the IEA of 50 m^3/tCO_2. If the specific water consumption is closer to the 4 m^3 indicated in other studies, the water consumption would be around 168 – 484 Mm^3. Water consumption of the energy sector has

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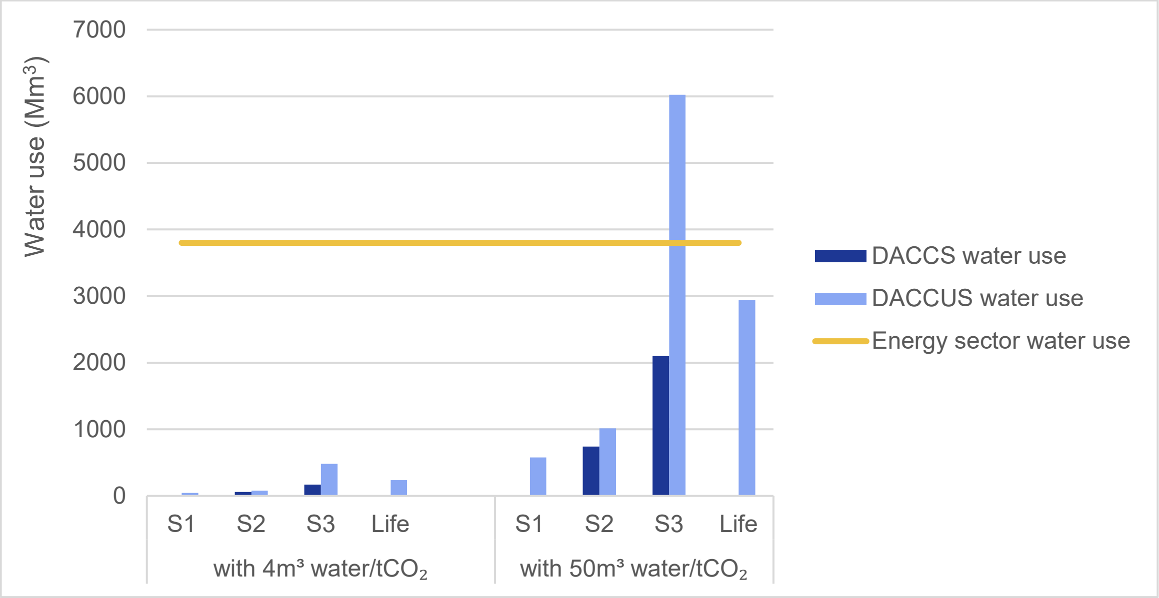
(11) Estimate provided in tonnes assuming that 1 tonne of water equals one m^3.

(12) The water footprint was calculated assuming a range of temperatures (from 0°C to 30°C), two sorbent molarities (5 M and 10 M), and relative humidity (from 25% to 75%).

(13) The number only considers two L-DACC technologies: absorption with liquid solvent through either i) high-grade heat or ii) low-grade heat stripping as release drivers.

been at around 3,800 Mm^3 in 2015 (Magagna, et al., 2018). This means that DACCUS could add significantly to the water consumption of the energy sector. Figure 17 shows the estimated water use for 4 m^3 and for 50 m^3, showing the high uncertainty around future water consumption of L-DACC.

Figure 17: Estimated water consumption in 2040 across the IA scenarios when using only L-DACC



Source: Own representation based on EC (2024), IEA (2022), Rosa et al. (2021).

Local water availability and the patterns of water scarcity will therefore be important factors in deciding the localisation of L-DACC units. DACCUS facilities that will be affected by blue water scarcity would risk their functionality and could generate sunk costs.

Local water scarcity is expected to worsen with the progressively rising temperatures due to changes in precipitation patterns. In addition, other water consumers may further impact both local and global water resources, possibly creating conditions of widespread blue and green water scarcity (Rosa, Sanchez, Realmonte, et al., 2021). Northern and Central Europe (e.g. Sweden, Finland, Austria and parts of Germany) experience relatively low water stress, and Scandinavia and the Baltic countries (Estonia, Latvia, Lithuania) are considered water-rich (EEA, 2024a, 2024b), making them highly suitable locations for L-DACC facilities. Southern European countries such as Spain, Greece, Italy and Portugal, on the other hand, face significant water scarcity, especially in their southern regions (EEA, 2024a, 2024b), making S-DACC more suitable. The same areas benefit from higher renewable energy potential, creating a potential trade-off consideration regarding the application of L-DACC facilities.

5.3 Conclusions

DACC is a relevant technology not only for industrial removals but even more so to produce CO_2 for e-fuels. The IA projects DACCS ranging from 15 Mt CO_2 to 42 Mt CO_2 (S2 and S3). In S3, this is considerably lower when compared to DACCU, where CO_2 is captured from the air for e-fuel production, which equals 79 Mt CO_2. In S2, DACCU is instead close to zero with 5 Mt CO_2 only. When compared to other scenarios, the IA projects much higher DACCS (and even more so DACCUS).

Despite these projections being higher than those of other scenarios, they are still of minor importance overall: the share of DACCS in total electricity supply remains below 0.5% for S2 and S3 and under consideration of the different specific electricity consumption levels and below 1% for energy consumption of DACCS. In S3 and adding CO_2 capture for e-fuels, the shares increase to max. 1.5% and 2.7% when using the high estimates for electricity and energy consumption from the IEA.

The IA's assumptions for electricity and energy requirements appear optimistic compared to other studies. More conservative estimates based on current technical understanding suggest potentially higher electricity and energy demands, highlighting the uncertainties associated with the technology's deployment trajectory and related assumptions on energy needs. Additionally, water consumption, particularly for L-DACC systems, emerges as a critical constraint that could significantly limit suitable deployment locations.

6 Index of figures, tables, abbreviations

List of Figures

Figure 1: GHG emissions and removals in 2005 and 2040 across the IA scenarios 3
Figure 2: Biomass demand of centralised electricity and heat generation and of BECCS in the IA 4
Figure 3: Specific electricity demand of different DACCS technologies and assumption in the IA 5
Figure 4: Typical S-DACC (top) and L-DACC (bottom) configurations 10
Figure 5: GHG emissions and removals in 2005 and 2040 across the IA scenarios 13
Figure 6: Industrial carbon removals by source in 2030, 2040 and 2050 across the IA scenarios 13
Figure 7: Estimates for available biomass, biomass for energy purposes, and biomass for electricity and centralised heat generation 16
Figure 8: Biomass availability and biomass demand for energy purposes in 2021 and in 2040, 2050 17
Figure 9: CO_2 captured and stored through BECCS 18
Figure 10: Biomass demand of centralised electricity and heat generation and of BECCS............19
Figure 11: Electricity generation, consumption of the energy sector and end-use sectors in 2015, 2021 and 2040 21
Figure 12: CO_2 capture and use (DACCU) or removal (DACCS) by 2040 and 2050 22
Figure 13: Specific electricity demand of different DACCS technologies and assumption in the IA 23
Figure 14: Electricity demand of DACCUS with underground storage and for use and storage in 2040 24
Figure 15: Specific energy demand of different DACC technologies and assumption in the IA............25
Figure 16: Energy consumption of DACC in 2040 25
Figure 17: Estimated water consumption in 2040 across the IA scenarios when using only L-DACC............27

List of Tables

Table 1: Technological options for DACC – general assumptions 9
Table 2: Projected industrial removals and net LULUCF removals in 2040 and 2050............12
Table 3: Water demand in tH_2O/tCO_2 as calculated in different publications............26

Abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
BioCCS	Carbon Capture and Storage from any biogenic source
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CRCF	Carbon Removals and Carbon Farming Certification Regulation
DACC	Direct Air Carbon Capture
DACCS	Direct Air Carbon Capture and Storage
DACCU	Direct Air Carbon Capture and Utilisation
DACCUS	Direct Air Carbon Capture and Utilisation/Storage (encompasses both DACCS and DACCU)
ECL	European Climate Law
EJ	Exajoule (unit of energy)
EU	European Union
GAE	Gross Available Energy
GHG	Greenhouse Gas
IA	Impact Assessment
IPCC	Intergovernmental Panel on Climate Change
L-DACC	Liquid Direct Air Carbon Capture
LULUCF	Land Use, Land-Use Change, and Forestry
RFNBO	Renewable Fuels of Non-Biological Origin
S-DACC	Solid Direct Air Carbon Capture
TRL	Technology Readiness Level
TWh	Terawatt-hour (unit of energy)

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