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*Discussion Paper*

# An Integrated Approach to Carbon Management: Requirements of an Overall Strategy Combining CCS, CCU and CDR

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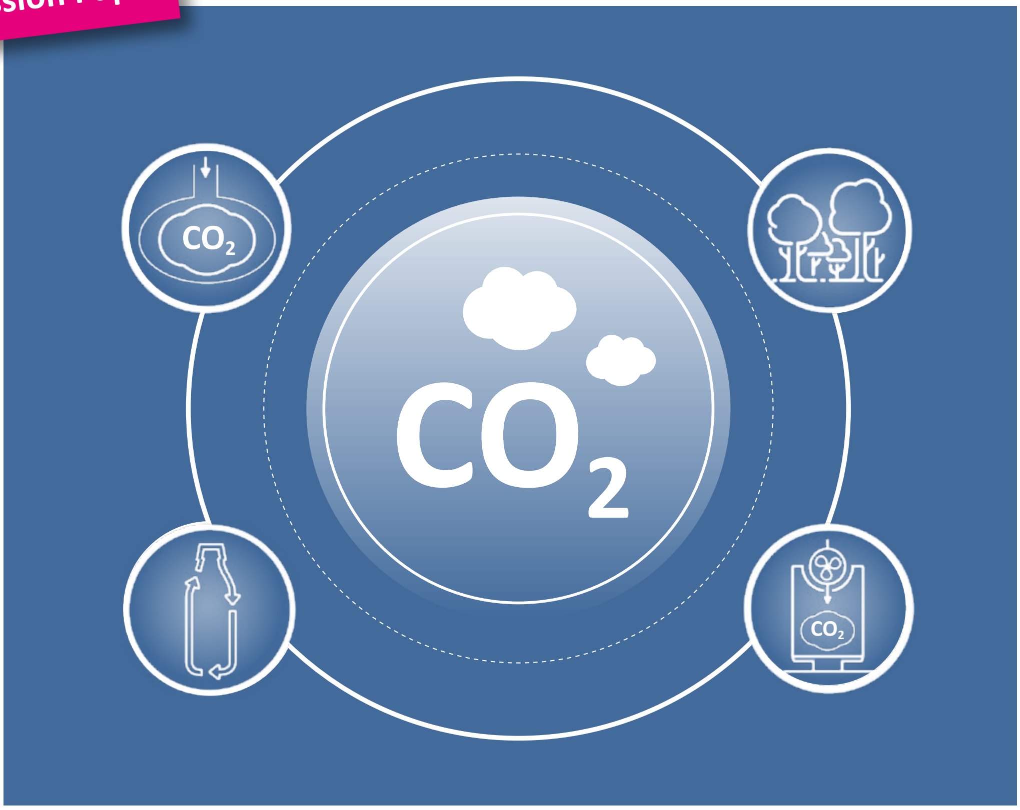
**Discussion Paper**



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# Requirements of an Overall Strategy Combining CCS, CCU and CDR

## What is carbon management?

**Carbon management** seeks to

- keep greenhouse gas emissions out of the atmosphere or remove them so that they don't contribute to global warming, and
- recycle carbon in order to reduce dependence on fossil carbon.

**It is made up of three pillars:**

- With **Carbon Capture and Storage (CCS)**, $CO_2$ produced in a cement works, for example, is captured and then injected underground for permanent storage there.
- **Carbon Dioxide Removal (CDR)** offsets greenhouse gas emissions that cannot be captured directly at source (because they are spread over a large area, for instance, as is the case in agriculture). CDR can also be used to go further and lower $CO_2$ levels in the atmosphere. The carbon is stored in different ways, depending on the method used – e.g. underground (CCS) or in vegetation and the soil.
- In the case of **Carbon Capture and Utilisation (CCU)**, carbon dioxide captured from industrial facilities or the atmosphere is used for manufacturing carbon-based products (e.g. plastics).

The three pillars require similar process steps and infrastructures in part and overlap in terms of their contribution to climate action. This is why an **overarching strategy** is needed for carbon management.

## No climate neutrality without CCS

Attempting to attain climate neutrality without CCS is likely to fail. Indeed, without CCS, emissions would have to be cut by even more than they need to be anyway.

- This would require particularly far-reaching **changes in behaviour**, e.g. in terms of nutrition – and public support for this is very uncertain.
- **Residual emissions** would primarily need to be offset by means of carbon storage in vegetation and soil, which is hampered by the limited availability of land. The permanence of this method is also far from assured.
- To achieve even **net-negative emissions** in future seems all the more implausible without the use of CCS.

## The climate footprint of CCU

Fossil carbon cannot be used in a climate-neutral industry. This makes CCU indispensable as a source of carbon for manufacturing many different products. In most cases, however, it does not represent an alternative to CCS and CDR:

- CCU only results in **permanent storage** of the $CO_2$ in the case of very **durable goods** such as building materials.
- Manufacture of goods with a short life can only be considered **climate neutral** if the $CO_2$ used **comes from the atmosphere or biomass** and the production process itself is climate neutral.

## Avoid greenhouse gases wherever possible, manage them where needed

**Compared to measures avoiding the production of greenhouse gas emissions, carbon management can only make a small contribution to climate action.**

This is because the potential sustainably to use is limited and ramping up the technology is a challenge, even if carbon management is targeted only at hard-to-abate emissions.

- This means it is important to **make systematic use of and keep developing all the different ways of avoiding greenhouse gases** – from developing renewables and the hydrogen infrastructure via energy-saving measures to lower-emission production techniques in industry and agriculture.

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# Abbreviations

| | |
|---|---|
| **BDI** | Federation of German Industries<br>(Bundesverband der Deutschen Industrie) |
| **BECCS** | Bioenergy with Carbon Capture and Storage |
| **BEHG** | German Fuel Emissions Trading Act |
| **BMWK** | German Federal Ministry for Economic Affairs and Climate Action<br>(Bundesministerium für Wirtschaft und Klimaschutz) |
| **CBAM** | Carbon Border Adjustment Mechanism |
| **CCS** | Carbon Capture and Storage |
| **CCU** | Carbon Capture and Utilization |
| **CDR** | Carbon Dioxide Removal (from the atmosphere) |
| **CMS** | Carbon Management Strategy (of the German government) |
| **$CO_2$** | Carbon dioxide |
| **DACCS** | Direct Air Carbon Capture and Storage |
| **EU ETS** | EU Emissions Trading System |
| **F-gases** | Fluorinated greenhouse gases |
| **GHG** | Greenhouse gases |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **KSpG** | German Carbon Dioxide Storage Act (Kohlendioxid-Speicherungsgesetz) |
| **LNe** | Long-term Strategy on Negative Emissions (strategy of the German government for removing $CO_2$ from the atmosphere – to first offset any remaining residual emissions and thereby achieve climate neutrality by 2045 and then achieve net-negative emissions in the second half of the century) |
| **LNG** | Liquefied Natural Gas |
| **LULUCF** | Land Use, Land-Use Change and Forestry |
| **UBA** | German Environment Agency<br>(Umweltbundesamt) |

# Glossary

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| **Back-up power plants** | Power plants that are operated flexibly to ensure a reliable supply of electricity rather than generate it constantly. They are only in use for a few hours a year, for example during “dunkelflaute” periods when insufficient wind and solar power is being fed into the grid. |
| **BECCS – Bioenergy with Carbon Capture and Storage** | How it works: plants use photosynthesis to absorb $CO_2$ from the atmosphere and convert it into high-energy carbon compounds. These are then used to produce electricity, heat or fuel. Rather than being discharged back into the atmosphere, the $CO_2$ that is released again in the process is captured and permanently stored underground (also known as geo-sequestration). This results in net removal of $CO_2$ from the atmosphere. |
| **Blue hydrogen** | Hydrogen manufactured from natural gas by means of steam methane reforming, while the $CO_2$ produced in the process is captured and stored underground (CCS) |
| **Carbon border adjustment mechanism** | Carbon border adjustment mechanisms are also referred to as “climate tariffs”. They serve to offset the disadvantages resulting from domestic carbon pricing with regard to international competitiveness, and thereby prevent an exodus of industry to regions with more lax climate policies (‘carbon leakage’). Such mechanisms impose a carbon levy on imported products that is equivalent to the carbon price of domestic production. The EU’s Carbon Border Adjustment Mechanism for iron, steel, cement, fertilisers, aluminium and electricity was launched in October 2023, starting with a transitional phase that will last until 2026. |
| **CCS – Carbon Capture and Storage** | $CO_2$ released by power or industrial plants is captured and permanently stored underground (also known as geo-sequestration). Depleted oil and natural gas reservoirs are mainly used for storage, along with deep saline aquifers. |
| **CCU – Carbon Capture and Utilization** | $CO_2$ is captured from an industrial process, for example, to then be used in a chemical process. Example applications include synfuels, which are synthetic fuels made from hydrogen and $CO_2$. CCU can be used to manufacture various carbon-based products, such as plastics and chemicals, with the $CO_2$ replacing oil or natural gas as the source of carbon. |
| **Carbon Contracts for Difference (CCfD)** | Carbon contracts for difference are a tool that can be used to enable climate-friendly industrial technologies to compete with conventional technologies that are harmful to the climate. How they work: a company wishing to switch to a climate-friendly technology concludes a CCfD with the state. A set $CO_2$ price is agreed in the contract for the lifetime of the new installation that should preferably equate to the company’s carbon abatement costs. If the market price for emissions allowances is lower than the agreed $CO_2$ price, the state pays the difference to the company. And if the market price is higher than the agreed $CO_2$ price, the company pays the difference to the state. |
| **CDR – Carbon Dioxide Removal** | Removal of carbon dioxide from the atmosphere – e.g. by means of bioenergy with CCS or reforestation – to offset any residual emissions and lower $CO_2$ levels in the atmosphere. |
| **Carbon sinks** | A carbon sink absorbs carbon dioxide from the atmosphere, thereby reducing the concentration of $CO_2$ in the air. Natural, land-based sinks convert the carbon dioxide into solid carbon compounds. The amount of carbon dioxide stored in vegetation or the soil increases. Young forests that are still growing are an example of this. |

| | |
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| **DACCS – Direct Air Carbon Capture and Storage** | Carbon removal technology where $CO_2$ is captured directly from the air in technical facilities through chemical binding. The $CO_2$ is then compressed and stored underground (also known as geo-sequestration). |
| **Flexibility (electricity supply)** | Technologies are needed to compensate for the fluctuations in wind and solar energy generation and therefore balance the energy being fed into and drawn from the power grid despite these variations. Such technologies include accumulators, flexibly operated power plants whose output can be quickly adjusted and consumers whose power consumption can be shifted – at least in part – into periods of high wind and solar power generation. |
| **Green hydrogen** | Hydrogen generated with renewable energies. It is usually produced by electrolysis using electricity from wind turbines or photovoltaic power plants. Electrolysis splits water into hydrogen and oxygen, a process which requires a lot of electrical energy. |
| **Negative emissions** | Removal of carbon dioxide from the atmosphere. Total emissions are said to be net negative if more $CO_2$ is removed from the atmosphere than is released into it (i.e. $CO_2$ levels in the atmosphere are lowered). |
| **Process emissions** | Greenhouse gas emissions generated by the chemical transformation of source materials into products during industrial processes. The term is used to differentiate these emissions from energy-related industrial emissions caused by supplying the energy required for the production processes (in particular, electricity and heat generation). |
| **Residual emissions** | Residual greenhouse gas emissions that remain once all carbon mitigation measures (including carbon capture and storage at point sources, such as cement plants) have been applied. They mainly stem from the agricultural and industrial sectors. In order to achieve climate neutrality, these unabatable or hard-to-abate residual emissions must be offset by removing carbon dioxide from the atmosphere (‘negative emissions’). |

## The main points in brief

- Considering the set climate targets and the current state of development of technologies and infrastructure, there is significant **pressure to take urgent action** and set the course for carbon management. The fact the German government is now tackling this specific issue is to be welcomed.

- The documents published by the German government only outline key points. They do not allow to draw final conclusions as to how far the Carbon Management Strategy (CMS) and Long-term Strategy on Negative Emissions (LNe) for handling unabatable residual emissions go towards establishing a **consistent overall strategy for the three pillars of carbon management** – Carbon Capture and Storage (CCS), Carbon Capture and Utilization (CCU) and Carbon Dioxide Removal (CDR).

- **CMS and LNe must be considered jointly.** There is overlap between CCS, CCU and CDR in terms of the technological components and infrastructures. The CMS strategy is essentially limited to CCS and CCU at (industrial) point sources. The LNe, meanwhile, focuses on CDR for offsetting residual emissions as well as the additional CDR needed to go still further and achieve net-negative greenhouse gas (GHG) emissions after 2045 in line with German climate protection targets. Among other things, the CMS and LNe should work together coherently in the planning and dimensioning of the $CO_2$ transport network, with scenarios forecasting that greater quantities of $CO_2$ will originate from CCS-based CDR (Bioenergy with CCS or BECCS/Direct Air Carbon Capture and Storage or DACCS) than from industrial processes with hard-to-abate or unabatable emissions in 2045.

- It is right and, indeed, vital that the CMS and the amendment to the German Carbon Dioxide Storage Act (KSpG) **set the stage for the deployment of CCS in Germany**. It is true that the public are concerned whether carbon can be stored safely on a permanent basis and are also worried that there will be less incentive to phase out the use of fossil resources. **The risks** that would **arise from not authorising CCS outweigh these concerns, though, in the overall assessment**: as things currently stand, even climate neutrality is barely achievable without CCS, let alone net-negative GHG emissions by mid-century. The emissions reductions required without CCS would necessitate far more extensive changes in behaviour in terms of e.g. nutrition, mobility and living habits than those needed anyway (which are already factored in by climate neutrality scenarios) and therefore entail a high risk of a lack of public support. At the same time, far-reaching technical advances, not all of which are foreseeable today, would also be needed – in the manufacture of cement for example – to enable process-related emissions to be reduced sufficiently without CCS. Moreover, not using CCS-based CDR would increase dependence on biological carbon sinks (carbon storage in vegetation and soil), which offer a less reliable means of long-term carbon storage and cannot be simply expanded at will due to the limited availability of land.

- The key points of the CMS **do not differentiate clearly enough between CCS and CCU:** CCU is no substitute for CCS and CDR for tackling hard-to-abate emissions. Among other things, the climate change mitigation impact of CCUis largely dependent on the duration the carbon is bound in products, the emissions generated by $CO_2$-utilization (e.g. when manufacturing synthetic fuels) and the carbon source (fossil, biogenic or atmospheric).

- The CMS key points do not give sufficient consideration to the fact that CCU based on non-fossil $CO_2$ is needed for climate-neutral production of carbon-based goods – for which, it can be safely assumed, there will continue to be a significant demand in future.

- CCS, CCU and CDR are not able to replace measures which avoid the production of $CO_2$ emissions in the first place. By comparison, they can only make a much smaller contribution to climate action if their deployment is to remain limited to sustainably achievable potentials and some leeway is to be maintained for attaining net-negative GHG emissions. In order to emphasize the need to prioritise avoiding GHG emissions, the CMS and LNe key points focus on **hard-to-abate (residual) emissions**. However, they neither provide a more precise definition of this rather vague term, nor maintain this focus consistently. Consequently, the key points sometimes contradict themselves with regard to how restrictively CCS/CCU should be deployed and which criteria determine this (technical definition of 'hard-to-abate'?; cost?; resilience/supply reliability considerations?). This can pose problems when designing the regulatory framework. It is especially problematic for reaching the necessary public understanding and consensus about carbon management which crucially builds on at least qualitative assessments and clear justifications for the decisions made.

- Focusing the deployment of CCS and CCU on **sectors with hard-to-abate emissions through the selection of government funding priorities** is a pragmatic approach that is compatible with the EU level. Emissions avoided through the deployment of CCS are already exempt from surrendering allowances in the EU ETS today. Due to the limited competitiveness of CCS at present, government funding has a strong steering effect – large-scale deployment of CCS is unlikely to occur in sectors where it is not supported by funding in the coming years. Government funding is supposed to be scaled back in the medium term. The danger of CCS then displacing future alternatives for avoiding the production of $CO_2$ can be limited by, among other things, speeding up the expansion and ramp-up of renewables and a green hydrogen economy.

- The key points of the CMS allow for the installation of **CCS at gas-fired power plants,** even if fossil natural gas is used there. This runs counter to the principle of only deploying CCS for hard-to-abate emissions as set out elsewhere by the key points. However, the key points neither provide a transparent assessment of why this option is necessary in the energy sector, nor do they carefully evaluate the risks of a technology lock-in, and therefore run the risk of jeopardising public support for CCS and carbon management as a whole. In actual fact, **the use of CCS at gas-fired power plants would need to be weighed up against the use of blue hydrogen in hydrogen-fired power plants**, which could also contribute to supply security while green hydrogen is not available in sufficient quantities. In this case, the $CO_2$ is simply captured elsewhere. The CMS basically has to clarify to what extent blue hydrogen can/should be deployed, for how long and where.

- The key points of the LNe aim at an economically efficient level of CDR, without specifying the relative importance of this compared to the priority of emissions reduction. The key points raise some important questions with regard to the necessary framework conditions for CDR which are to be addressed in the ongoing elaboration of the LNe. It is clear that **simply including CDR in the EU ETS is not sufficient.** As with CCS and CCU, not only would this call for reliable reporting of carbon removals, it would also require complementary regulations to be drawn up that can effectively control risks such as $CO_2$ being released again. Inclusion of CDR also needs to be considered very carefully with regard to the **funding of CDR for net-negative GHG emissions and the future of the EU ETS after 2040**.

- The CMS key points formulate a pragmatic approach for commencing geological storage of $CO_2$: offshore storage on German territory should be permitted, but onshore storage in Germany should continue to be generally prohibited (apart from an opt-in for the individual German states). As far as the same safety and environmental standards apply, there is no technical justification for ruling out offshore storage in the North Sea within the German Exclusive Economic Zone while exporting $CO_2$ for storage to other countries bordering the North Sea. In spite of the legitimate doubts regarding potential and, above all, public acceptance, the **possibilities for onshore storage should continue to be explored** in order to create a database for evaluating the pros and cons of onshore storage, taking into account factors such as costs and transportation routes.

# 1 Introduction

Germany and Europe are striving to achieve climate neutrality by the middle of this century. By 2045, the amount of greenhouse gas emissions (GHG emissions) released into the atmosphere in Germany should already not exceed the amount of carbon dioxide ($CO_2$) from the atmosphere stored in sinks over the same period. After that, the plan is to attain net-negative GHG emissions, meaning that more carbon dioxide is removed from the atmosphere than is released. These climate targets make it imperative to also consider emissions that cannot or only at high expenses be mitigated for the time being and could previously be ignored when less ambitious climate targets were pursued.

Whereas the switch to renewable energies makes it relatively easy to avoid energy-related $CO_2$ emissions, this is not technically possible or involves a great deal of effort when it comes to non-$CO_2$ emissions (especially methane, nitrous oxide and F-gases) from agriculture, some process-related industrial $CO_2$ emissions, such as those from cement and lime production, and emissions from thermal waste treatment. Although such emissions can also be reduced through changes in consumer behaviour and in production processes (for example, increased use of timber in construction), they cannot be completely mitigated, even in the longer term. What's more, non-fossil carbon must be used for manufacturing carbon-based products in the future in order to avoid any impact on the environment due to the release of $CO_2$ at the end of product life.

The **term "carbon management"** is used to collectively refer to all methods for preventing $CO_2$ getting into the atmosphere once it has been produced, removing $CO_2$ from the atmosphere again and/or ensuring climate-neutral supply of carbon for manufacturing products. Carbon management is made up of **three pillars**:

- **Carbon (dioxide) Capture and Storage (CCS)**, which prevents any $CO_2$ produced escaping into the atmosphere
- **Carbon Dioxide Removal (CDR) from the atmosphere**, which can lead to negative emissions when used in tandem with carbon (dioxide) storage[1]
- **Carbon (dioxide) Capture and Utilization (CCU)**, where the carbon dioxide captured from industrial facilities or the atmosphere is used as a substitute for newly mined fossil resources, such as oil or natural gas, in the manufacture of carbon-based products.

As part of its proposal for an intermediate climate policy target for 2040[2], the European Commission recently presented its Industrial Carbon Management Strategy[3]. Meanwhile, the German government has also published **two position papers** outlining the key points of a **Carbon Management Strategy (CMS)** and a **Long-term Strategy on Negative Emissions (LNe) for handling unavoidable residual emissions**. This Discussion Paper is using their publication as an opportunity to consider the role and limits of carbon management, to identify any room for improvement in the key points and to highlight challenges going beyond the key points and possible courses of action.[4]

The German government is seeking to systematically tackle the whole topic area of carbon management with its planned CMS and the LNe. As explained in greater detail below, this is to be welcomed in principle

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[1] CCS forms part of the process in the case of the CDR methods Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS). BECCS and DACCS are referred to in the following as CCS-based CDR methods. With other CDR methods, the carbon dioxide is converted into solid carbon compounds and stored in vegetation or the soil. Table 1 on page 19 provides an overview of the various CDR methods.

[2] See European Commission 2024-1.

[3] See European Commission 2024-2.

[4] This paper complements the recently issued ad-hoc statement from the German National Academy of Sciences (Leopoldina) entitled "Key Elements of Carbon Management", which already makes initial recommendations for the future development of carbon management, see Leopoldina 2024.

and there is certainly an urgent need for it. The **key points so far known for the CMS**[5] already set out relevant steps for removing existing barriers (through, among other things, modifications to the German Carbon Dioxide Storage Act, the KSpG). However, they fail to clearly and consistently outline the areas of use CCS and CCU should be authorized for and how strongly avoidance of greenhouse gases should be prioritized over CCS. Even though this ambiguous positioning should only have relatively limited consequences in terms of actual implementation, the CMS runs the risk of further heightening the controversies surrounding CCS instead of contributing to the broad political and social consensus needed for implementation. The initial public response already points in this direction.[6] The **key points for the LNe**[7] are different in nature and largely outline a work programme rather than concrete steps for developing CDR in Germany. They cover pertinent questions and challenges at great length. However, they also remain vague as to the relative strategic importance played by CDR compared to the mitigation of GHG emissions.

### Is CCS a carbon abatement technology?

Only substances that actually get into the atmosphere count as emissions. If $CO_2$ produced at an industrial or power plant is captured directly at the plant, transported to a geological storage site and injected there, it won't get into the atmosphere. This avoids emission of the produced $CO_2$ but not its production. The term "carbon abatement" doesn't differentiate between production and emission, which can sometimes lead to confusion.

The figures for 'residual emissions' derived by climate action scenarios refer solely to the greenhouse gases that are emitted into the atmosphere and need to be offset by CDR to achieve climate neutrality. Therefore, carbon dioxide that doesn't get into the atmosphere in the first place due to the application of CCS is not included in the residual emissions. So, the amount of residual emissions in a scenario does not give any indication of how much CCS is being employed in that scenario.

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[5] See German Federal Ministry for Economic Affairs and Climate Action (BMWK) 2024-1.

[6] See WWF 2024 or Germanwatch 2024

[7] See BMWK 2024-2.

# 2 Carbon management as part of the climate action strategy: Building block, overlaps and limits

## Pursuing all three pillars of carbon management is foreseeable a sensible and necessary approach to reach the climate protection targets.

**Current scenarios for climate neutrality in Germany** make restrictive assumptions regarding the use of CCS and CCU, and limit it from the outset to areas where emissions cannot be avoided in any other way based on current knowledge. Although the scenarios give very high priority to the abatement of greenhouse gases, **they all have to resort to CCS, CCU and CDR** to attain climate neutrality. According to the scenarios, in 2045 it still won't be possible to prevent around **three to six percent of the 1990 levels of non-LULUCF**[8] **greenhouse gas emissions** from escaping into the atmosphere, meaning they will have to be offset by CDR (see Figure 1). The contribution from carbon management in the various scenarios is nonetheless even more considerable, and also includes $CO_2$ that is produced but doesn't get into the atmosphere thanks to the use of CCS and CCU (indicated in Figure 2 by the "CCS (fossil)" bar).

**Agriculture** accounts for the greatest proportion of residual emissions in all scenarios. In the **industrial** sector, the scenarios assume that process-related $CO_2$ emissions (e.g. in the cement and lime industry) can be largely avoided – although only through the use of CCS. Residual emissions remain, mainly from smaller, more decentralized plants where direct capture at the plant is not possible, and from plants with CCS, as it is not possible to capture all the carbon dioxide for technical reasons. The scenarios envisage that emissions from the energy, transport and building sectors, on the other hand, will be almost completely eliminated as a result of the switch to renewable energy, electrification and the use of hydrogen as a fuel.

As the scenarios only depict the period up until 2045 or 2050, the need for net-negative emissions in the second half of the century is not yet factored in. This will require deployment of CDR beyond the level necessary when just offsetting residual emissions, meaning carbon management will continue to play an increasingly important role in climate action.

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[8] With regard to the figures for residual emissions, it should be noted in general that emissions and removals in the LULUCF sector are not accounted for separately. Instead, the carbon removals, especially by forests, are deducted from the sector's (gross) emissions for the purpose of its emissions balance. The actual total (gross) residual emissions are therefore usually higher. According to the latest figures from the German Environment Agency (UBA), the LULUCF sector failed to achieve net carbon removal in 2023, as in previous years. The (gross) emissions from land use and land-use change in the categories cropland (15.3 megatonnes $CO_2$ equivalent), grassland (22 megatonnes $CO_2$ equivalent), wetlands (9.8 megatonnes $CO_2$ equivalent) and settlements (0.6 megatonnes $CO_2$ equivalent) exceeded the removals achieved by forest land (-37.7 megatonnes $CO_2$ equivalent) and harvested wood products (-6.4 megatonnes $CO_2$ equivalent) (see UBA 2024).

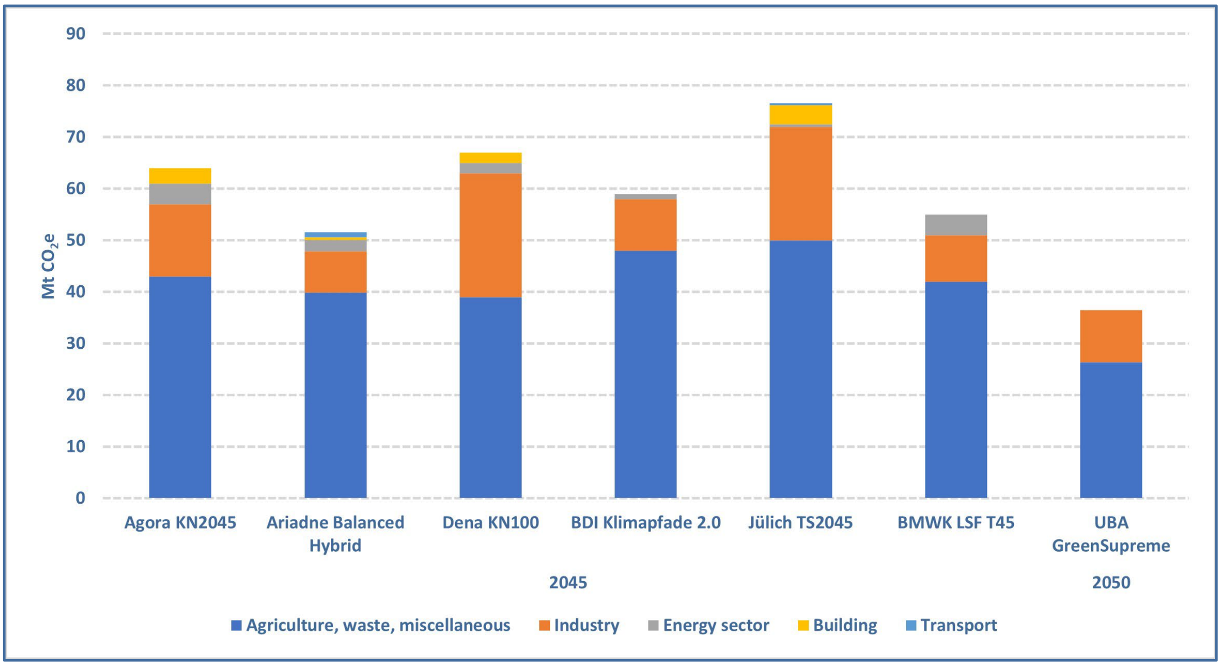

**Figure 1: Meta-analysis – illustration of sector-specific residual emissions in the year 2045 excluding (gross) emissions from the LULUCF sector.** Source: own updated diagram based on Ragwitz et al. 2023. Unlike the other, newer scenarios, the target year for climate neutrality in UBA GreenSupreme is 2050 rather than 2045.

The scenarios of the impact assessment[9], on which the European Commission is basing its proposal for a 2040 climate target for the EU, basically paint a similar picture for Europe. Technological carbon capture for storage (CCS) and utilization (CCU) is necessary both for climate neutrality by 2050 and the proposed target of a 90 percent reduction in net GHG emissions by 2040 compared to 1990 levels. **Compared to Germany's climate neutrality studies, CCS and CCU play a (far) more prominent role in the EU scenarios and are also deployed in the power plant sector.**[10] In 2050, the scenarios foresee around 450 million tonnes of carbon dioxide being captured by means of CCS, CCU or CCS-based CDR from the atmosphere or at point sources, representing about 9.5 percent of (net) GHG emission levels in 1990. On top of this come at least another 330 million tonnes in carbon dioxide equivalent (net) removals from the LULUCF sector in order to achieve climate neutrality in the EU in 2050.[11]

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[9] See European Commission 2024-3.

[10] See ibid Part 1/5, Table 6, p. 36. Depending on the scenario, between 26 and 41 megatonnes of $CO_2$ will be captured from fossil-fuel power plants throughout Europe and geologically sequestered in 2040, with this quantity increasing to 55 megatonnes of $CO_2$ for climate neutrality in 2050.

[11] See ibid Part 3/5, pp. 9 and 17ff. The various scenarios considered vary in their level of ambition for the 2040 climate target, leading to differences in the scale of technological carbon capture by 2040. Whereas technologies are used to capture around 80 to 130 megatonnes of $CO_2$ (2-3 percent of GHG emission levels in 1990) for a less ambitious climate target of a 78 percent reduction in net emissions by 2040 compared to 1990, this figure rises to 150 to 240 megatonnes of $CO_2$ (4-6 percent of 1990 GHG emissions) by 2040 already in the case of the most ambitious reduction target of 92 percent (p. 18). The majority of the captured carbon goes to geological storage sites. In the most ambitious reduction scenario, around a third of the captured carbon is used for manufacturing synthetic fuels. Storage in the form of carbon-based durable materials/goods does not take place on a larger scale until after 2040 (see Part 3/5, p. 22, Figure 10).

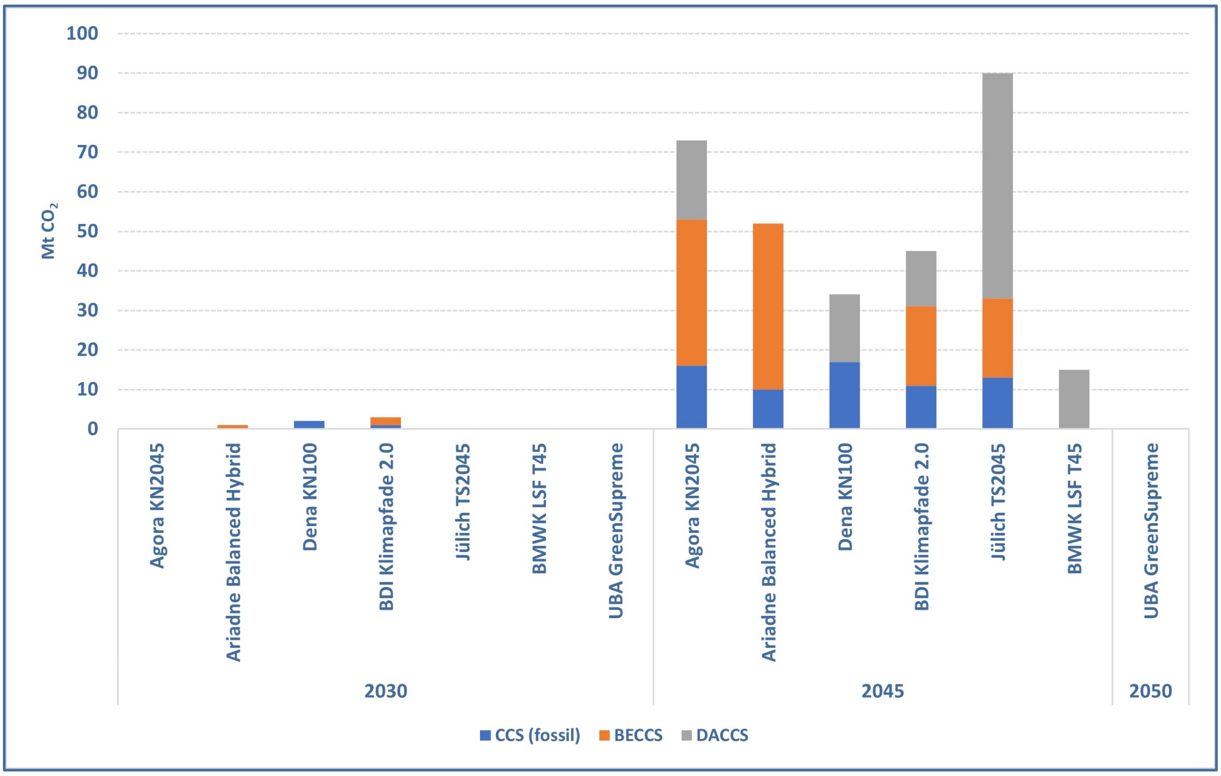

**Figure 2: Contribution from various CCS methods in 2030 and 2045 in climate neutrality scenarios for Germany.** Source: own updated diagram based on Ragwitz et al. 2023. Unlike the other, newer scenarios, the target year for climate neutrality in UBA GreenSupreme is 2050 rather than 2045.

## CMS and LNe cannot be clearly separated and are interrelated, yet they ultimately should form a consistent strategic framework for carbon management.

The **CMS** is meant to develop a framework for the **use of CCS and CCU** in relation to emissions whose production cannot be avoided or is very difficult to avoid, whereas the **LNe** is intended to “create a common understanding of the role played by **carbon removal** for climate action in Germany”[12]. Separating and limiting CMS and LNe in this way may be beneficial for not overcomplicating the political and social debate. However, it is not possible to draw a definitive conclusion as to whether the separate strategies actually form a consistent overall framework for carbon management based on the available key points. There is a risk, though, that the **separate and non-concurrent strategic processes** – the main points of the LNe go into far less detail than the key CMS points, which are already very specific in part – could result in not enough consideration being given to either the reciprocal effects between CMS and LNe or **any conflicts of use and potential for synergies between the different pillars of carbon management**.

The **European Commission's industrial carbon management strategy**[13] takes a different approach again, building on the concept of **technological carbon capture**. The strategy thereby considers carbon capture at sources of (fossil) $CO_2$ as well as from the atmosphere and includes both the use of carbon for products (CCU) and its storage (CCS, CDR). **In contrast to the German CMS, it therefore at least factors in CCS-based CDR,** although it also doesn’t take all possible methods of carbon management fully into account.

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[12] See BMWK 2024-2, p. 4.

[13] See European Commission 2024-2.

There is obvious **overlap between CMS and LNe** as a result of both the technological components and the transport and storage infrastructures required by CCS, CCU and (CCS-based) CDR. The possible applications for **CCS-based CDR** (biomass energy with carbon capture and geological storage, BECCS, and direct carbon capture from the atmosphere and geological storage, DACCS) are therefore directly contingent on the legal framework for CCS, the creation of $CO_2$ transport networks and the possibilities for developing geological storage sites. Consequently, when determining the **possible applications for CCS and CCU,** it is strategically important to **also bear in mind the available potential for CDR**. The overlap between CMS and LNe is also plain to see when it comes to **CCU. CCU is within the scope of the CMS when fossil $CO_2$ is being used, and within the scope of the LNe when the $CO_2$ comes from non-fossil sources**. So, both position papers address CCU accordingly.

These interrelations are not discussed as systematically as would be required for a consistent overall carbon management strategy, at least not in the position papers published so far. The main points of the CMS do make reference to the shared need for carbon infrastructures and storage facilities with regard to CCS, CCU and CDR. CDR for offsetting residual emissions is an LNe topic, however, as are the additional quantities of CDR required in future for attaining net-negative GHG emissions. **The CMS is meant to take precedence over the LNe when it comes to addressing carbon infrastructure development without being able to make use of the LNe's more dependable assessments of the future application of BECCS and DACCS in Germany. This falls short of the findings of** the known climate neutrality scenarios for Germany, which show that more $CO_2$ from BECCS and DACCS will probably have to be transported and stored than $CO_2$ produced from fossil resources at point sources (see Figure 3).

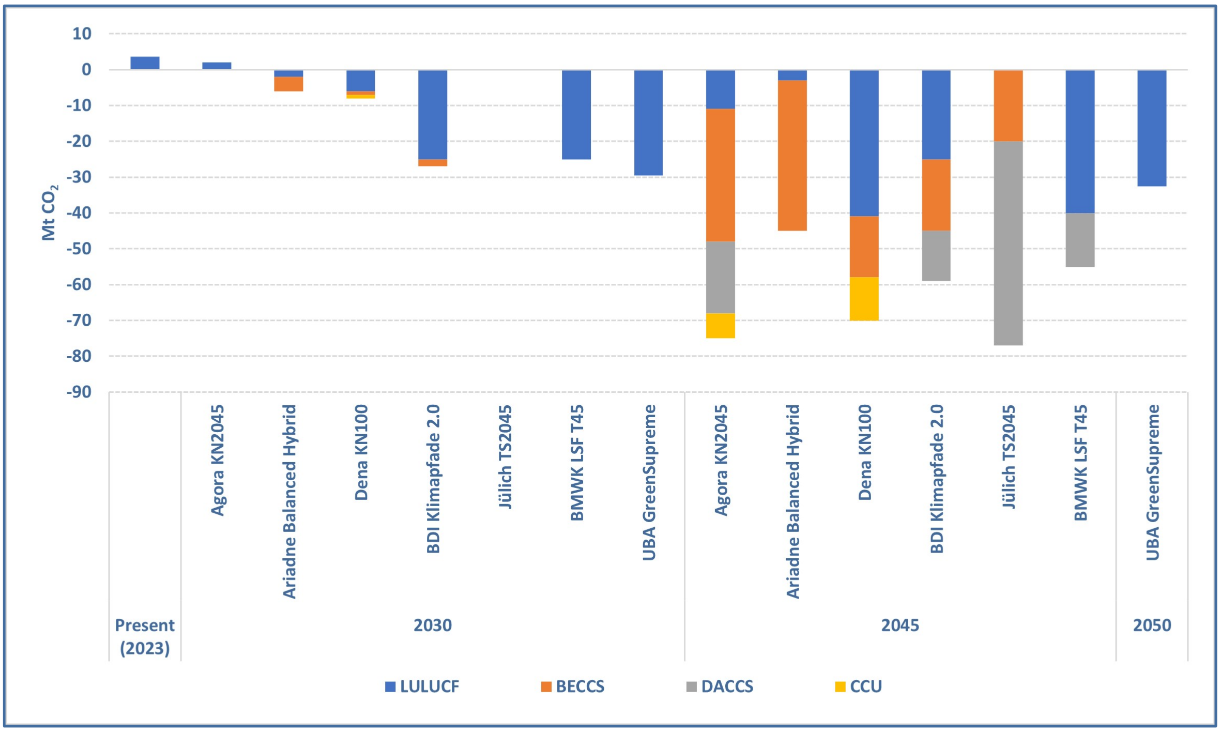

**Figure 3: Contribution from the various carbon removal methods and the net balance for the LULUCF sector[14] in climate neutrality scenarios for Germany.** Source: updated diagram based on Ragwitz et al. 2023; LULUCF for 2023 from UBA 2024. Unlike the other, newer scenarios, the target year for climate neutrality in UBA GreenSupreme is 2050 rather than 2045.

**Moreover, the construction of carbon removal facilities, transport infrastructures and carbon storage sites can foreseeably not be speeded up without any limits.** As a result, the annual capacities available for storing carbon and removing it from the atmosphere will be restricted for a long time. CCS for fossil emissions and CCS-based CDR methods will have to share the limited storage capacities. Carbon transport infrastructures are needed in the case of both carbon utilization (CCU) and storage. Facilities that capture carbon from the air (DAC) can be used either for CDR (DACCS) or for supplying $CO_2$ for climate-friendly production of products (CCU). It would also be advisable to take a closer look at these **conflicts of use** and the potential implications for transformation pathways – in industry for instance – as part of a strategic examination of carbon management. Points that would have to be clarified include prioritizing how the limited capacities are to be allocated between the pillars of carbon management, and whether explicit political decisions are to be taken for this. It is also essential that the CMS and LNe are considered in conjunction with the **biomass strategy** from the outset in order to take possible conflicts of use into account. On the one hand, carbon management results in a need for biomass for BECCS. On the other, biomass can represent another alternative source of carbon alongside CCU for the chemical industry (in combination with carbon from recycling streams) in a largely defossilized energy and industry system.

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[14] Many studies indicate net removals for the LULUCF sector. The figure for gross removals is higher, but some of it is needed to offset the sector's gross emissions. The increase in net removals shown in many scenarios is due, at least in part, to a decrease in gross emissions (as a result of peatland restoration, among other things).

## CCS holds risks that must not be ignored, but which must be weighed against the risks of a CCS ban to obtain an overall assessment.

The key points of the CMS and the proposed **amendment to the Carbon Dioxide Storage Act (KSpG)** support and pave the way for the deployment of CCS, which for a long time was the subject of great debate in Germany and is still flatly rejected in some quarters.[15] The course they set is nevertheless appropriate and necessary too.

CCS doubtless holds certain risks: For instance, preliminary (test) drilling for extracting oil or natural gas can result in carbon dioxide escaping from the geological storage sites, which can pollute groundwater or acidify the oceans, not to mention its climate impact.[16] It should also be noted that carbon capture uses up a lot of energy (and water).[17] Plus, CCS can only prevent 90 to 95 percent of point source emissions from getting into the atmosphere, even under ideal conditions. Consequently, a certain amount of residual emissions remains that must be offset by CDR even though capture and storage technologies are used.

When assessing the **risks of CCS, the practical experience already gained with it should be taken into account**. $CO_2$ capture, transport and storage technologies are not completely new. Experience has already been gained with all steps in the CCS process chain through various projects worldwide. The capture and transport of $CO_2$ can be considered to be industrially proven standard processes. And projects such as the Sleipner CCS project – which has been carrying out geological $CO_2$ storage off Norway's coast since 1996 – have provided experience with carbon storage. Past **experience indicates that the technologies can be operated reliably**; it does not, however, provide proof that carbon can be stored safely for several centuries.[18] Results are not fully transferable from one storage site to the next either – or are only transferable to a limited extent – meaning that each site has to be considered individually and assessed with respect to its specific risks.

The **risks of CCS need to be weighed up against the risks that would result from ruling out CCS today with regard to meeting climate targets**.[19] As things currently stand, it is barely possible to realistically achieve even climate neutrality by 2045 without CCS, let alone net-negative GHG emissions in the second half of the century. Not implementing CCS would necessitate far **more extensive changes in personal behaviour in terms of e.g. nutrition, mobility and living habits** than those required anyway and already factored into the illustrated climate neutrality scenarios. There would be a need for a much sharper reduction in meat consumption (to cut methane emissions), for instance, and tougher restrictions on both the creation of housing and mobility. It is very doubtful, to say the least, whether society would be willing to accept all these changes, which would have to take place in a relatively short period of time. In any case, the **need for even greater economic and social transformation holds high potential for social conflict** and puts public support for climate action at considerable risk. Technical advances with a far wider impact, not all of which are foreseeable today, would also be needed on top of this to enable process-related emissions, e.g. from the cement industry, to be lowered sufficiently even without CCS. **In light of all this, abandoning CCS would most probably lead to an increase in residual emissions that would have to be offset by CDR.** At the same

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[15] See Deutsche Umwelthilfe 2024 or Greenpeace 2024.

[16] See UBA 2023.

[17] See IPCC 2022, p. 643. The amount of energy consumed for capturing carbon largely depends on the concentration of $CO_2$, meaning that capture from the air requires a much higher energy input than capture at industrial point sources or power plants, see Bui et al. 2018.

[18] See Kearns et al. 2021, Bui et al. 2018 or Budinis et al. 2018 regarding the status of CCS development.

[19] See Shu et al. 2023 who demonstrate, for instance, that authorising CCS could not only lower the costs of Germany's transition towards climate neutrality, but – in a broader-based life cycle analysis – also offer ecological and health benefits that go beyond just its impact on climate action.

time, a decision to not use CCS would rule out CDR methods with geological storage of $CO_2$ (BECCS and DACCS), thereby severely limiting the potential of CDR.

From an economic point of view, sectors and value creation that produce hard-to-abate $CO_2$ emissions would be exposed to **increased pressure from international competition**, especially as **CCS is going to be deployed in a far less restrictive form in foreign (and other European) countries**, as already set out in the European Commission's industrial carbon management strategy. If this prompted the affected manufacturing to simply relocate abroad with demand in Germany being covered by imports, no progress would have been made on a climate policy level. Scenario analyses for Germany also indicate that even ambitious assumptions about how consumer behaviour will change are not enough to meet the target of climate neutrality without the use of CCS.[20] **CCS is therefore deployed in all the current scenarios for Germany** (see Figure 2).[21] As far as the EU is concerned, the LIFE scenario in the impact assessment on the proposed European 2040 climate target illustrates that **more sustainable lifestyles** substantially reduce the use of CCS (including CCS-based CDR methods), but could not substitute geological carbon sequestration for the proposed 2040 climate target for the EU either.[22]

Some of the public debate focuses heavily on the risks of CCS. The public are concerned whether carbon can be stored safely permanently and also worried there will be less incentive to phase out the use of fossil resources. These concerns need to be taken seriously. An **overall assessment must, however,** also give consideration **to the risks that would arise from not enabling CCS**. As things currently stand, climate neutrality cannot be realistically achieved without CCS. Provided that CCS is deployed in a way that maintains high social and ecological standards and avoids lock-ins that perpetuate the use of fossil resources and their long-term harmful effects, the risks of not using CCS therefore seem to be greater. The public debate should touch more on the risks of not using CCS. This can be done, for example, by illustrating the changes in behaviour necessitated in the various scenarios in a clear and easily accessible way. This could be helpful as a basic source of information for public deliberation of the conditions under which CCS will be accepted and to what extent, including vis-à-vis a more intense transformation on the demand side.

## Land-based biological carbon sinks are unable to meet future CDR needs and are generally less reliable.

Prohibiting the use of CCS doesn't just tend to lead to an increase in residual $CO_2$ emissions; it precludes CCS-based CDR (BECCS and DACCS) at the same time. Land-/nature-based biological CDR methods (reforestation, soil carbon sequestration) that are already more fully developed are therefore gaining in importance. Compared to CCS-based CDR, these techniques are viewed in some quarters as being more eco-friendly and therefore less objectionable. It should be noted, however, that their **potential is limited simply due to the restricted availability of land** and that **carbon storage in vegetation and soil is harder to measure and verify, and the duration of storage is also subject to greater uncertainty** (see box on "CDR methods"). Forest fires, pest infestation and direct human impact can result in stored $CO_2$ being released again. **These CDR methods are therefore jeopardised by climate change itself.** It is also uncertain whether the projected potential of biological sinks could actually be fully harnessed.

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[20] See Merfort et al. 2023.

[21] The UBA GreenSupreme scenario rules out CCS, see UBA 2019. Despite extremely ambitious assumptions regarding consumer sufficiency and reduction of industrial residual emissions (e.g. the development of alternative types of cement) combined with zero economic growth from 2030, climate neutrality by 2050 can only be achieved in this study on the basis of very optimistic expectations about the growth of sink performance in the LULUCF sector.

[22] See European Commission 2024-3 Part 1/5, p. 40.

The **scenarios for Germany vary greatly in terms of their reliance on land-based biological sinks, but they all already deploy BECCS and DACCS in 2045** (see Figure 3). In the scenarios, the amount of $CO_2$ from BECCS and DACCS applications stored in geological sites is in some cases considerably greater than the quantity of $CO_2$ captured and stored from fossil emission sources. The scenarios on which the European Commission bases its proposal for the 2040 climate target also already deploy technological CDR in addition to land-based sinks in 2040 in order to reduce net GHG emissions by 90 percent compared to 1990. The need for CCS-based CDR then continues to rise as the scenarios progress towards climate neutrality in 2050.[23]

### CDR methods

**Various methods** can be used to remove carbon dioxide from the atmosphere.[24] They differ in terms of **how they capture $CO_2$ from the air** and **how it is then stored long-term**. Table 1 provides an overview of the various CDR methods. **The method of storage affects how reliably the $CO_2$ is permanently kept out of the atmosphere**.

When carbon is stored in vegetation and the soil, for instance, the risk of the $CO_2$ escaping again is greater than when it is injected underground. This is because forest fires, droughts and pest infestation can cause the $CO_2$ to be released again – a risk that must not be underestimated, not least due to the ongoing effects of climate change. Deforestation or improper management of carbon-rich soils can also lead to stored $CO_2$ being released into the atmosphere again. The **permanence of storage is of relevance when it comes to crediting the carbon removal as a contribution to climate action**, particularly in comparison with emissions reduction. The possible future re-release of removed carbon raises the question of who would be liable for the ensuing damage.

Another important aspect for **crediting storage performance** is the **accuracy** with which this performance can be calculated and verified in the first place. While the quantity of carbon dioxide removed in BECCS or DACCS facilities can be monitored directly using gas measurement technology, determining the quantity of carbon stored in vegetation and the soil is a much more complex task. The various uncertainties involved with monitoring the storage performance of different CDR methods need to be taken into account for their regulation. The $CO_2$ capture and storage of some methods, such as reforestation and carbon sequestration in the soil, is already accounted for in national emissions inventories. However, for an integration into emissions trading, for example, and the legally secure attribution of the amounts stored to individual companies needed for this even stricter monitoring and verification standards would have to be met.

Apart from this, other differentiating characteristics of the various CDR methods include the amount of land needed, energy demand and costs.[25]

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[23] The spread of more sustainable lifestyles and consumer habits in the LIFE scenario is merely able to reduce the need for technological CDR but not substitute it completely. One of the factors in this is the rather unambitious projections for the change in emissions in the agricultural sector that form the basis for the impact assessment, see European Commission 2024-3.

[24] See Erlach et al. 2022 for an overview of the various methods.

[25] See MCC 2021 or Smith et al. 2023.

| CDR methods | Permanence of storage | Calculation and monitoring of storage performance | Regulatory category |
|---|---|---|---|
| **Reforestation** | Reversible | Complex | LULUCF (already factored in by national inventories) |
| **Soil carbon sequestration** | Reversible | Complex, high level of inaccuracy | LULUCF (already factored in by national inventories) |
| **Biochar** | Medium storage time (decades to millennia)[26], low risk of reversibility[27] | Stored quantity can be calculated relatively accurately, monitoring of storage time complex[28] | Could be incorporated into LULUCF if added to soil,[29] or into new inventory categories yet to be developed |
| **Enhanced weathering** | Long-term, non-reversible sequestration in rock | Complex, methods are still being developed[30] | Could be incorporated into LULUCF given that a method of calculating storage performance is developed |
| **Bioenergy with Carbon Capture and Storage (BECCS)** | Long-term storage in underground geological formations | Relatively straightforward and accurately measurable | Could be incorporated into the ETS; sustainability criteria for the biomass origin would additionally be required |
| **Direct Air Carbon Capture and Storage (DACCS)** | Long-term storage in underground geological formations | Relatively straightforward and accurately measurable | Could be incorporated into the ETS |

Table 1: Overview of CDR methods

Achieving the **net-negative GHG emissions targets** already set out in legislation for Germany and the EU from 2050 onwards **will definitely be implausible without CCS-based CDR** from today's perspective. The debate surrounding CCS often gives too little consideration to this long-term outlook and the requirement for climate action. It is also worth noting that, **on a global level too, the goals of the Paris Agreement would be severely threatened** (or be beyond reach) **if BECCS and DACCS were not available in future.**[31] This means that Germany and Europe can also make a major contribution to international climate action by investing in the (further) development of these technologies and testing appropriate governance structures.[32]

Nonetheless, the land-based CDR methods also offer benefits and should therefore be included in the overall portfolio of CDR techniques. They are usually relatively inexpensive and can in some cases already be implemented on a large scale today. This means they could be used to gain time for ramping up other methods that are still at a less advanced stage of development, such as DACCS. Such methods could additionally have a positive impact on biodiversity, especially if a project involves restoring damaged or destroyed ecosystems, such as forests and grasslands.

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[26] See Smith et al. 2023, p. 15.
[27] See Merfort et al. 2023.
[28] See Smith et al. 2023, p. 19.
[29] A methodology devised by the IPCC can be taken as a basis here for crediting storage performance (IPCC 2019: https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch02_Ap4_Biochar.pdf).
[30] See Amann / Hartmann 2022.
[31] See IPCC 2022.
[32] See MCC 2021.

## In the long term, CCU does not represent an alternative to CCS and CDR for tackling hard-to-abate emissions.

The **key points of the CMS** consider CCU to be also an option for bringing industrial process emissions or emissions from the waste industry, for instance, in line with climate targets, and thereby **do not differentiate sufficiently between CCS and CCU**. The key points of the LNe also contemplate CCU, this time as a way of achieving negative emissions, but acknowledge that this holds only under certain conditions.[33] Such a nuanced assessment of **CCU** is important and should also be adopted in the CMS, as CCU can merely complement CCS and CDR as a means of tackling hard-to-abate emissions:[34] The climate protection impact of CCU depends on

- the source of the carbon being used (fossil, biogenic, atmospheric)
- the duration it is bound in the manufactured product (i.e. for how long the $CO_2$ is removed from the atmosphere after being bound in the product)
- what happens to it at the end of the manufactured product's lifetime
- the emissions generated by the product's manufacture (for example, from using fossil fuels to supply the energy required for the production process and the upstream emissions for building the facilities)
- the consequences for the system as a whole, which depend on the functions performed by the CCU products and what other products or processes they replace.

## CCU is not climate neutral per se and rarely results in long-term removal of carbon dioxide from the atmosphere.

Figure 4 shows a schematic diagram of various CCU process pathways and example applications in terms of their contribution to climate action, based on source of carbon, duration of binding and what happens to the used $CO_2$ in the longer term. **Basically, CCU merely delays the release of carbon by the length of the product's life**. Consequently, only very durable goods such as building materials serve to keep carbon out of the atmosphere for a long time. In the case of goods with a shorter life, the duration the carbon is bound in the sphere of products can be extended by applying circular economy methods, e.g. through (mechanical or chemical) recycling of the product or capture and renewed utilisation of the $CO_2$.

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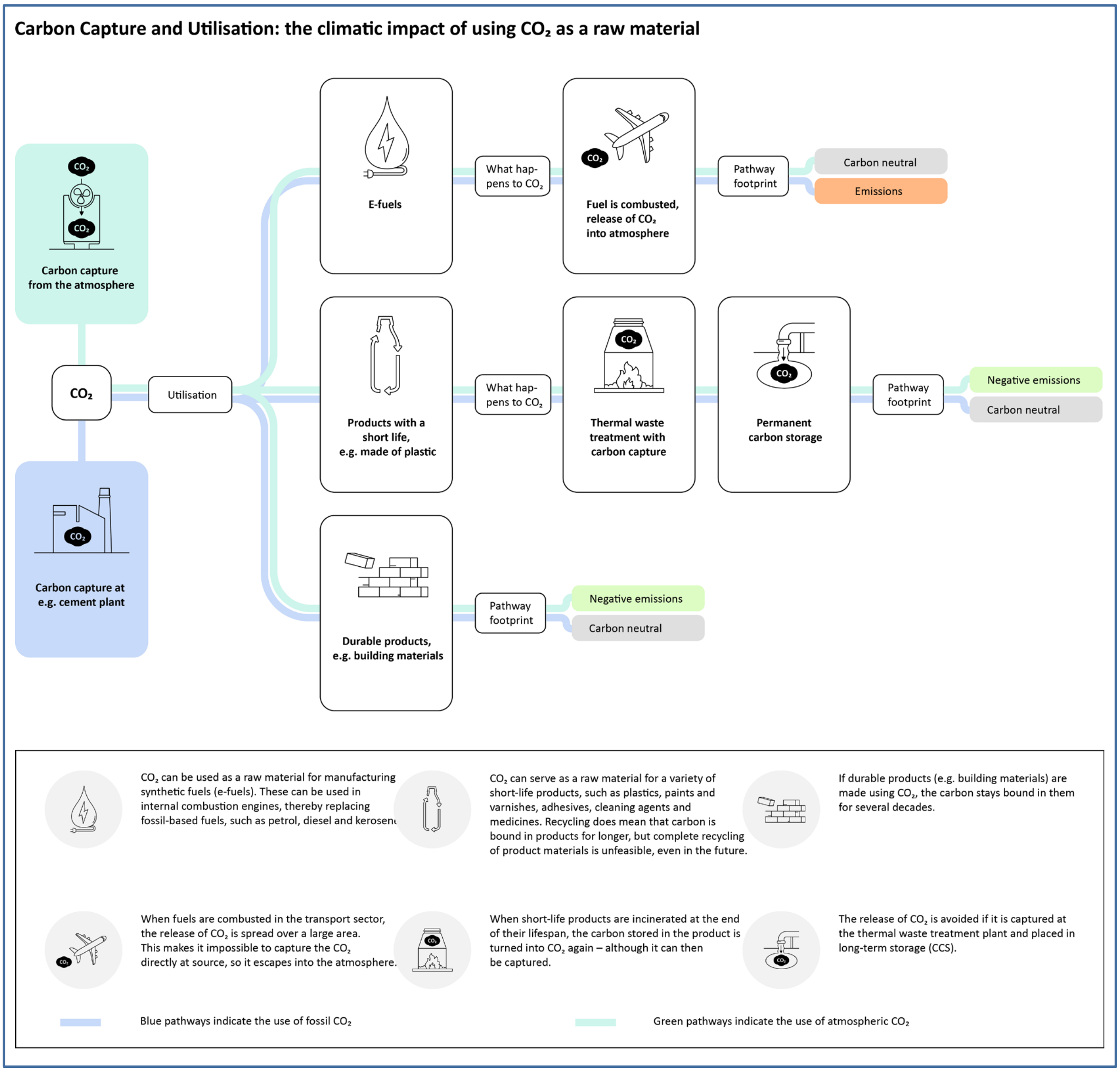
[33] See BMWK 2024-2, p. 8.

[34] See Hepburn et al. 2019.



**Carbon Capture and Utilisation: the climatic impact of using $CO_2$ as a raw material**

$CO_2$ can be used as a raw material for manufacturing synthetic fuels (e-fuels). These can be used in internal combustion engines, thereby replacing fossil-based fuels, such as petrol, diesel and kerosen

$CO_2$ can serve as a raw material for a variety of short-life products, such as plastics, paints and varnishes, adhesives, cleaning agents and medicines. Recycling does mean that carbon is bound in products for longer, but complete recycling of product materials is unfeasible, even in the future.

If durable products (e.g. building materials) are made using $CO_2$, the carbon stays bound in them for several decades.

When fuels are combusted in the transport sector, the release of $CO_2$ is spread over a large area. This makes it impossible to capture the $CO_2$ directly at source, so it escapes into the atmosphere.

When short-life products are incinerated at the end of their lifespan, the carbon stored in the product is turned into $CO_2$ again – although it can then be captured.

The release of $CO_2$ is avoided if it is captured at the thermal waste treatment plant and placed in long-term storage (CCS).

Blue pathways indicate the use of fossil $CO_2$

Green pathways indicate the use of atmospheric $CO_2$

**Figure 4**: **Carbon footprint for example CCU pathways**. The diagram only assesses the source and duration of binding of the $CO_2$ captured and its fate; it does not take systemic aspects, such as the quantity and source of the energy needed for the CCU process, into consideration. Source: Energy Systems of the Future (ESYS); Illustration by Figures GmbH.

**Regardless of the form and duration of use, a long-term neutral carbon footprint** can ultimately only be achieved if all $CO_2$ that is newly extracted from fossil or mineral resources in the ground and introduced into the carbon cycle **is balanced out by removal and permanent storage of carbon at the end of product life.**

Even a theoretically conceivable fully closed-loop system with ongoing reutilisation of fossil (or mineral) carbon does not offer a consistent, long-term approach to continue to use fossil resources. This approach would imply that $CO_2$ that has been newly extracted from fossil or mineral sources would be continuously introduced into the cycle and used in an application. However, the reuse of $CO_2$ together with an increase in (mechanical or chemical) product recycling – that would be worthwhile anyway for a host of other reasons, such as conservation of resources – would reduce the demand for additional $CO_2$ for manufacturing carbon-based products (e.g. plastics). So, in order to keep bringing newly produced hard-to-abate $CO_2$ emissions (e.g. from the cement industry) in line with the goal of climate neutrality through CCU alone, production of carbon-based goods would have to increase accordingly over time.[35] This appears – from a global standpoint at least – to be out of step with other social objectives, such as reducing levels of plastic pollution in the environment.[36] Figure 4 does not offer a broader systemic or life cycle assessment. The **amount of energy required for the CCU process** – i.e. for activating the inert carbon dioxide – and the energy sources used for this, for instance, are also important factors in the emissions savings that can be achieved with the help of CCU compared to conventional methods of manufacturing carbon-based products, such as plastics or fuels. A systemic evaluation would also have to factor in the products and production processes that are replaced by CCU.

The timescale factor is of vital importance: **CCU cannot make a long-term contribution to climate action if $CO_2$ from fossil sources is used** and is only bound in products with a shorter life-time, for instance. **This approach could nevertheless be worthwhile as a transitional solution, especially in the case of multiple usage.**[37] There is also a benefit to be had though if, for example, the use of the CCU product, such as a synthetic fuel, for instance, doesn't just act as a 1:1 substitute for the use of fossil resources, but also helps to achieve a fundamental reduction in the demand for fuel as a result of price-induced effects. **The use of $CO_2$ from fossil sources can additionally expedite the market ramp-up of new CCU technologies while providing fresh impetus for further technological development in the process**. Due to the close technical similarities, such technologies could also benefit CCS and CDR approaches. In all of the above cases, action must be taken on a regulatory level to ensure these possible commercial uses for fossil $CO_2$ do not lead to any lock-in effects that create new obstacles for the measures needed in the long term which avoid the production of $CO_2$. Transitional arrangements are one possible solution here.[38]

### CCU is a necessary building block for climate-neutral production of carbon-based goods.

The CMS key points neglect the fact that CCU opens up the prospect of climate-neutral manufacture of carbon-based goods, for which it can be safely assumed there will continue to be a significant demand in future. This prospect is barely mentioned in the key points of the LNe either. As a means of climate-friendly carbon supply, CCU can and, indeed, must be a key building block for a climate-neutral society and industry/economy. Thus, it has a key role to play in the chemical industry of the future. **In order to ensure carbon neutrality, the $CO_2$ then must have been previously obtained from the atmosphere (DAC) or from biomass**. This role is emphasised by the European Commission's industrial carbon management strategy, in contrast to the German position papers.[39]

Many products contain carbon, including plastics, synthetic fibres and fertilisers. When such goods are put into circulation and consumed, there is always a risk that the carbon bound inside them could ultimately be released into the atmosphere. Cutting back the consumption of these goods is an important climate action strategy but is unlikely to be sufficient, partly because equivalent alternatives are not always available. CCU

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[35] The key points of the LNe at least highlight this correlation between the contribution of CCU to climate action and the quantity of carbon-based goods, see BMWK 2024-2, p. 8: "If carbon from $CO_2$ in the atmosphere is permanently bound in products in the form of e.g. calcium carbonate, negative emissions can be attained. Temporary use can also help to achieve negative emissions in a closed-loop cycle for atmospheric carbon dioxide, provided the total quantity in the loop increases."

[36] See IPCC 2022, ch. 11, p. 1194.

[37] See ibid ch. 11, p. 1186.

[38] At EU level, for instance, synthetic fuels (known as renewable fuels of non-biological origin or RFNBO) can be credited against the renewable energy targets in accordance with Art. 25 Sec. 2 of the Renewable Energy Directive (EU) 2018/2001, assuming the $CO_2$ originates from plants in the EU ETS that are required to obtain allowances and EU ETS allowances were surrendered for the used $CO_2$. To reduce the risk of lock-in effects, however, they are only allowed to be credited in this way for a limited period of time – until 2035 (for $CO_2$ from the electricity sector) or 2040 (for $CO_2$ from other sectors).

[39] See European Commission 2024-2, section 4.4.

offers a way of avoiding these emissions from additional fossil $CO_2$ from the very outset in the future by providing the carbon needed for manufacturing the goods no longer from the material use of fossil resources, such as oil or natural gas, but from using $CO_2$ that has been removed from the atmosphere. The fact that **sustainably sourced biomass and recycling cannot be expected to completely meet industry's demand for carbon** further adds to the significance of these possibilities for switching the source of carbon. This is another reason why all current climate neutrality scenarios for Germany as well as the European Commission's industrial carbon management strategy envisage the deployment of CCU. **However, neither the CMS nor the LNe key points address the issue of future carbon demand.** This carbon demand is of relevance, however, if only because of the conflicting objectives that can result from carbon removal for storage and negative emissions on the one hand and for use in production processes on the other. After all, the annual carbon capture rates will be limited, at least in the medium term (due to factors such as the speed of scale-up and energy consumption). Although utilising the captured carbon instead of storing it (with the additional effort this involves) may seem to be the more attractive option in this case, this could potentially result in a much smaller contribution to climate action.

## CCS, CCU and CDR are only able to complement, and not replace, measures avoiding the production of emissions in the first place.

Both the key points of the CMS and LNe and the European Commission's industrial carbon management strategy[40] stress that avoiding emissions should continue to be of great importance and the overriding priority. **This is the right approach in view of the risks of carbon management and its limited and, in part, uncertain potentials**: CCS, CCU and CDR are not able to **replace measures avoiding the production of emissions in the first place**. By comparison, they can only make a much smaller contribution to climate action, if their deployment is to remain limited to sustainably achievable potential and some leeway is to be maintained for attaining net-negative GHG emissions.

The principal risks of carbon management include **the limits on how reliably CCS, CCU or CDR can keep the carbon out of the atmosphere in the long term**. The individual pillars and the methods they entail differ significantly in this respect. Carbon can be stored in different ways: in materials (CCU), in geological formations (CCS, BECCS, DACCS), in vegetation/soil and in the ocean (sediments). There is a small residual risk of carbon being re-released into the atmosphere even in the case of geological storage, which – based on the constantly growing practical experience available today – is deemed to be a more reliable means of storage than, for instance, biological carbon sinks such as forests or soil, and one that is more easily to monitor.[41] Also of relevance in this regard are the **ecological and social risks** that the various carbon management methods might involve as a result of their consumption of energy or natural resources (strain on ecosystems, conflicts with food security).[42] Methods that rely on ecosystems for removing carbon from the atmosphere and/or storing it, such as BECCS, could come into conflict with food security or environmental/biodiversity protection efforts. The less the individual technologies and methods have to be applied, the easier it is to manage these risks.[43]

Moreover, the **state of development of technologies and infrastructure** and their costs significantly limit the potential that carbon management holds for climate action. Many of the technologies, such as the di-

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[40] See European Commission 2024-1, p. 16ff.

[41] See IPCC 2022, Cross-Chapter Box 8, p. 1261. The reliability problems raise liability questions and place restrictions on the total potential that carbon management can actually achieve, as capacity must be reserved for offsetting any future carbon releases.

[42] See Budinis et al. 2018, Qiu et al. 2022, Madhu et al. 2021 or Shu et al. 2023.

[43] See Smith et al. 2023.

rect removal of carbon dioxide from the atmosphere (DAC), are still in the (very) early stages of development and currently unable to compete with either land-based CDR or abatement technologies. What is more, facilities for capturing $CO_2$ and infrastructures for its transportation cannot be developed nor geological storage sites opened up and filled at unlimited speed. In light of this, their future availability (and economic viability) is still uncertain. In addition, the annual carbon capture and transport volumes that can be achieved if CCS and the associated technologies are set off today will be limited for the foreseeable future and insufficient to capture a large part of current emissions. This alone means that CCS will only be able to make a very restricted contribution to the 2030 climate targets especially. The total available geological storage capacity, on the other hand, is very large and does not represent an limiting factor for the potential of CCS-based methods, at least not in the short and medium term.[44] Looking further ahead, though, and considering, for example, the quantities of CDR that could become necessary to offset an overshoot of global average temperatures beyond 2°C,[45] geological storage capacity could become scarce.

In view of the risks and uncertainties associated with both carbon management in general and CDR in particular, it makes sense to pursue a **broader portfolio of different technologies and methods**. This portfolio approach provides a safeguard against the risks and uncertainties of individual technologies should, for instance, the pace of development or scaling up fall short of expectations. What is more, any harmful side effects of individual techniques (impact on biodiversity, land-use conflicts, high material and energy requirements, etc.) can be mitigated by only having to implement each technology to a limited extent. This portfolio idea also lends further support to the argument for allowing the general use of CCS technologies in Germany. For the portfolio approach to work, the (further) development of technologies and methods which are still not very well established or competitive must also receive funding at an early stage, if necessary stimulated by targeted government measures.

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[44] The European Scientific Advisory Board on Climate Change, for instance, anticipates that the annual storage volume can reach a maximum of 425 megatonnes of $CO_2$ by 2050. In total, some 57 gigatonnes of carbon storage capacity could be unlocked by 2050, see ESABCC 2023, p. 78ff.

[45] See Schleussner et al. 2023.

# 3 Policy options for developing the carbon management regulatory framework

## The focus of the CMS and LNe key points on hard-to-abate (residual) emissions is imprecise and sometimes contradictory.

The CMS and LNe key points stress the importance of avoiding the production of GHG emissions and the need to prioritise this over carbon management. They focus on the deployment of CCS, CCU and CDR for hard-to-abate (residual) emissions. However, they do not provide a more precise definition of this rather vague term, and the focus on these emissions is not maintained consistently. Both "key points" documents are **sometimes self-contradictory with regard to how widely CCS, CCU and CDR should be deployed and the criteria determining their deployment in relation to $CO_2$-abatement** (technical criteria?; cost?; resilience/security of supply?). One of the contradictions in the CMS key points is that although they purport to focus on hard-to-abate emissions, they do not restrict the deployment of CCS and CCU to these emissions. In particular, their use in gas-fired power plants is explicitly permitted. This can lead to problems when designing the regulatory framework. It is also especially **problematic for the necessary public acceptance of carbon management**. In order to build public acceptance, it is important that the **decisions taken should be based on at least qualitative assessments and reasoning**.

"Hard-to-abate emissions" is a widely used term. However, the criteria for measuring how hard emissions are to abate are rarely specified. It is also not clear whether or how a concrete regulatory distinction should be drawn between abatable and hard-to-abate emissions. One way of defining the term more precisely is to confine it to **technically unavoidable emissions**. Emissions that cannot be avoided because it is technically impossible to switch to renewable energy, alternative production methods, etc. occur in sectors such as agriculture or as industrial process emissions. The CMS key points repeatedly cite the cement and waste management industries as examples of sectors where CCS is necessary. There is a broad scientific consensus around the need for carbon management in these sectors. That said, it is perfectly possible that, over the long timescales involved in climate policy, further technological advances could (significantly) push back the boundaries of emission abatement. While the CMS key points focus on emissions that are technically unavoidable today, it would be preferable to also include a **dynamic perspective** that considers possible future technological advances. This would require the $CO_2$ emission categories for which carbon management is prioritised to be regularly assessed and readjusted over time. Support for technologies that increase the potential to avoid the production of GHG in the future would also need to form a key part of a comprehensive carbon management strategy.

Moreover, even if it is technically possible to avoid the production of GHG, the cost of doing so may be very or disproportionately high. The definition of hard-to-abate emissions used by the CMS and the LNe (as well as the European Commission's Industrial Carbon Management Strategy) includes these **economically hard-to-abate emissions**. Allowing the deployment of CCS could, for example, provide the chemical and steel industries with a means of cutting their emissions and thus reducing the expected costs associated with rising allowance prices in the European Emissions Trading System, especially while the availability of alternative technologies remains limited (e.g. while the hydrogen market is still developing). **In principle, it makes sense to adopt a wider definition of "hard-to-abate emissions" that is not confined to technically unavoidable emissions**. However, if the avoidance of the $CO_2$-production is (at least to some extent) to be prioritised over CCS, CCU and CDR, it will be necessary to clarify the level at which avoidance costs become "too or disproportionately" high, justifying the use of carbon management.[46] The key points of both strategies are unclear on this point. The **CMS key points refer to industrial applications where cost-efficient avoidance will not be possible for the foreseeable future**,[47] but without specifying exactly what is meant by "cost-efficient". Simply considering the current cost of different avoidance technologies to private companies does nothing to prioritise particularly economically hard-to-abate emissions. On the contrary, it essentially means that CCS/CCU and carbon emission avoidance are treated the same for all technically avoidable emissions.[48] The **LNe key points state that future non-abatable residual emissions will depend on the economic costs of CDR, with the aim being to achieve an economically efficient level of negative emissions**.[49] However, they too fail to specify how economic efficiency as guiding principle relates to the top climate action priority of GHG mitigation  stated elsewhere in the document.

In addition to the technical feasibility and financial cost aspects, the level of hard-to-abate emissions also ultimately depends on **society's willingness to change established patterns of behaviour**. Lifestyle changes, for example in people's dietary, mobility, consumption and residential habits, could reduce demand for products and services associated with emissions that are either technically impossible or very costly to avoid. **However, the CMS key points completely neglect this demand-side perspective**, while the LNe key points fail to specify to which extent demand side changes are taken into account in projections of residual emissions and/or the notion of economic efficiency.

**It is not scientifically possible to unequivocally draw a precise and full distinction between abatable and hard-to-abate emissions**. Any such distinction would be contentious and open to dispute, not least due to the large number of possible criteria and the dynamic development over time of technologies, behavioural patterns and economic structures. However, some form of prioritisation and qualitative classification of hard-to-abate emissions is necessary at a policy level, if for no other reason than to enable the effective establishment and planning of carbon management (funding) instruments, frameworks and infrastructure. A qualitative classification is even more important for the necessary public acceptance of carbon management, particularly in view of the serious concerns in some quarters in Germany. In order to support public acceptance, it is vital that policy decisions should be transparent and consistent with each other. At present, neither of the "key points" documents address this adequately.

The less restrictive approach to the deployment of CCS in the CMS key points is at odds with the debate in Germany, which until now favoured a much narrower definition of hard-to-abate emissions. However, it is **in line with the European scenarios and European policy approach**. And while the European Commission states that industrial carbon management is particularly important for technically hard-to-abate process emissions, it clearly doesn't regard the definition of allowable applications or sectors as a priority. Instead, it calls for the creation of economically viable value chains and financial incentives to invest in the relevant technologies and infrastructure, in order to create a competitive market for carbon and carbon capture that forms an integral part of the EU's economic system after 2040. In the Impact Assessment scenarios, the role

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[46] In economic terms, the appropriate benchmark would be the macroeconomic cost of CCS, CCU or CDR. However, this is based on a more general, systemic definition of costs that does not usually tally with the private costs that companies use as a basis for choosing between $CO_2$ emission avoidance and CCS, CCU or CDR. Moreover, the long timescales involved mean that the risks associated with emission avoidance and carbon management are not always properly quantified.

[47] See BMWK 2024-1, p. 3.

[48] There is even less clarity regarding the deployment of CCS in gas-fired power plants ("power generation facilities using gaseous fuels"). The only justification provided for this is that it is in the interests of technology neutrality, ibid., p. 3.

[49] See BMWK 2024-2, pp. 12 and 16.

of "industrial carbon management" (CCS, CCU and CCS-based CDR) supplementing land-based CDR also goes beyond addressing solely for hard-to-abate process emissions.[50]

## Targeting the deployment of CCS and CCU through the selection of government funding priorities is a pragmatic approach that is compatible with the EU level.

The **CMS key points make it clear that the regulatory restrictions on the deployment of CCS and CCU should not be too tight**. The only explicit ban, implemented through the Carbon Dioxide Storage Act (KSpG), should be on its use in coal-fired power plants.[51] In order to concentrate on hard-to-abate emissions, however, **the intention is to target the deployment of CCS and CCU** by only directing the planned **government funding instruments** (primarily carbon contracts for difference) at applications considered to be particularly relevant by the Federal Government. This is a pragmatic approach that is compatible with the EU level.

The difficulty in drawing a clear distinction between abatable and hard-to-abate emissions means that providing an exhaustive, explicit regulatory definition of permitted CCS and CCU applications would be both challenging and liable to error. Furthermore, it would be hard to continuously update the definition to reflect the latest technological advances. **The chosen approach also ensures that Germany's national regulatory framework remains compatible with the EU level.**[52] The most recent revision of the European Emissions Trading System (EU ETS) fully included CCS in the system, while CCU was included in principle. Emissions avoided through the deployment of CCS are exempt from surrendering allowances. In the case of CCU, the exemption only applies if the captured $CO_2$ is permanently chemically bound in a product. However, the European Commission has yet to provide a precise definition of what it means by "permanently bound". There are thus already considerable financial incentives for CCS in particular.[53] But the avoidance of the production of $CO_2$ emissions is not prioritised through the EU ETS in itself.[54] As in other energy and climate policy areas, the German government can set its own national priorities. However, it should ensure their compatibility with the European level and consider whether potential distortions and competitive disadvantages could arise in relation to other European countries, ultimately resulting in unwanted offshoring if Germany were to adopt a much more restrictive regulatory approach to the deployment of CCS. The German government accounts for that by just supplementing the EU ETS price signals and financial incentives with targeted funding.

**In reality, this approach can also result in a much more targeted deployment of CCS and CCU in Germany** than might initially be expected based on the rather vague description of these technologies' area of application in the key points. Since **CCS and CCU are not currently competitive in the majority of applications,**[55] **additional government funding should have an even stronger impact in terms of targeting their deployment**. Furthermore, there would currently seem to be little danger of the inclusion of CCS and CCU in the EU ETS significantly undermining the incentives necessary for measures avoiding the production of $CO_2$-

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[50] This is also driven by the fact that all the scenarios in the Impact Assessment assume rather unambitious emission reductions in the agricultural sector (see "concept of emissions without additional mitigation in the agricultural sector", European Commission 2024-3 Part 3/5, Appendix 8, p. 110). In conjunction with the strengthening of circular economy practices, a transition to more sustainable lifestyles, and especially changes in dietary habits, could significantly reduce the need for "industrial carbon management" in the EU, see European Commission 2024-3 Part 1/5, p. 40). This is consistent with scenario analyses for Germany, see Merfort et al. 2023.

[51] This is implemented through the provision in the draft KSpG bill stipulating that it is unlawful to transport $CO_2$ from coal-fired power plants.

[52] The European Scientific Advisory Board on Climate Change, however, also recommends better targeted deployment of CCS and CCU at EU level, see ESABCC 2024, p. 50.

[53] Ibid., p. 73.

[54] This is in line with the EU Industrial Carbon Management Strategy, in which the Commission states its aim of developing a sustainable single market for captured $CO_2$ in the EU by no later than 2040 by focusing strongly on creating the right market conditions and on price signal-based coordination.

[55] See Hepburn et al. 2019, Kearns et al. 2021 or IEA 2021 for details of the mitigation costs of CCS and CCU for different applications. At present, the main danger of mitigation incentives being undermined would occur if land-based CDR were allowed as a complete substitute for emission mitigation. This is not envisaged in the CMS and is also not currently being discussed at EU level, not least due to the major, as yet unresolved problems with reliable recording and monitoring.

emissions, since **large-scale deployment of CCS is unlikely to occur in sectors where it is not supported by funding**. The detailed priorities for funding should only be established for the definitive version of the CMS. At present, the only really clear policy relates to gas-fired power plants, where CCS will be allowed but will not be supported by government funding. It seems unlikely that this will have more than a very minor effect on the deployment of CCS in gas-fired power plants. However, it is important to consider the effect that explicitly including gas-fired power plants in the CMS could have on public acceptance of CCS and especially the views of environmental organisations, which have hitherto strongly opposed the deployment of CCS in power plants.

In the medium term, limited budgetary resources will force the Federal Government to scale back the use of funding instruments. Moreover, although the deployment of government funding instruments to supplement the incentives provided through the EU ETS is currently fully justified and worthwhile, reasons such as promoting the development of the technology and the market will only remain valid for a limited time. Furthermore, targeting the deployment of CCS and CCU is not in itself a reason for providing government funding – it is only an ancillary effect. **However, it is far from clear whether, in the absence of targeted funding, additional regulatory prioritisation of certain CCS and CCU applications will be necessary at all in the medium term to ensure that the avoidance of $CO_2$-production is prioritised.** In conjunction with government funding, $CO_2$ infrastructure planning and expansion over the coming years will create specific path dependencies for the deployment of CCS and CCU in certain areas of application. These could mitigate the danger of CCS (and CCU) suppressing alternative future carbon emission abatement technologies. The rate at which renewables and hydrogen infrastructure are expanded will also be key. If rapid progress is made with these requirements for alternative climate-friendly production methods and technologies, it should make the use of CCS for technically avoidable emissions far less attractive in the first place. Accordingly, the regulatory approach outlined in the CMS key points should be seen as an interim step that allows initial investment decisions to be made and the necessary structures to be built now, also buying time to progress the development of a consistent European framework.

### CDR needs a regulatory and financial framework, but should be integrated into the EU ETS only with a thorough assessment and careful preparations.

The **LNe key points** outline proposals for separate, additional **CDR expansion targets** for 2035, 2040 and 2045 in Germany, as already envisaged by the planned amendment to Germany's Federal Climate Change Act. Moreover, a **new German climate target for 2060** is to be set, specifying the exact volume of **net-negative GHG emissions** to be achieved by this date. The key points also point out that it will be necessary to establish appropriate economic incentives and regulations for the expansion of CDR that create a "consistent, ambitious and reliable framework"[56] for both CDR and the avoidance of GHG emissions production. However, they do not describe any detailed, concrete regulatory measures. Instead, they set out a significant, wide-ranging agenda for developing a framework that can help to achieve an "economically efficient level of negative emissions".[57] It is true that they do not further explicate the notion of "economic efficiency" here and how it relates to the principle that reducing GHG emissions is still supposed to be the top priority. Nevertheless, it is a positive fact that CDR is not to be prematurely included in the EU ETS before a number of fundamental questions that step raises have been answered. The promise that the ongoing LNe

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[56] See BMWK 2024-2, p. 12.

[57] See BMWK 2024-2, p. 15.

drafting process will closely incorporate developments at European level is also both welcome and important, since **the European Commission has already announced in its proposal for a 2040 climate target and its Industrial Carbon Management Strategy to take key decisions relating to the framework for CDR**.[58]

German and European climate policy has hitherto focused on nature-based and primarily land-based carbon removal such as (re)afforestation and soil carbon sequestration through changes in agricultural management practices. Unlike CCS-based CDR, natural carbon sinks are already separately, albeit not fully,[59] included in the European climate governance architecture within the LULUCF pillar. **However, a regulatory system to offer more targeted compensation for CDR's climate benefits is missing so far**. Current government financial incentives for CDR in Germany and the rest of the EU are largely confined to technology funding through the Innovation Fund and public funding for individual land-based CDR initiatives such as afforestation projects. Other than this, the voluntary – i.e. non-state-regulated – carbon market also provides some financial incentives for CDR. However, the future development of this market is uncertain. Moreover, although it can help to initiate the scaling of CDR required to meet climate policy goals, it cannot enforce fulfilment of the climate targets.[60] **Determining a (macro)economically efficient level of CDR is a fundamentally complex challenge**. It involves thinking on long timescales, assessing the different risks of CDR and GHG reduction measures, and establishing the appropriate domestic contributions to global net carbon removal.[61] Furthermore, it has yet to be conclusively shown that the inclusion of CDR in the EU ETS will in fact enable the efficient expansion of CDR.

The **inclusion of CDR in the EU ETS** would require the recognition of new "CDR allowances" as an alternative to the traditional EU ETS emission allowances,[62] and therefore **a reliable monitoring and verification of carbon removals as well as their precise attribution to the relevant CDR operator**. The feasibility of this is currently very limited (without causing unreasonable expenses), especially for land-based biological CDR methods, but also for CCU and in the agricultural and LULUCF sectors in general.[63] Emitters in the EU ETS would need to purchase either CDR or emission allowances which would directly finance or help to finance CDR capacity. As a result, the EU ETS emissions cap would change from an absolute emissions cap to an upper limit for allowable net emissions. Offsetting emissions in this way could result in negative emissions undermining emission avoidance efforts if they are competitive enough. At present, however, this only really is the case for land-based biological methods such as afforestation, where the monitoring problems alone make a strong case against inclusion in the EU ETS.[64] The main problem with offsetting emissions like this occurs if the participants in the emissions trading system are not properly held liable for the costs arising if the $CO_2$ they are credited with having removed from the atmosphere is released again at some point in the future. Broadly speaking, the inclusion of CDR in the EU ETS will thus only create macroeconomically efficient and consistent incentives if **carbon pricing is complemented by regulations that effectively address the risks of CDR. In particular, these regulations must ensure that society is not left with the full**

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[58] See Directive 2003/87/EC (EU ETS Directive) Art. 30 (5)(a), which calls on the European Commission to submit to the Parliament and the Council a report and proposals on these matters and possible regulatory options by no later than 31.07.2026. Concrete targets for CDR at European level currently only exist for the LULUCF sector. The LULUCF Regulation (EU) 2018/841 sets an EU-level net removals target of 310 million tonnes $CO_2$-equivalent a year by 2030 for the Union's natural sinks, along with national targets for each member state.

[59] However, the LULUCF Regulation does not currently cover CDR methods such as biochar or enhanced weathering, see Fridahl et al. 2023.

[60] See Borgmann et al. 2023 and Edenhofer et al. 2024.

[61] See Edenhofer et al. 2024.

[62] See Rickels et al. 2021.

[63] See Fuss et al. 2022.

[64] If these land-based biological CDR methods are to be further strengthened as planned, they too will need more effective financial incentives. Funding instruments for specific measures, e.g. government funding for specific agricultural management practices, based on average (rather than individual) empirical carbon capture data, could also be used, for example under the Common Agricultural Policy. Applying at least implicit uniform carbon prices could then improve funding efficiency. The planned (voluntary) European CDR certification system (which includes carbon farming) could provide the basis for creating uniform, standard assessment criteria. See the provisional compromise text for a Regulation establishing a voluntary certification framework for carbon removals and carbon farming of 8 March 2024: https://data.consilium.europa.eu/doc/document/ST-7514-2024-INIT/en/pdf .

**burden of dealing with $CO_2$ released back into the atmosphere in the future**. But this in turn largely relies on the availability of effective monitoring solutions.[65]

**The regulatory options are thus largely dependent on the available monitoring solutions and the amount of effort involved**. However, these could change over time, for instance due to advances in remote sensing of land-based carbon sinks. If reliable monitoring proves to be impossible or a liability regulation cannot be credibly enforced, a more sensible regulatory approach will be to clearer separate between the incentives for CDR and GHG reduction and refrain from the inclusion of CDR in the EU ETS. In any case, it will be vital to make sure that the credibility of an established climate instrument like the EU ETS is not jeopardised by the hasty incorporation of CDR. It may also make sense to at least temporarily include only those CDR methods where there is a prospect of resolving the monitoring and liability issues.[66] Targeted research and development of appropriate monitoring methods could then be ramped up in parallel.[67]

The LNe key points quite rightly touch upon two other mainly long-term challenges that are key to determining whether CDR should be included in the EU ETS. The first is that **the EU ETS currently only creates limited financial incentives for CDR**. Emitters required to hand in allowances only purchase CDR allowances as long as they need to offset (residual) emissions in order to meet the EU ETS net emissions target. However, there is no demand in the EU ETS for the additional carbon removals needed to achieve net-negative GHG emissions. This will remain the case unless additional allowance requirements are established for the remaining emitters (even if the EU ETS establishes a negative emissions target) or unless there is demand from public institutions.[68] The second issue is that **the number of tradable allowances and emitters will decline when approaching net zero emissions, and this will pose challenges for the emissions trading system**.[69] An increasingly thin emission allowance market might be expected to give rise to pronounced price fluctuations which could jeopardise the EU ETS' role as lead instrument and main pillar of the post-2040 climate governance architecture. In view of the above, it may be preferable not to include CDR in the EU ETS, not least in order to limit the regulatory uncertainty caused by multiple changes in the framework. On the other hand, its inclusion could help to stabilise and develop emissions trading as a governance system in a net-zero economy.[70]

A **separate CDR funding system**, on the other hand, could either set a price for carbon removals or establish a quantitative removals target, with CDR providers competing for government funding in an auction system. The provision of separate incentives would ensure that avoidance efforts in the EU ETS were not undermined. Moreover, the impacts of any potential monitoring problems would mostly be confined to the CDR sector. Separate incentives could also directly help to deliver the promised national CDR targets. This could not be expected of the EU ETS on its own due to CDR's limited competitiveness.[71] One challenge would be to set the CDR price or quantitative target at the "right" level to ensure that the overarching climate targets were actually achieved and that this was done as efficiently as possible. Another challenge would be how to draw appropriate boundaries between the EU ETS and the separate CDR funding system with regard to

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[65] For some risks, the question of adequate instruments controlling them arises not just for incentives for CDR or CCU, but also for abatement incentives, for example in connection with the high demand for land/biomass that is critical from a sustainability perspective (e.g. sustainability certifications, pricing of emissions induced by land-use change).

[66] At least in the case of geological carbon storage and the CDR methods based on it, the CCS Directive (in conjunction with the EU ETS) already provides a detailed regulatory framework for liability questions.

[67] See Fuss et al. 2022.

[68] See e.g. Edenhofer et al. 2024, who propose a carbon central bank that could perform this role. This (limited) government funding for CDR would certainly be justified, as it would enable a genuine positive (net) contribution to climate action as a public good. An alternative approach would be to introduce an offsetting scale for converting emission allowances into CDR allowances. For instance, one tonne of residual $CO_2$ emissions could only be offset by two tonnes of $CO_2$ removals (or similar).

[69] See Pahle et al. 2023 and ESABCC 2024, p. 216ff.

[70] In this context, it is also necessary to consider whether the EU ETS could be stabilised with the aid of new institutions like a central bank that would be tasked with managing the emissions cap but could also support the (gradual) incorporation of CDR, see also Edenhofer et al. 2024.

[71] In the event of inclusion in the EU ETS, on the other hand, separate CDR targets would have a more indicative function.

CCU.[72] As well as overlapping with CDR in terms of its technical aspects, CCU with atmospheric carbon removal could be classified either as emission avoidance under the EU ETS or as negative emissions under the CDR funding system, depending on how long the carbon is captured for.

### The economic incentives for CCU must clearly differentiate with respect to its climate benefits.

The aim of a consistent incentive system for CCU should be to support a transition from fossil to non-fossil carbon sources and to establish closed product carbon cycles. CCU overlaps with CCS and CDR in terms of its technical aspects and to some extent also its function. Consequently, an appropriate framework should be **closely aligned with the frameworks for CCS and CDR and should furthermore differentiate the respective climate benefits of CCU**.

One of the main challenges is the **difficulty in tracking captured $CO_2$ across multiple CCU process chains, from its source up to individual CCU products' end-of-life and potential subsequent recycling stages**. Consequently, the EU ETS, which has incorporated CCU in principle, plans to distinguish between carbon-based products where the $CO_2$ is permanently and non-permanently bound. Firms in the EU ETS do no longer have to submit allowances for $CO_2$ that is captured and utilised only if the $CO_2$ is "permanently chemically" bound in a product. This approach is consistent from a climate policy perspective, since it only treats CCU as equivalent to emission avoidance and CCS if it actually keeps $CO_2$ out of the atmosphere on a long-term basis. However, it does not in itself create a complete, consistent incentive system that provides sufficiently strong, differentiated incentives for CCU.[73]

**The transition from fossil to non-fossil carbon sources currently is hindered by a structural incentive problem** that is not solved by distinguishing between products where the carbon is permanently and non-permanently bound. The use of fossil resources as feedstock in sectors such as the chemical industry is generally exempt from carbon pricing on the grounds of international competitiveness. Consequently, CCU processes that produce goods which permanently bind fossil $CO_2$ are currently treated no differently to conventional production processes in the EU ETS. Meanwhile, as long as it is still necessary to submit allowances for $CO_2$ non-permanently bound in CCU products, the EU ETS actually treats these products and production routes less favourably than products made by conventional methods using fossil resources as feedstock.[74] Furthermore, it is to be questioned whether it is actually possible to accurately determine in advance how long the carbon will be captured for in every conceivable CCU product and process chain, and whether it is possible to meaningfully include (mechanical or chemical) recycling that extends the length of time the carbon is captured for in a product.

In view of the above, **more fundamental regulatory and/or pricing measures for CCU** should be investigated, at least **for the period post-2030**. These should address both the difficulty in tracking $CO_2$ across multiple CCU process chains and the more structural incentive problem associated with the necessary tran-

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[72] See ESABCC 2024 (p. 206).

[73] The European Commission itself recognises the need to develop further measures in its Industrial Carbon Management Strategy, see European Commission 2024-2, p. 17.

[74] Synthetic fuels/"renewable fuels of non-biological origin" (RFNBOs) are already classified as a short-lived carbon-based product that does not bind carbon permanently. The plants that make these fuels must still surrender allowances for the $CO_2$ used to produce them. In other words, the $CO_2$ is still priced at source. However, for a transition period ending no later than 2040, synthetic fuels made with $CO_2$ from fossil sources can be counted towards the renewable energy use targets in the Renewable Energy Directive EU 2018/2001. This provides some support for the use of these fuels.

sition from fossil to non-fossil carbon sources. The Industrial Carbon Management Strategy raises the prospect of this happening by 2026, as part of the review of further reforms and additions to the EU ETS. There are two possible approaches that are also briefly touched upon in the EU strategy:[75]

1. One option is to apply carbon pricing to all $CO_2$ emissions regardless of the carbon source, while at the same time remunerating all atmospheric carbon removals regardless of how long the $CO_2$ is captured and bound. This **"closed downstream pricing system"** for $CO_2$ emissions and removals would have to apply equally to CCU and CDR. This approach would remove the need for complex certification of the duration the carbon is bound or stored. Remunerating atmospheric carbon removals would ensure that CCU production processes using non-fossil carbon were treated more favourably than the use of fossil carbon/resources.
2. The second option is to shift emission pricing to the point where fossil resources enter the market, an approach currently taken by the German Fuel Emissions Trading Act (BEHG). This **upstream approach** involves direct pricing of newly extracted fossil carbon/resources, regardless of what they are used for and how long the carbon may be bound in a product. Under this approach, there is no pricing of actual emissions. However, it is harder to coordinate this with the remuneration of carbon removals, which would need to differentiate between CDR and CCU in cases where the carbon was only bound/stored on a shorter-term basis. Certification would be necessary in these instances.

The approaches outlined here **are intended as suggestions for the further development of the current pricing systems**. They will need to be carefully examined, for example with regard to their competitive implications, potential leakage effects and especially their compatibility with future CDR incentives. **In particular, they will need to be more precisely aligned with the planned inclusion of municipal waste incineration emissions in the EU ETS**, which the Commission has been tasked with studying as part of the review of the potential expansion of the EU ETS due to be completed by 31 July 2026.[76] This could indirectly result in emission pricing for the use of fossil resources as feedstock. Nevertheless, it can only help to solve the more structural incentive problem associated with the necessary transition from fossil to non-fossil carbon sources if the municipal waste incineration rules distinguish between fossil carbon and biogenic carbon or carbon captured from the atmosphere by other means. However, as long as the EU ETS requires allowances to be submitted for $CO_2$ that is captured and utilised but not permanently bound in a product, fossil $CO_2$ would be subject to double carbon pricing.[77] In Germany, municipal waste incineration has been included in the Fuel Emissions Trading Act (BEHG) emission pricing system since 01.01.2024.

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[75] See European Commission 2024-2, p. 17. More specifically, as part of the review of the feasibility of appropriately including technological CDR in the EU ETS, the Commission is also tasked with studying options for creating financial incentives for CCU, and especially non-permanent CCU.

[76] See Art. 30 Directive 2003/87/EC.

[77] In its Industrial Carbon Management Strategy, the European Commission itself raises the question whether the downstream emission pricing due to the inclusion of municipal waste incineration in the EU ETS could create incentives for non-permanent CCU, see European Commission 2024-2, p. 17.

### More specific government funding instruments for CDR, CCS and CCU are worthwhile, particularly in the early stages of development and market ramp-up for new technologies and methods.

Many carbon management technologies and methods are in the early stages of development and also (still) unable to compete with measures avoiding the production of GHGs. This is especially true of direct carbon capture from the atmosphere for CCU or CDR (DACCS). The **LNe key points** highlight the **significant amount of further research and development** still needed and announce a new, large-scale **research agenda into CDR** for the LNe. They do not go into any specifics regarding government funding instruments for CDR. The **CMS key points envisage the use of government funding instruments – in the form of carbon contracts for difference to be precise – for CCS and CCU in addition to the financial incentives from the EU ETS**. They provide only brief justification for these instruments, stating that the financial incentives from the EU ETS are insufficient in the short to medium term to kick start the necessary investment and market ramp-up for CCS/CCU technologies.

From a scientific point of view, the simple fact that carbon allowance prices are “too low” is not sufficient reason to justify additional government funding on a long-term basis. Additional funding at first only makes sense if the technologies receiving funding have the potential to establish themselves as a competitive option within the regulatory framework of their own accord at some point. Until such time, government funding can help to limit any risks and uncertainties (e.g. with regard to the evolution of carbon allowance prices and framework conditions for climate policy as a whole).

Apart from this, government funding for the application of new technologies – and not just research and development – can also be worthwhile for gaining valuable experience for the technologies’ continued advancement and refinement faster and across a broader basis. Such learning effects can help to unlock substantial potential cost savings in some cases. As is the case with successful technological developments in general, however, these learning effect do not just benefit the stakeholder or company who is willing to bear the cost and take the risks in the first place. Without government funding, there is therefore a considerable risk that private companies will cease to drive technological advances. Government funding instruments can provide a targeted means of countering this, while also strengthening the portfolio idea by ensuring less established technologies and methods that are not yet competitive are also brought into play. The CMS key points do not refer to these motives for technology funding, which, however, do not justify long-term use of government funding instruments either.

As for the form of funding, the key points envisage the use of **carbon contracts for difference** that can protect against price risks and compensate for the extra cost of climate-friendly technologies compared to conventional methods. Another advantage of this funding approach is that it can be closely coordinated with the existing investment incentives of the EU ETS. By comparison, **green lead markets** can, however, provide a more market-oriented funding approach, at least for technologies at a more advanced stage of development.[78] To be specific, lead markets would be worth considering for CCU products manufactured with non-fossil $CO_2$.

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[78] See Scientific Advisory Board at the German Ministry for Economic Affairs and Climate Action 2022.

### Not ruling out CCS at gas-fired power plants from the outset keeps options open, but it would have to be fully weighed against the energy sector relevance and the public response.

The CMS key points permit the use of **CCS at gas-fired power plants,**[79] even if fossil natural gas is used there. Although this means they coincide with the European Commission's industrial carbon management strategy on this point,[80] permitting such use runs counter to the principle of only deploying CCS for hard-to-abate emissions as set out elsewhere by the CMS key points. The German climate neutrality scenarios (including the long-term scenarios commissioned by the BMWK) rule out the use of CCS in the energy/electricity sector and illustrate that a secure energy supply can be achieved in future even without the use of fossil-fuel power plants with CCS (and CCU). The key points thereby clearly deviate from the stance to date in the public debate surrounding CCS and CCU in Germany. At the same time, they neither provide a transparent assessment of the energy sector's need for this step, nor do they carefully evaluate the risks of a technology lock-in that could result from the deployment of CCS at gas-fired power plants. They therefore run a particular risk of jeopardising public support for CCS and carbon management as a whole. The cautious acceptance of the use of CCS by some environmental associations, for instance, comes with the clear condition that it is limited to hard-to-abate/unavoidable emissions not including applications at power plants.[81]

**A systematic comparison between gas-fired power plants using CCS and the possible use of blue hydrogen in hydrogen-fired power plants would be essential for assessing the energy economic relevance of the decision**. Both pathways can facilitate the energy system's transformation (for a transitional period). In particular, they can play a fundamental role in helping to mitigate foreseeable bottlenecks in the supply of green hydrogen during the initial transition to a hydrogen economy. The German hydrogen strategy also already anticipates the use of blue hydrogen for this same reason.[82] In both cases, fossil natural gas continues to be used for energy supply and $CO_2$ is still captured and placed in geological storage. The only difference with blue hydrogen is that the carbon is captured at a different point of the process chain and this may take place abroad.

So far, the CMS key points published do not address the questions of whether blue hydrogen is considered to be an alternative to natural-gas power plants with CCS and whether it is to be produced on a larger scale in Germany or mainly imported. These gaps should be filled in by the final version of the CMS, while dovetailing neatly with further developments of the National Hydrogen Strategy and the Hydrogen Import Strategy that is still being elaborated. Pending issues thereby are to what extent blue hydrogen can be deployed, for how long and where, and what contribution the potential domestic production of blue hydrogen is meant to make.

A systematic comparison of these alternatives would require more in-depth analyses, which should look at the following aspects in greater detail, among other things:

**Technical requirements and security of supply:** Neither natural-gas power plants with CCS nor the production of blue hydrogen for electricity generation in hydrogen or $H_2$-ready power plants are established technologies. There are technological uncertainties with both concepts due to the shortage of operational experience. For not too heavily relying on a single, not fully proven technology, it might be wise to keep both options open and keep developing the two technologies. It would also be necessary to check, however, to

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[79] See BMWK 2024-1, p. 3.

[80] All scenarios of the associated impact assessment for the 2040 climate target envisage the use of CCS in the electricity sector without excluding even coal-fired power plants from the deployment of CCS/CCU, see European Commission 2024-3 Part 1/5, table 6.

[81] See Germanwatch 2024.

[82] See BMWK 2023, p. 4: following the 2023 update to the National Hydrogen Strategy, the use of blue hydrogen should even be eligible for funding at the application level.

what extent the business model and the mode of operation of CCS gas-fired power plants are compatible with the increasingly widespread deployment of intermittent renewable energies. Adding the CCS component can be anticipated to reduce the plants' flexibility and load dynamics.[83]

**Energy efficiency of the entire electricity generation route**: Since the start of Russia's war of aggression on Ukraine, the goal of becoming less dependent on natural gas has gained new importance. The energy efficiency (kilowatt hours of electricity produced per kilowatt hour of natural gas used) of natural-gas power plants with CCS should therefore be compared with the energy efficiency of the entire route from natural gas to blue hydrogen to conversion into electricity at the hydrogen plant. This efficiency has an impact on many other key parameters, including greenhouse gas emissions, upstream emissions and costs.

**Cost structures and operating modes of power plants:** The expensive fuel and a cost structure mainly dominated by variable costs as a result mean that hydrogen or $H_2$-ready power plants are operated as peaking and pure back-up power plants. They basically respond flexibly to the variable electricity generation from renewable energies and are presumably only in operation for a small number of hours overall. Gas-fired power plants with CCS, on the other hand, have a different cost structure. The CCS component increases the capital and fixed costs of gas-fired power plants.[84] Natural gas – the starting substance for manufacturing blue hydrogen – is the lower-priced fuel, too. Given high fixed costs and lower variable costs, there is little incentive to operate gas-fired power plants with CCS as pure peaking power plants. Cost-effective operation is presumably only possible at higher rates of capacity utilisation.[85] Consequently, (direct) consumption of natural gas in the power system can increase in comparison to the alternative path of hydrogen power plants. It is not clear, however, whether this would increase the German economy's overall dependence on natural gas. This depends on substitution effects in the industry, for instance. Any effects on the dynamics of renewables expansion would also have to be analysed more profoundly.

**Development of infrastructure:** Both a hydrogen and a carbon transport network have to be established anyway. The two alternatives therefore mainly differ in the details of which plants are connected to which network and when. Here, development of a suitable hydrogen supply network for $H_2$-ready power plants must be weighed up against development of a $CO_2$ transport network and the costs of connecting gas-fired power plants to it. Consideration must also be given to whether natural gas distribution networks and, in particular, long-distance pipelines can be operated cost-effectively in the medium to long term as the consumption of gas for heating declines. With regard to $CO_2$ infrastructure costs, studies have indicated there could be certain synergies to benefit from if CCS is deployed in both the industrial and the energy sector, as better use could then be made of $CO_2$ pipelines.[86] Such synergies could be created, for instance, if, besides avoiding process emissions from the chemical industry through CCS, heat-driven co-generation plants in the same location are also connected to the $CO_2$ transport network at the same time. Similar synergy effects are also obtained, however, by using hydrogen transport networks for both industry and power plants. Another aspect to bear in mind for supply structures is that natural gas (LNG) can be procured more flexibly and easily, even from more distance sources, than (blue) hydrogen if the latter is not produced in Germany.[87]

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[83] See Domenichini et al. 2013.

[84] Capital costs can be expected to roughly double in the case of conventional gas-fired power plants, see IPCC 2022, chapter 6.4.2.5.

[85] Among other things, the ESYS working group "Base-load Power Plants in a Decarbonized European Energy System" models scenarios in which gas-fired power plants with CCS are available and analyses how the plants are operated. Plants for producing blue hydrogen are also expensive/capital-intensive to run, meaning utilisation of their capacity must be sufficiently high for cost-effective operation. As hydrogen is much more suitable for storage than electricity and the demand for hydrogen derives not just from the power system but from industry too, this wouldn't have any immediate implications for the power system.

[86] See Turgut et al. 2021 or Holz et al. 2021.

[87] As a result of its response to Russia's war of aggression on Ukraine, Germany now has well-developed LNG import structures. It is planned to repurpose these too for the import of climate-neutral hydrogen (or derivatives). In accordance with section 5 para. 2 of the LNG Acceleration Act, they may be used for LNG until 2043 at the latest.

**System costs:** Consideration would have to be given to the question of whether allowing CCS at gas-fired power plants can reduce the costs of the energy supply system and the overall sector-wide transformation towards climate neutrality when compared to a transformation path building solely on hydrogen power plants and the use of blue hydrogen in the energy sector. One factor that can play a role here is that existing gas-fired power plants can be retrofitted with CCS technology instead of having to build new hydrogen power plants. The differences in infrastructure costs could also be significant. Looking beyond the energy sector, the fact that CCS gas-fired power plants are able to mitigate the shortage of hydrogen and therefore increase its availability for industry could lead to further effects on the macroeconomic cost of climate action.[88] The familiar climate neutrality studies referred to above do not offer any insight into (system) costs, as they do not envisage the use of CCS in the energy sector – in keeping with the social and political stance to date – nor do they undertake a clear comparison of these different development routes. In other scenario analyses, however, as well as in all scenarios of the impact assessment for the 2040 EU climate target,[89] CCS is deployed in the energy sector at gas-fired (or even coal-fired) power plants. With regards to Germany, the analyses of Shu et al. 2023 demonstrate that increased availability of CCS helps to reduce the costs of climate policy transition across all sectors without, however, allowing any clear conclusions to be drawn regarding the importance of CCS deployment in the electricity sector.[90] As for the European energy sector, Holz et al. 2021 explicitly identify (albeit insubstantial) cost-cutting effects of the use of CCS.[91] Analyses of the impact of Russia's war of aggression and the significant restrictions on supplies of natural gas from Russia indicate that, for the European energy system, the significance of CCS for the energy sector will tend to increase for a transitional period in the coming years, provided at least that CCS can also be deployed for coal-fired power plants.[92] When comparing CCS gas-fired power plants and hydrogen power plants using blue hydrogen, it is important to note that the cost effectiveness of both alternatives is directly contingent on the evolution of natural gas prices. Increases in prices for natural gas (LNG) would strengthen the competitiveness of green hydrogen in particular, which a system comprising hydrogen power plants allows better to use economically.

**Greenhouse gas emissions and impact of the EU ETS:** CCS gas-fired power plants fall under the scope of the EU ETS. Both the economic incentives for operating them and their operating times are therefore limited by the carbon price in the EU ETS that is incurred for the portion of the produced $CO_2$ emissions that cannot be avoided with CCS.[93] The manufacture of blue hydrogen in the EU is also regulated by the EU ETS though (while the import of hydrogen and the related emissions are subject to the Carbon Border Adjustment Mechanism[94]). In this respect, high or rising allowance prices affect the cost effectiveness of both alternatives. In which of the two cases rising carbon prices in the EU ETS could perhaps lead to a greater reduction in the operating times of power plants therefore depends not least on the capture rates that can be achieved at gas-fired power plants compared to hydrogen production. In any case, rising carbon prices clearly make green hydrogen in particular a more competitive option.[95]

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[88] This could help lead to CCS being deployed less in industrial applications. One potential benefit of this is that CCS would only achieve lower carbon capture rates in the steel industry, for instance, when compared to power plants (see Durakovic et al. 2024). However, emissions from power plants and from steelworks are both recorded in the EU ETS, meaning that lower capture rates in the industrial sector would not directly result in higher total emissions. Instead, they would just lead to an increase in allowance prices in the ETS at first.

[89] See European Commission 2024-3 Part 1/5, table 6; capture at fossil point sources: 26-41 Mt/year of CO2 in 2040.

[90] See Shu et al. 2023.

[91] In this analysis though, CCS is also approved for use in coal-fired power plants.

[92] See Durakovic et al. 2024, who demonstrate, for instance, that the restrictions on Russian gas supplies lead to differences, particularly in the medium term, i.e. in the transitional phase to climate neutrality. As a result, the quantity of $CO_2$ that is captured and stored increases sooner, thereby forcing the expansion of CCS. In the long term, on the other hand, there are no significant differences with respect to the annual quantity of captured $CO_2$ and the carbon infrastructure that is required.

[93] See Holz et al. 2021, p. 11.

[94] See Regulation (EU) 2023/956.

[95] See George et al. 2022, who reach the conclusion, however, that extremely high carbon prices would be needed to trigger a switch from blue to green hydrogen.

**Upstream emissions:** The environmental impact (and the competitiveness of green hydrogen) does not only derive from the direct carbon emissions resulting from the utilisation of the fuel, but also upstream emissions. As already discussed, the $CO_2$ emissions generated by the production of blue hydrogen either domestically or abroad are regulated by the EU ETS or the CBAM. The fact the German government would like to advocate stricter recording and pricing of the upstream emissions and particularly the methane emissions in the natural gas supply chain[96] is to be welcomed.[97] These upstream emissions occur with both natural gas and blue hydrogen, however, meaning the question about which alternative produces lower upstream emissions must basically depend on the specific source of supply for the fuel.

**Path dependencies:** The high amounts of capital and investment required alone mean that gas-fired power plants in Germany are only retrofitted (or newly built) with a CCS component if sufficiently long operating times are to be expected. To counter the risk of path dependency, the German government wants approvals for CCS gas-fired power plants (and gas pipelines) to be granted in a legally compliant way that ensures they cannot continue to be operated with fossil fuels beyond 2045.[98] An operating period until 2045 seems rather short, at least for completely new power plants and any gas-fired power plants intended to be run on fossil natural gas only. The connections to the carbon transport infrastructure that are required and the need to design them accordingly for power plant sites are further reasons why such short-term and temporary use of this type of power plant is not to be expected. Production facilities for blue hydrogen also need to be in use for a certain amount of time, however, to ensure cost-efficient operation and likewise require their own connections to the carbon transport and storage infrastructures. In this case, however, the other stages along the energy system's value chain would already be prepared for a future hydrogen-based system, inasmuch as hydrogen-ready power plants are built and a hydrogen transport network can be established and used. With regard to the energy sector, this means the risk of path dependency can probably be deemed to be (a little) higher for CCS gas-fired power plants. The fact that existing gas-fired power plants can be retrofitted with CCS only mitigates this risk to a certain extent due to the amount of money that also needs to be invested in this case for the CCS component and connection to the carbon transport infrastructure alone. From a macroeconomic point of view, however, potential implications for other sectors also need to be taken into account. In light of the scarcity of hydrogen, for instance, CCS gas-fired power plants could facilitate the transformation of other sectors.

Overall, it does not appear possible **to clearly justify either implementing blanket regulatory exclusion of CCS at fossil gas-fired power plants or affirming its absolute benefit for the energy system in Germany** without first analysing the aforementioned points in detail. This is true at any rate when the use of blue hydrogen is considered as an alternative for comparison with CCS natural-gas power plants – something anticipated by many stakeholders due to the fact that the availability of green hydrogen is likely to be limited during at least the start-up phase of a hydrogen economy. If CCS gas-fired power plants are indeed to play a future role in the German energy system, further framework conditions would most probably have to be adapted too. There are very limited incentives for investing in these power plants at present. Not only is the timeframe for operation with fossil fuels meant to be limited to the period up until 2045 by law, the key points of the CMS also explicitly state that CCS at gas-fired power plants should not be eligible for separate government funding. The upcoming tender processes for safeguarding power plant capacity as part of the Power Plant Strategy are also meant to be limited to gas-fired power plants that switch to using hydrogen between 2035 and 2040.[99] In view of the further policy process and levels of public acceptance,

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[96] See BMWK 2024-1, p. 5.

[97] See ESABCC 2024, p. 51, which also advocates pricing of upstream emissions.

[98] See BMWK 2024-1, p. 5.

[99] See BMWK 2024-1, p. 3, and German government 2024. The key points do not, however, clearly rule out the possibility of CCS gas-fired power plants being incorporated into the future capacity mechanism that is due to be introduced as part of the Power Plant Strategy in 2028.

this raises the question to what extent it is worth once again jeopardising the increased public support for CCS and carbon management in general – which has been built up with so much effort – just to keep open the option of a technology that is unlikely to play a significant role in practice. There is a definite danger of losing the backing of significant stakeholders from the environmental movement, as the deployment of CCS in the power plant sector is taboo even for those environmental associations who support CCS. The debate surrounding it would heat up and resistance to it increase as a result, making delays in implementation likely.

However, there has not yet been a full public discourse to systematically compare the two alternative paths discussed here and highlight the advantages of keeping at least one of them open. Public acceptance of the use of blue hydrogen for generating electricity is, after all, also rather uncertain as things currently stand. This applies to both domestic and foreign production of hydrogen, for it is clear that importing blue hydrogen would simply shift the “CCS issue” abroad rather than resolving it.

### The legal and economic requirements for the development of carbon transport infrastructure should be met quickly.

The lack of clarity surrounding future availability of suitable transport and storage infrastructure has created a high degree of uncertainty for companies and possible CCS/CCU projects. With this in mind, it is to be welcomed that the CMS key points and, in particular, the proposed amendment to the KSpG already put forward specific measures **to remove the existing legal uncertainties and regulatory hurdles and so enable the development of (cross-border) infrastructure**. The changes to the legal framework are intended to enable joint European pipeline projects and – with ratification of an amendment to the London Protocol – allow carbon transport to storage sites in other EU countries. These proposals should be implemented as quickly as possible. Still pending are, in particular, more specific statements on the development of carbon transport infrastructure and details on the financing and regulation, which should be addressed in the final CMS.

The key points of the CMS do not yet provide any more precise details on the size and routing of the transport network. This is only expected in the final CMS. It makes sense that the transport infrastructure should **not only be designed for short-term transport requirements** and that projections of future transport requirements – taking into account CCS-based CDR – should be included in planning as far as possible. **The extent to which this is done systematically by separating CMS and LNe cannot yet be conclusively assessed.** Integrated network planning would also appear to make sense, i.e. incorporating carbon transport infrastructures into joint network development plans for electricity, natural gas and hydrogen. In this way, for example energy and hydrogen requirements of CCU projects can be included in planning at an early stage. Ultimately, the ability to connect with neighbouring European countries must be secured, e.g. with a view to future transport of carbon from Austria to storage sites in the North Sea.[100]

At the same time, **three projects for carbon transport networks in Germany are currently in the planning stage.**[101] The gas transmission grid operator Open Grid Europe is planning (with Tree Energy Solutions) to create a transport network of around 1,000 kilometres in length in western Germany (existing pipelines for natural gas transport cannot be used, as things stand), which will be capable of transporting more than 18 million tonnes of $CO_2$ annually.[102] For this “start-up network”, a market survey has been launched to better

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[100] See VDZ 2024, p. 10, which estimates that 15-20 million tonnes of $CO_2$ will be transported per year from 2035.
[101] See Federal Government 2022; VDZ 2024, p. 35ff.
[102] See Zukunft Gas e.V. (https://gas.info/carbon-management/co2-netz).

assess future transport requirements in a decentralised way, based on feedback from individual companies.[103] The "$CO_2$peline" project is aimed at connecting industrial and chemical centres in the border region of Bavaria and Austria and developing temporary carbon storage sites before this regional network is hooked up to the future transmission network.[104] A third project ("CapTrans$CO_2$") is currently being planned in central Germany.[105] The CMS is intended to develop a more overarching goal for transport infrastructure in the future, as this has so far been lacking.[106]

As with the hydrogen network, the carbon transport infrastructure presents a "chicken-and-egg" situation between infrastructure development and demand for carbon transport capacity by companies that only invest in new (capital-intensive) carbon capture plants themselves if they have planning certainty regarding connection to transport routes. This c**oordination problem cannot be solved by market mechanisms or the price signals from the EU ETS alone**, but requires a certain degree of state coordination.[107] It is therefore to be welcomed if the CMS provides further clarification on the future availability of the transport infrastructure and thus creates greater investment security for companies. Further details regarding the regulation of the infrastructure and non-discriminatory access to the transport networks still need to be worked out. In this respect, the key points only make it clear that the $CO_2$ pipelines are to be built and operated by private companies. **The extent to which the state will be involved in this remains open, but it is unlikely it can be avoided** if the pipelines are to be built today with sufficient capacity for future increases in transport requirements. This is because private infrastructure operators have little incentive to build such pipelines when capacity utilisation is initially low (and uncertain), or would have to demand very high usage fees from the early users of the transport capacity. As with the question of financing for the hydrogen infrastructure, **a suitable distribution of costs between early and later users of the transport infrastructure** must therefore also be found here, for which at least interim state financing may be necessary. The model of an amortisation account envisaged in the hydrogen sector could also be carried over for carbon transport infrastructure in order to limit the user fees for pipelines that are initially "too large" for early users and to provide interim financing by the state to make up for any shortfalls.[108]

In its strategy for industrial carbon management[109], the European Commission is announcing a future regulatory package for $CO_2$ transport. Work on a coordination mechanism for EU-wide infrastructure planning and the necessary cooperation between member states is also set to begin in 2024. Regulatory ambiguities, for example with regard to liability for leaks during (non-pipeline) carbon transportation, are to be resolved promptly and common minimum standards for the purity of carbon streams are to be defined to facilitate the cross-border transport of $CO_2$ and its utilisation. In view of the proposed EU climate target for 2040, a European carbon transport network involving various modes of transport (pipeline, ship, truck, train) could reach a length of around 7,000 kilometres by 2030 and grow to as much as 19,000 kilometres by 2050.[110]

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[103] See OGE (https://oge.net/de/co2/co2-netz).

[104] See bayernets (https://www.co2peline.com/).

[105] See Hypower Mitteldeutschland (https://hypower-mitteldeutschland.com/projekte/captransco2/).

[106] In its recent study on the future carbon transport network, the Verein der deutschen Zementwerke is predicting that this network will reach a length of 4,800 kilometres in Germany, and require investment of around EUR 14 billion (VDZ 2024, p. 37).

[107] See Wolf 2024, p. 26ff.. One possibility is the integrated development of projects that cover the entire value chain from capture and transport to utilisation/storage. However, this approach may conflict with a transport infrastructure that is open to as many different projects as possible. The extent to which the envisaged state subsidies will be aligned with infrastructure development remains unclear in the key points of the CMS.

[108] See Fraunhofer IEG et al. 2024 for the concept of the amortisation account in the financing of the hydrogen core network.

[109] See European Commission 2024-2, p. 8.

[110] See Joint Research Centre 2024. This would require substantial investment of EUR 6.5-12.2 billion by 2030 and EUR 9.3-23.1 billion by 2050.

## The CMS key points formulate a pragmatic approach for commencing geological carbon storage.

Offshore carbon storage within Germany's Exclusive Economic Zone (EEZ) – with the exception of existing marine protected areas – should be permitted, as should links to storage projects in other countries. To justify why German storage sites should also be developed, the CMS key points rightly refer, among other things, to the responsibility for $CO_2$ produced domestically. It would **not be technically justifiable to rule out offshore storage in the North Sea in the German EEZ with the same safety and ecological standards,** while at the same time planning the export of $CO_2$ for storage in other countries bordering the North Sea. In contrast, onshore storage in Germany remains in principle out of the question. This can be explained by the force of public opinion in Germany against it. In view of the storage potential required, Germany could probably do without onshore storage in the future as well. Nevertheless, the **possibilities of onshore storage should at least be explored further** in order to improve the data availability for evaluating the pros and cons of onshore storage, taking into account costs and transport routes, among other things. Existing estimates on storage potentials are not complete and are already several years old. Additional storage sites closer to home could help reduce costs, transport routes and ultimately also environmental pollution. The key points for the CMS propose an opt-in provision that individual German states can utilise in order to develop onshore storage facilities after all. Another argument in favour of including such a clause is that it would enable a rapid response to new findings and a possible increase in acceptance of the technology.

Current knowledge suggests that **large-volume carbon storage sites are available on land and under the seabed** in Germany, neighbouring European countries, the Norwegian Sea and the North Sea.[111] These storage sites are sufficient for the storage requirements identified in the German climate protection scenarios, for example. The same applies to the storage requirements in European scenarios, such as the scenarios for the European Commission's 2040 climate goal proposal. Provided a significant reduction in generated emissions is achieved, the absolute available potential of geological storage sites does not therefore represent a directly binding restriction on the use of CCS and CCS-based CDR.[112] In the short and medium term, more binding restrictions will result from the **lead times required to develop the storage sites**, which will limit annual storage volumes and cumulative storage volumes that can be achieved by, for example, 2050.[113] How the absolute physical scarcity of geological storage sites (and the necessary scarcity signals or economic scarcity rents) possible in the long term should be dealt with, particularly in regulatory terms, is nevertheless still an open (research) question.

The forceful public rejection of CCS in Germany to date has largely been triggered by the idea of constructing storage sites on land. Some sections of the population fear that the storage sites pose a risk to nature and human health if saline groundwater is displaced (and other water resources are contaminated) or $CO_2$ escapes, leading to a drop in ground-level oxygen concentrations, for example.[114] Although according to many experts **safe storage is possible and the risks are considerably overstated, a lack of acceptance can be a difficult hurdle to overcome** when it comes to getting started with carbon management. Against this backdrop, the decision presented by the CMS key points to forego onshore storage sites in order to avoid conflicts with local residents appears pragmatic and sensible in the short term. The development of at least

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[111] According to current knowledge, storage potential of at least 150 gigatonnes of $CO_2$ can be assumed at European level, see Federal Government 2022, p. 39 and acatech 2018, p. 34. For Germany, estimates for onshore and offshore storage potential of 6.3-12.8 gigatonnes of $CO_2$ can be expected, whereby the geological areas in question have not yet been fully explored (see Federal Institute for Geosciences and Natural Resources). The offshore storage potential of the North Sea (including the "Entenschnabel") for Germany is estimated at 2.9 gigatonnes of $CO_2$, see acatech 2018 , p. 33.

[112] This would not apply if Germany and Europe were to focus on the capture and storage of $CO_2$ emissions rather than avoiding the production of emissions.

[113] According to estimates, European storage volumes will reach a maximum of 425 megatonnes of $CO_2$ per year in 2050. In absolute terms, a good 57 gigatonnes of carbon storage potential could be opened up by 2050, see ESABCC 2023, p. 78ff.

[114] See UBA 2023.

the German offshore storage sites is not only suggested to adequately take on responsibility and to apply "polluter pays" principle. Indeed, **shorter transport routes with geographically closer storage sites can reduce both costs and environmental impacts**. However, **the planned links to storage sites in other European countries would appear to be essential** for rapid entry into carbon management; the development of these sites is at a more advanced stage, enabling utilisation of storage capacity in the near future.

# 4 Conclusion and outlook

Without CCS, CCU and CDR, it is difficult to see how climate neutrality is realistically achievable as things stand – let alone net-negative GHG emissions in the long term. The planned CMS is intended to set the ground for carbon management, and is therefore very welcome – as is the far-reaching initiative of Germany's Federal Government for the LNe.

The **key points of the CMS are based on a comparatively broad stakeholder process** in which different positions on the necessity of carbon management and technical storage methods have been discussed. However, the public still lack sufficient information and understanding when it comes to carbon management, the need for action and the various risks that need to be weighed up against each other. The participation process for the CMS has been able to address this issue to a limited extent so far. **A comparable participation process for the LNe has not yet taken place, but announced in the key points.**

Even broader and more detailed communication processes would be desirable in view of the public's reservations about carbon management and the CCS technology in particular. However, **postponing some initial decisions on commencing carbon management no longer seems appropriate.** In Germany, the **pressure to act** is too great, given the time left until 2045, the long lead times for creating the requisite infrastructure and technologies, and the planning security needed by companies when making decisions on locations. To be able to make a noteworthy contribution to achieving climate neutrality by 2045, technologies will likely need to be developed and made ready for use in a very timely fashion. **For this reason, it is the right move to put in place the regulatory framework for the development of carbon transport infrastructure and geological storage – and to create financial incentives for utilising CCS, CCU and CDR – without delay.** After first steps are taken, **the development of the regulatory conditions can and must continue on an ongoing basis** and be adapted to reflect technological progress. Indeed, in a few years' time, there may well be emissions avoidance options available in some areas, where today there appears to be no alternative to CCS.

In recent years, **a broad consensus has emerged among experts from the worlds of science, industry, politics and civil society that CCS is necessary in certain areas. However, the extent to which CCS should be permitted reaches beyond these areas according to the key points of the CMS.** In climate neutrality scenarios for Germany, CCS has so far been restricted to "hard-to-abate" emissions, and this has been reflected in the public and political debate. The term "hard-to-abate emissions" is also taken as a basis in the key points of the CMS (and the LNe). However, both position papers are vague and inconsistent in their use of the term. Due to the limited competitiveness of CCS (and CDR) and the further steering options via funding priorities and infrastructure planning, this is likely to be less problematic in practical implementation than when it comes to securing the necessary public support. This can be seen not least in the emerging debate surrounding the use of CCS at gas-fired power plants, which is even a no-no for environmental organisations that are open to CCS.

**Particularly in fields of application in which there are technological alternatives to CCS – including the CCS gas-fired power plants already mentioned – it would be important in the public debate to at least make the basis for the decision transparent and to argue the decision well or, if necessary, to revise it in an evolution of the CMS.** There is a lot of catching up to do here to build trust and widespread backing for the various stages of implementation. Indeed, broad-based support from politics, industry and civil society will be needed in order to put the necessary steps into action with sufficient speed.

Precisely because the benefits for the energy sector of gas-fired power plants with CCS over hydrogen power plants and the use of blue hydrogen are not clear and CCS gas-fired power plants are unlikely to be built on a large scale within the German energy landscape – not least as state subsidies have been explicitly ruled out – it could have been advantageous in the political process to forgo technology neutrality in this area.

The extent to which the CMS and LNe dovetail cannot be assessed on the basis of the white papers. In any case, special attention should be paid to this in the final strategies and the forthcoming steps of their development. It will be essential that these separate strategies ultimately form **an overarching and consistent framework for carbon management** that reflects the overlaps between CCS, CCU and CDR through technological components, infrastructure requirements and interdependencies in their contributions to the realisation of climate protection goals.

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In the initiative “Energy Systems of the Future” (ESYS), acatech – National Academy of Science and Engineering, the German National Academy of Sciences Leopoldina and the Union of the German Academies of Sciences and Humanities provide input for the debate on the challenges and opportunities of the German energy transition. Within the Academies’ Project, over 160 experts from the science and research communities come together in interdisciplinary working groups to develop policy options for the implementation of a secure, affordable and sustainable energy supply.

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