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Support for the revision of the Monitoring and Reporting Regulation for the 4th trading period (focus: Carbon Capture and Utilisation (CCU))

Final report

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Support for the revision of the Monitoring and Reporting Regulation for the 4th trading period (focus: Carbon Capture and Utilisation (CCU))

Final report

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Abstract: Support for the revision of the Monitoring and Reporting Regulation for the 4th trading period (focus: Carbon Capture and Utilisation (CCU))

In light of the upcoming phase 4 of the European Union Emissions Trading System (EU ETS, 2021-2030), the Monitoring and Reporting Regulation (Regulation 601/2012/EU; MRR) and the Accreditation and Verification Regulation (Regulation 600/2012/EU; AVR) are currently under review. One topic of particular interest is the question to what extent greenhouse gas (GHG) emissions transferred to Carbon Capture and Utilisation (CCU) installations should be deductible for the transferring installation, so that they would not have to be offset under the ETS. The current regulations are restrictive, but a recent ruling of the European Court of Justice (ECJ) has set precedent when it judged that the company Schaefer Kalk may deduct their own calcination emissions for the use in precipitated calcium carbonate production.

In reaction to this ruling this project examines whether and to what extent greenhouse gas emissions transferred to CCU installations can be deducted from the transferring installation's emission. It develops and discusses a set of generally applicable criteria that can evaluate CCU applications with regard to climate protection and integrity of the ETS.

Based on the complexity of the analyzed criteria, only the criterion "energy source" is assessed as enforceable criterion. This criterion becomes part of a decision tree which helps to come to a yes/no decision for deductibility of transferred GHG for the use in a CCU process. Additionally, a blacklist is introduced to avoid deductibility for environmentally disadvantageous CCU processes (e.g. proven by the criteria "life cycle assessment") or which are for other reasons undesired. A first field test of the decision tree and its implications leads to the conclusion that an estimated additional effort of 30% would be required compared to a standard verification process of emissions reporting. This appears to be realisable in practice but requires clear definitions and requirements in the regulation on monitoring and reporting.

Kurzbeschreibung: „Unterstützung bei der Überarbeitung der Monitoring-Verordnung für die 4. Handelsperiode (Schwerpunkt: Carbon Capture and Utilisation (CCU))"

Im Hinblick auf die bevorstehende Phase 4 des EU-Emissionshandels (EU-ETS, 2021-2030) werden derzeit die Monitoring-Verordnung (Verordnung 601/2012/EU; MRR) und Akkreditierungs- und Verifizierungsverordnung (Verordnung 600/2012/EU; AVR) überarbeitet. Ein Thema von besonderem Interesse ist die Frage, inwieweit Treibhausgasemissionen (THG), die in eine CO_2-Nutzung überführt werden, für die weiterleitende Anlage abzugsfähig sein sollen und damit für diese THG keine Emissionsberechtigungen abgegeben werden müssen. Die aktuellen Vorschriften stehen dem restriktiv gegenüber. Jedoch hat ein kürzlich ergangenes Urteil des Europäischen Gerichtshofs einen Präzedenzfall geschaffen, als es der Firma Schaefer Kalk den Abzug der Emissionen aus der Kalzinierung gewährte, wenn es für die Herstellung von gefälltem Kalziumkarbonat verwendet wird.

Als Reaktion auf dieses Urteil wird in diesem Projekt untersucht, ob und inwieweit THG, die an CCU-Anlagen weitergeleitet werden, von den Emissionen der weiterleitende Anlage abgezogen werden können. Dazu wird eine Reihe von allgemein gültigen Kriterien entwickelt und diskutiert, anhand derer CCU-Anwendungen in Hinblick auf den Klimaschutz und die Integrität des Emissionshandels bewertet werden können.

Aufgrund der Komplexität der analysierten Kriterien ist im Ergebnis nur das Kriterium "Energiequelle" als vollziehbares Kriterium geeignet. Dieses Kriterium wird Teil eines Entscheidungsbaums, der bei einer Ja/Nein-Entscheidung über die Abzugsfähigkeit von weitergeleiteten THG zur Nutzung in CCU-Prozessen unterstützen soll. Zusätzlich wird eine „Blacklist" eingeführt, um zu vermeiden, dass umweltschädliche (z. B. mit Ökobilanzen nachgewiesen) oder aus anderen Gründen unerwünschte CCU-Prozesse im Rahmen des ETS zu

Abzugsfähigkeit führen. Ein erstes Ad-Hoc-Gutachten des Entscheidungsbaumes und seiner Auswirkungen führt zu dem Schluss, dass für die Emissionsberichterstattung ein geschätzter zusätzlicher Aufwand von 30% im Vergleich zu einem Standard-Verifizierungsprozess hinzukommt. Dies scheint in der Praxis realisierbar, erfordert aber klare Definitionen und Anforderungen in der MRR und AVR.

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ASA	Acetylsalicylic acid (Aspirin)
AVR	Accreditation and Verification Regulation
$CaCO_3$	Calcium carbonate
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CCUS	Carbon Capture, Utilisation and Storage
CO	Carbon monoxide
CO_2	Carbon dioxide
DAC	Direct air capture
DME	Dimethyl ether
ECJ	European Court of Justice
EGR	Enhanced Gas Recovery
EO	Ethylene oxide
EOR	Enhanced Oil Recovery
EU-ETS	EU Emissions Trading Scheme
FT	Fischer-Tropsch process
GHG	Greenhouse gas
GWP	Global warming potential
H_2	Hydrogen
ILCD	International Reference Life Cycle Data System
IPCC	International Panel on Climate Change
ISO	International Organization for Standardisation
LCA	Life cycle assessment
$MgCO_3$	Magnesium carbonate
MRR	Monitoring and Reporting Regulation
MRV	Monitoring, reporting & verification
N_2O	Nitrous oxide (laughing gas)
NH_3	Ammonia
OME	Oyemethylene dimethyl ethers
PCC	Precipitated calcium carbonate
PE	Polyethylene
PEC	Polyethylene carbonate
PET	Polyethylene terephthalate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
PO	Propylene oxide
PPC	Polypropylene carbonate
PS	Polystyrene

ASA	Acetylsalicylic acid (Aspirin)
PtG	Power-to-Gas (any power-based gaseous fuels)
PtL	Power-to-Liquid (any power-based liquid fuels)
PtP	Power to Proteins
PUR	Polyurethanes
RED	Renewable Energy Directive
ReFuNoBio	Renewable fuels of non-biological origin
UBA	Umweltbundesamt (German Environment Agency)
UNFCCC	United Nations Framework Convention on Climate Change
WP	Work Package

Summary

Background of the project

In light of the upcoming phase 4 of the EU ETS (2021-2030), the Monitoring and Reporting Regulation (Regulation 601/2012/EU; MRR) and the Accreditation and Verification Regulation (Regulation 600/2012/EU; AVR) are currently under review. In that context, it will be examined whether and to what extent greenhouse gas emissions transferred to Carbon Capture and Utilisation (CCU) installations should be deductible for the transferring installation. A positive ETS-position towards CCU would allow installations within the ETS to transfer their greenhouse gas emissions to CCU technologies without the need to surrender allowances for those emissions.

In principle, two main alternatives emerge how to tackle the topic CCU within the context of the ETS:

a) Restrictive regulations/definitions that in fact do not lead to deductibility, but support the polluter pays principle and cause low transaction costs.

b) Complex rules/definitions that allow deductibility, but cause high transaction costs

But a recent ruling of the European Court of Justice (ECJ) has set precedent when it judged that the company Schaefer Kalk may deduct their calcination emissions when utilized for precipitated calcium carbonate production in another installation not subject to ETS. As a result of this ruling, it seemed to be reasonable to examine if feasible and applicable rules within the ETS context could be developed in order to have a basis for future enforcement decisions dealing with different CCU cases. Furthermore, CCU is a relevant topic on the political agenda.

Goal of the project

Against the background of ongoing political discussions and the ruling of the ECJ, this project aims to develop generally applicable criteria for identifying CCU application cases that can be considered as "desirable" with regard to climate protection. These criteria should allow for a clear and simple yes/no decision concerning the deduction of transferred greenhouse gases for CCU purposes in the fourth trading period. In a second part of the project, an ad-hoc statement is drafted to assess the practicability and feasibility of the developed criteria and the necessary monitoring and reporting requirements.

Please note that the document does not represent a general assessment of CCU technologies, but is an attempt to discuss possible assessment criteria for the implementation in ETS and the possibility for deductibility of transferred CO_2 for CCU processes. This discussion takes place in a situation in which neither the national nor the European discussion processes have been concluded. The update process of the MRR and AVR is expected to be finalized in the second half of 2019.

Content of the project

The original outline of the project planned to include the following work packages (WP):

► WP1: Development of criteria to evaluate CCU technologies

This work package developed and defined criteria on the basis of which CCU technologies can be assessed with regard to environmental and climate policy aspects. For WP1, a total of 9 different criteria have been discussed:

1. Life Cycle Assessment
2. Percentage of CO_2 actually being bound

3. Non-avoidable GHG
4. Substitution of fossil carbon
5. Chemical stability and lifetime duration
6. Proof of carbon source
7. Other greenhouse gases
8. Double counting
9. Energy source

Based on the discussion results of the criteria, a decision tree was designed with the intention to guide decision makers when assessing CCU processes in regards to the deductibility of transferred GHG for these CCU processes within the ETS context.

► WP2: Evaluation of CCU technologies based on criteria of WP1 and creation of a ranking

Originally, in this work package a ranking of CCU technologies were to be developed on the basis of the criteria evaluated in WP1. In the course of the discussion in the project and this document, almost all criteria for assessing deductibility have been omitted due to their complexity and lack of feasibility for actual enforcement. The only relevantly remaining criterion is the energy source. Additionally, a blacklist is introduced to avoid deductibility for environmentally disadvantageous CCU processes (e.g. proven by the criteria "life cycle assessment") or which are for other reasons undesired. The criterion percentage of CO_2 actually being bound is reflected in the decision tree, but after a yes-decision is made.

However, the other criteria are still highly relevant from a climate perspective. While they might not be relevant for a yes/no decision, their consideration is still important to avoid pitfalls, lock-in effects and supporting CCU processes with negative consequences. Based on the lack of criteria to rank different technologies, WP2 has been consequently adapted into a chapter that provides background information on several topics relevant for the evaluation of CCU technologies.

► WP3: Field test to evaluate practicability and feasibility

The third work package consists of an ad hoc opinion in written form with the goal to test the practicability of the results from WP 1 and 2 and to discuss considerations for the implementation practice of the MRR revision. In particular, the following two questions were considered:

1. Is the decision tree actionable in practice for operators and verifying authorities?
2. What additional effort from both verifying authorities and operators of ETS installations is required?

Results of the project

Based on the discussions of WP1, the project has derived a decision tree that helps to come to a yes/no decision concerning the deduction of transferred GHG when assessing a CCU technology or process. The energy source was identified as the only remaining key criterion. To be more precise, any energy that is required to transform the CO_2 gas stream into a CCU product will have to be renewable or, in case of fossil fuels (e.g. energy contained in a waste gas stream), it could have to be offset by the according amount of renewable energy. Thus, when checking for the deductibility of transferred GHG for a CCU process, for all process steps it has to be checked whether any energy used throughout the process comes from a renewable energy source or whether it is offset by renewable energy purchases. Resulting limitations to incentives for using such carbon containing off-gas streams need to be carefully considered.

As an additional measure to control which CCU technologies are accepted within the ETS context, a so-called blacklist is considered a feasible tool. On this list, CCU processes which are proven/suspected to be environmentally disadvantageous or which are for other (e.g. political) reasons undesired can be added. All processes on the blacklist are excluded from deductions within the ETS but could be removed from said list in case compelling evidence can be presented, e.g. by providing a reviewed Life Cycle Assessment (LCA) of the process.

To ensure that credit is only given in case CO_2 is actually kept out of the atmosphere, only the amount of CO_2 that is actually bound in the product of the CCU process will be accounted for. This assessment has to be performed after a yes-decision was made.

A first field test of WP3 leads to the conclusion that verification of additional data and methodologies for accounting for the transferred and deductible carbon requires an estimated additional effort of 30 % compared to a standard verification process of emissions reporting. This estimate is based on the additional requirements and can differ between installations depending on the number and complexity of CCU processes. The larger scope appears to be reasonable and realisable in practice. An important condition for this are clear definitions and requirements in the MRR. The use of standard values wherever reasonable and possible can further decrease the burden of monitoring, reporting and verification (MRV) obligations for operators. These pre-conditions accompanied by clear guidance can provide the framework needed for the implementation of emission reductions at ETS installations via transferred CO_2 to CCU processes.

Nevertheless, the additional administrative effort might hinder operators to apply for deductibility of their CCU processes. Increasing complexity of the interdependencies between installations (both ETS and non-ETS) result in higher additional transaction costs. In particular for smaller CCU projects the suggested rules on energy use and carbon bound can be expected to hamper implementation as they decrease the amount of actually deductible CO_2 for many applications. Therefore, it is likely that with the suggested decision tree only larger CCU projects will claim deductions, go through the MRV processes and adhere to the additional obligations.

Zusammenfassung

Hintergrund des Projekts

Im Hinblick auf die bevorstehende 4. Handelsperiode des EU-ETS (2021-2030) werden derzeit die Überwachungs- und Berichterstattungsverordnung (Verordnung 601/2012/EU; MRR) und die Akkreditierungs- und Verifizierungsverordnung (Verordnung 600/2012/EU; AVR) überarbeitet. In diesem Zusammenhang wird untersucht, ob und inwieweit die Treibhausgasemissionen, die an Carbon Capture and Utilisation (CCU)-Anlagen weitergeleitet werden, für die weiterleitende Anlage abzugsfähig sein sollen. Eine Anerkennung von CCU würde es den Anlagen innerhalb des ETS ermöglichen, ihre Treibhausgasemissionen für CCU-Technologien zu verwenden, ohne dass für diese Emissionsberechtigungen abgegeben werden müssen.

Im Prinzip ergeben sich zwei Hauptalternativen, wie mit dem Thema CCU im Rahmen des ETS umgegangen werden kann:

a) Restriktive Regelungen/Definitionen, die nicht zu einer Abzugsfähigkeit führen, sondern das Verursacherprinzip stützen und nur geringe Transaktionskosten verursachen.

b) Komplexe Regeln/Definitionen, die eine Abzugsfähigkeit ermöglichen, aber hohe Transaktionskosten verursachen.

Ein kürzlich ergangenes Urteil des Europäischen Gerichtshofs (EuGH) hat einen Präzedenzfall geschaffen. Er stellte fest, dass die Firma Schaefer Kalk ihre Emissionen aus der Kalzinierung abziehen darf, wenn sie für die Herstellung von gefälltem Kalziumkarbonat in einer anderen, nicht emissionshandelspflichtigen Anlage verwendet werden. Als Ergebnis dieser Entscheidung soll untersucht werden, ob anwendbare Regeln im Rahmen des ETS entwickelt und damit eine Grundlage für künftige Vollzugsentscheidungen in verschiedenen CCU-Fällen geschaffen werden können. Darüber hinaus ist CCU ein relevantes Thema auf der politischen Agenda.

Ziel des Projekts

Vor dem Hintergrund der laufenden politischen Diskussion und des Urteils des EuGH sollen in diesem Projekt allgemein anwendbare Kriterien für CCU-Anwendungsfälle entwickelt werden, die im Hinblick auf den Klimaschutz als wünschenswert angesehenen werden. Diese Kriterien sollen eine klare und einfache Ja/Nein-Entscheidung über den Abzug der weitergeleiteten Treibhausgase für CCU-Zwecke in der vierten Handelsperiode ermöglichen. Im zweiten Teil des Projekts wird eine Ad-hoc-Stellungnahme verfasst, um die Praktikabilität und Durchführbarkeit der entwickelten Kriterien sowie die erforderlichen Überwachungs- und Berichtspflichten zu bewerten.

Bitte beachten Sie, dass das Gutachten keine allgemeine Bewertung von CCU-Technologien vornimmt. Es stellt vielmehr einen Versuch dar, mögliche Bewertungskriterien für die Umsetzung im ETS und die Möglichkeit der Abzugsfähigkeit von weitergeleitetem CO_2 für CCU-Prozesse zu diskutieren. Diese Diskussion findet in einer Situation statt, in der weder der nationale noch der europäische Diskussionsprozess abgeschlossen ist. Die Überarbeitung von MRR und AVR wird voraussichtlich in der zweiten Jahreshälfte 2019 abgeschlossen sein.

Inhalt des Projekts

Der ursprüngliche Entwurf des Projekts sah folgende Arbeitspakete (AP) vor:

► AP1: Entwicklung von Kriterien zur Bewertung von CCU-Technologien

In diesem Arbeitspaket wurden Kriterien entwickelt und definiert, anhand derer CCU-Technologien unter umwelt- und klimapolitischen Aspekten bewertet werden können. Für AP1 wurden insgesamt 9 verschiedene Kriterien diskutiert:

1. Ökobilanz
2. Prozentsatz des tatsächlich gebunden CO_2
3. Nicht vermeidbare Treibhausgase
4. Substitution von fossilem Kohlenstoff
5. Chemische Stabilität und Lebensdauer
6. Nachweis der Kohlenstoffquelle
7. Andere Treibhausgase
8. Doppelzählungen
9. Energiequelle

Basierend auf den Diskussionsergebnissen zu den Kriterien wurde ein Entscheidungsbaum entworfen. Dieser soll die Entscheidungsträger bei der Beurteilung der Abzugsfähigkeit von weitergeleiteten THG für CCU-Prozesse im Rahmen des ETS unterstützen.

► AP2: Bewertung von CCU-Technologien anhand der im Arbeitspaket 1 entwickelten Kriterien und Erstellen einer „Rangliste“

Ursprünglich sollte in diesem Arbeitspaket ein Ranking der CCU-Technologien auf der Grundlage der in AP1 diskutierten Kriterien entwickelt werden. Im Laufe des Projekts fielen fast alle Kriterien zur Beurteilung der Abzugsfähigkeit wegen ihrer Komplexität und mangelnden Vollzugstauglichkeit weg. Das einzige Kriterium, das für die Bewertung bestehen blieb, ist die Energiequelle. Zusätzlich dazu wird eine „Blacklist“ eingeführt, um zu vermeiden, dass umweltschädliche (z. B. mit Ökobilanzen nachgewiesen) oder aus anderen Gründen unerwünschte CCU-Prozesse im Rahmen des ETS zu Abzugsfähigkeit führen. Das Kriterium „Prozentsatz des tatsächlich gebundenen CO_2" wird im Entscheidungsbaum berücksichtigt, jedoch erst nachdem eine positive Entscheidung für den CCU-Prozess getroffen wurde.

Aus Sicht des Klimaschutzes sind die anderen Kriterien jedoch weiterhin von Bedeutung. Auch wenn sie hier für eine Ja/Nein-Entscheidung der Abzugsfähigkeit nicht in Frage kommen, sollten sie trotzdem in Betracht gezogen werden, um Fallstricke, Lock-in-Effekte und die Unterstützung von CCU-Prozessen mit negativen Folgen zu vermeiden. Aufgrund der wenigen, verbliebenen Kriterien zur Erstellung einer Rangfolge von CCU-Technologien, wurden in AP2 Hintergrundinformationen zur Bewertung von CCU-Technologien zusammengetragen.

► AP3: Ad-hoc Stellungnahme zur Beurteilung der Praxistauglichkeit und Machbarkeit

Das dritte Arbeitspaket besteht aus einer Ad-hoc-Stellungnahme mit dem Ziel, die Praxistauglichkeit der Ergebnisse aus den AP 1 und 2 zu prüfen und Überlegungen zur Umsetzungspraxis der MRR zu diskutieren. Insbesondere wurden die folgenden beiden Fragen behandelt:

1. Ist der Entscheidungsbaum in der Praxis für Betreiber und Verifizierer umsetzbar?
2. Welcher zusätzliche Aufwand ergibt sich sowohl für die Verifizierer als auch für die Betreiber von ETS-Anlagen?

Ergebnisse des Projekts

Basierend auf den Diskussionen in AP1 hat das Projekt einen Entscheidungsbaum abgeleitet, der dabei unterstützt, eine Ja/Nein-Entscheidung bezüglich des Abzugs von weitergeleiteten Treibhausgasen zu einer CCU-Technologie oder einem CCU-Prozess zu treffen. Die Energiequelle wurde als einziges Schlüsselkriterium identifiziert. Genauer gesagt, muss jede Energie, die benötigt wird, um das CO_2 in einem CCU-Produkt zu nutzen, erneuerbar sein, oder, im Falle fossiler Brennstoffe (z. B. Energie, die in einem Restgas enthalten ist), durch die entsprechende Menge an erneuerbarer Energie kompensiert werden. Bei der Überprüfung der Abzugsfähigkeit von weitergeleiteten THG für einen CCU-Prozess ist daher für alle Prozessschritte zu prüfen, ob die während des Prozesses benötigte Energie aus einer erneuerbaren Energiequelle stammt oder ob sie durch den Bezug von erneuerbarer Energie kompensiert wird. Eine daraus resultierende Anreizminderung zur Nutzung solcher kohlenstoffhaltigen Restgasströme muss sorgfältig geprüft werden.

Als ein zusätzliches, praktikables Kontrollinstrument, welche CCU-Technologien im Rahmen des ETS akzeptiert werden, wird eine sogenannte Blacklist eingeführt. Auf diese Liste können CCU-Prozesse hinzugefügt werden, die sich als umweltbelastend erweisen/vermutet werden oder die aus anderen (z. B. politischen) Gründen unerwünscht sind. Alle Prozesse auf der Blacklist sind von der Abzugsfähigkeit weitergeleiteter THG ausgeschlossen, können aber von dieser Liste gestrichen werden, wenn stichhaltige Nachweise vorgelegt werden (z. B. durch die Vorlage einer überprüften Ökobilanz (LCA) des Prozesses).

Um sicherzustellen, dass der Abzug von weitergeleitetem CO_2 nur für nicht in die Atmosphäre emittiertes CO_2 anerkannt wird, darf nur das tatsächlich im Produkt des CCU-Prozesses gebundene CO_2 berücksichtigt werden. Dieser Schritt muss nach einer Ja-Entscheidung durchgeführt werden.

Die Bewertung der Praxistauglichkeit in AP3 führt zu dem Schluss, dass die Überprüfung zusätzlicher Daten und Methoden zur Bilanzierung des weitergeleiteten und abzugsfähigen Kohlenstoffs einen geschätzten zusätzlichen Aufwand von 30 % im Vergleich zu einem Standard-Verifizierungsverfahren der Emissionsberichterstattung erfordert. Diese Schätzung bezieht sich auf die zusätzlichen Anforderungen und kann je nach Anzahl und Komplexität der CCU-Prozesse zwischen den Anlagen variieren. Der größere Prüfumfang scheint jedoch in der Praxis sinnvoll und realisierbar zu sein. Eine wichtige Voraussetzung dafür sind klare Definitionen und Anforderungen in der MRR. Die Verwendung von Standardwerten, wo immer sinnvoll und möglich, kann den Aufwand für Überwachungs-, Berichts- und Verifizierungspflichten (MRV) für Betreiber weiter verringern. Diese Voraussetzungen zusammen mit klaren Hilfestellungen können den notwendigen Rahmen für Emissionsreduktionen bei ETS-Anlagen mittels Weiterleitung von CO_2 für CCU-Prozesse schaffen.

Dennoch könnte der zusätzliche Verwaltungsaufwand die Betreiber daran hindern, den Abzug von weitergeleitetem CO_2 für CCU-Prozesse zu beantragen. Die zunehmende Komplexität durch Verflechtung von Anlagen (sowohl ETS als auch Nicht-ETS) führt zu höheren Transaktionskosten. Insbesondere bei kleineren CCU-Projekten dürften die vorgeschlagenen Regeln für den Energieverbrauch und den Prozentsatz des tatsächlich gebunden CO_2 die Beantragung eines Abzugs behindern, da sie die Menge an tatsächlich abziehbarem CO_2 für viele Anwendungen verringern. Daher ist es wahrscheinlich, dass mit dem vorgeschlagenen Entscheidungsbaum nur bei größeren CCU-Projekten Abzüge beantragt, zusätzliche MRV-Verfahren durchgeführt und zusätzliche Anforderungen einhalten werden.

1 Introduction

The Monitoring and Reporting Regulation (Regulation 601/2012/EU; MRR) contains provisions for the monitoring and reporting of greenhouse gas emissions in accordance with Directive 2003/87/EC, which establishes and regulates the European Emission Trading Scheme (ETS). The current revision of the MRR will examine the extent to which greenhouse gas emissions transferred to Carbon Capture and Utilisation (CCU) installations should be deductible for the transferring installation. This would mean that no compensation would have to be provided under the ETS for greenhouse gas emissions that continue to be used in CCU technologies. In the course of the revision of the ETS and MRR for the second and third trading periods, there have already been lengthy disputes on the question of whether CCU applications should be eligible for deduction, and if so, in which cases. The most recent regulations are restrictive with regard to CCU technologies and only Carbon Capture and Storage (CCS) processes are deductible for the transferring installation. The European Court of Justice (ECJ), in its ruling on the Schaefer Kalk case of 19 January 2017 (C-460/15), has now established that the European Commission has exceeded its competence with the most recently valid regulation in Annex IV No. 10 of the MRR and that CO_2 emissions resulting from calcination and collected and transferred for the production of precipitated calcium carbonate (PCC) are deductible. The judgement specifically and only refers to the case of Schaefer Kalk, stating that CO_2 for the production of PCC is chemically stable bound in a product, thus not counted as an emission of the installation.

There is interest in criteria that can be easily implemented and enforced, but where climate protection can still be guaranteed. Against the background of the political discussions and the ruling of the European Court of Justice, this project aims to develop generally applicable criteria for identifying CCU application cases that are to be regarded as "desirable" with regard to climate protection. The criteria take into account the considerations of the ECJ ruling on Schaefer Kalk.

This report is intended to provide criteria based on which CCU technologies could be entitled to deduct greenhouse gases in the fourth trading period, which runs from 2021 to 2030. Also, it discusses how future technologies can be assessed and how undesirable side effects and the promotion of unsuitable technologies can be avoided. In the second, smaller part of the project, an ad hoc statement will be drafted to examine the practicability of changed requirements for monitoring and reporting greenhouse gases.

The overall structure of the project is split into the following 3 work packages:

- WP1: Development of criteria to evaluate CCU technologies
- WP2: Technologies and background information
- WP3: Field test to evaluate practicability and feasibility

2 Work package 1: Development of criteria to evaluate CCU technologies

In work package 1 (WP1), the project develops criteria, based on which CCU technologies can be evaluated with a view on climate aspects that are relevant to emissions trading. The focus of the project is on fossil CO_2 which is transferred from installations obligated to report and surrender allowances for their emissions under the EU ETS to other installations and which can be used for chemical and material applications. It should be noted that the project aims at developing criteria and recommendations for implementation within the currently existing system. Potential future developments which might have an even stronger positive influence on climate mitigation, such as a political decision to stop energy production from coal or a complete decarbonisation of Europe's industry, are not considered as a scenario in this project. The criteria and recommendations aim at providing the largest climate benefit while recognising political and industrial realities as of the year 2017.

The core question of the project is which greenhouse gas transfers should be recognised as deductible from the transferring installation's emissions under the trading scheme. As basis for such a decision, WP1 will determine clear and enforceable criteria which enable a pragmatic evaluation and thus lead to a yes/no decision with regard to deductibility. For clarification purposes the following definitions will be provided:

CCU: Carbon capture and utilization stands for the utilization of CO_2 as a source of carbon. More specifically, it refers to the separation of carbon dioxide (CO_2), in particular from combustion or process gases, and its subsequent use, either directly or in other chemical processes. Instead of treating CO_2 as waste, the CCU process transfers or converts the carbon into commercially viable products such as chemicals, carbonates, polymers and fuels.

CCS: Carbon capture and storage is the collection and sequestration of carbon dioxide for long-term storage and isolation from the atmosphere. It is applied to CO_2 emitted in fossil fuel power plants and other industrial or energy-related point sources, which then is transported to a storage location creating a geological formation onshore or offshore.

CCU and CCS processes can often be distinguished – CCS is a long-term storage without any further application of the carbon, CCU processes have the distinct goal to utilize the carbon to produce products. There are some applications that combine the utilization with a storage aspect, called Carbon Capture, Utilization and Storage (CCUS), for example enhanced oil recovery where CO_2 is injected to increase the amount of oil extracted from a reservoir.

In the following, the criteria will be discussed in detail in chapter 2.1, with the main focus being put on practicability of implementation within the monitoring system. Chapter 2.2 draws an interim conclusion of the discussion and ranks the criteria into priorities, section 2.3 transfers the results into a decision tree for assessing CCU processes within the ETS context.

2.1 Criteria discussion

2.1.1 Criterion 1 – Life Cycle Assessment: What are the overall environmental impacts according to different allocation rules

During the discussions at the kick-off meeting it became clear that it will not be expedient to set up criteria which require transferring installations to deliver complete life cycle assessments in order to make the criteria verifiable. There are number of reasons for this decision: In general, every LCA heavily depends on data for the processes in questions. Enforcing transferring installations to provide an LCA would incur additional efforts and costs and ask for sensible data which these installations might be unwilling to share. Furthermore, in case of CCU, the choice of methodology is an important decision that can have large influence on the result of the LCA. Chapter 3.5 discusses this point in more detail. For these reasons the individual GHG balance of a CCU-based product or process will only play a minor or no role for the deductibility of emissions in emissions trading. That said, LCAs are highly useful when they are available for specific CCU processes. Instead, in the further development of the criteria it was therefore checked whether there are 'typical' or standardised GHG values for certain technologies or processes which could at least provide a rough benchmark (similar to the default and typical emission reduction values for biofuels determined by the Renewable Energy Directive II). The background information collected in work package 2 therefore includes an overview of existing LCA data and methodologies on CCU processes and will attempt to draw preliminary conclusions on GHG data. If an already existing LCA shows that a CCU process results in comparatively negative environmental impacts, the process would have to be excluded.

The idea was discussed in further detail, both internally at the Umweltbundesamt (UBA) and at the project meeting on July 5th at the UBA in Berlin. Based on upcoming harmonizing guidelines for CO_2 use in LCA and the long duration of the upcoming 4th trade period until 2030, LCAs could be used for preliminary testing in the context of ETS enforcement when there are strong clues for negative effects. The creation of a "blacklist" for CCU-processes was consequently proposed, discussed and decided upon. It will be placed next to the actual decision tree and serve as an additional and feasible means to exclude unwanted or environmentally disadvantageous processes. To implement a functional blacklist, a procedure would have to be developed and implemented that clearly defines how products and processes can be placed on the blacklist. Such procedure could for example be based on political aspects or environmental impact assessments like LCAs and would have to allow for continuous updating based on new developments and results. The list as a whole could be kept more generic, removing process pathways rather than single processes, if negative environmental impacts are suspected or confirmed by LCAs.

2.1.2 Criterion 2 – Percentage of CO_2 actually being bound: What is the overall efficiency of the CO_2 utilisation?

In the case of Schaefer Kalk and the technology to produce PCC, the European Court of Justice's judgement refers to Art. 49 (1) and point 10 of Annex IV MRR (transfer of CO_2 out of EU ETS is non-deductible) as "invalid in so far as they systematically include the carbon dioxide transferred to another installation for the production of precipitated calcium carbonate in the emissions of the lime combustion installation, regardless of whether or not that CO_2 is released into the atmosphere" without further implementation remarks. With a view on climate mitigation, however, it makes sense to differentiate the potential products and processes in more detail in order to avoid that 100% of transferred CO_2 become deductible, if after the transfer a relevant share is immediately released back into the atmosphere without being conversed or used.

According to the ETS logic, only the amount of GHG which is actually avoided from being emitted should be deductible under the rules applicable to CCU technologies. But the total amount of the stored GHG is not relevant in order to derive a yes/no decision with regard to deductibility. This criterion, therefore, should not play a role with determining deductibility and is not feasible for a hard "yes/no" criterion, but, should other criteria lead to a "yes/no" decision, it should be made sure that only the actually bound amount of GHG is accounted for in the deduction. The final decision tree accounts for this aspect by including the "actual bound % of CO_2", which refers to the amount of carbon ending up in the product of a CCU process compared to the amount of CO_2 that was contained in the utilized gas stream.

The direct use of CO_2 should in this case be considered particularly careful because the CO_2 is technically not bound in another chemical composition. Instead, it is rather bound within the target product/process of the CCU: When using CO_2 directly in fire extinguishers or air condition, it will be used entirely for the target process. Therefore, 100% of the CO_2 fulfils its intended use, so that also a 100% of the carbon dioxide should be deducted. On the other side, when using CO_2 directly in a greenhouse, only a minor part (e.g. 20%) of the carbon dioxide will be taken up by the plants for the intended use, while the remaining majority will be directly released into the atmosphere.

2.1.3 Criterion 3 – Non-avoidable GHG: What are non-avoidable GHG emissions which can be addressed by the CCU technology?

The reason for such a criterion would be that the potential political support of CCU technologies should not lead to a "lock-in effect", i.e. to favourable conditions incentivising a technology to produce cheap additional emissions even though viable alternatives exist. Lock-in effects in this case refer to political measures that bind society longer to fossil carbon. In that regard, it has to be noted that the EU ETS is a key tool for reducing greenhouse gas emissions cost-effectively, but it is not a feasible instrument for reducing and completely phasing out fossil carbon. Answering the question about the potential volumes of non-avoidable GHG emissions would first require a clear definition which process emissions could be classified as non-avoidable and which could not. This in turn would require definite knowledge about alternative technologies and how they can develop in the future, including their environmental impacts. Furthermore, the term "non-avoidable" itself is not clearly defined and could, for example, refer either to technological or political issues. Another potential approach critically discussed was the differentiation between energy-based and process-based GHG emissions. In the end, such considerations are hardly feasible to lead to a "hard" yes/no criterion. As this contradicts the concept of implementation practicability, the criterion will be removed entirely from the scope of this project. If such a criterion is demanded in the future, it will need to be discussed and decided upon on a higher level (blacklist, see criterion 1).

2.1.4 Criterion 4 – Substitution of fossil carbon: How much fossil carbon (petroleum, coal, natural gas) can be substituted?

Every CCU application avoids an immediate emission from a plant and thus can lead to reduced overall emissions, in line with the goal of the emission trading system. Furthermore, every time a product is made from previously emitted CO_2 (or CO) instead of from fossil fuels, a certain amount of fossil resources is left in the ground which would have been used instead if it was not for the CCU technology. In other words, CCU substitutes the, usually fossil, carbon source by reusing the carbon instead of releasing it into the atmosphere. In principle, CCU can substitute any carbon, which means also bio-based or recycled carbon, but fossil carbon as the dominant option on the market is most likely to be substituted. Furthermore, substituting bio-based or recycled carbon with CCU can also make a lot of sense: the CCU product/process might be economically more competitive than the alternatives and because biomass is limited, a CCU alternative opens up the use of bio-based carbon / biomass for other applications.

While in some cases, carbon-based processes can become obsolete in the future – i.e. in liquid fuels for road person transport which can be replaced through electric mobility based on renewable energy sources – for certain cases this is not possible. The most important case where this is true is organic chemistry, which will always require carbon as a basis for its products, i.e. base chemicals and plastics. Also, for long-distance transport shipping and aviation, the replacement of liquid fuels by other energy sources will take a significant amount of time or will not be possible in future at all, which could make the substitution of the fossil carbon through previously emitted CO_2 more feasible from a climate point of view. On the opposite end of the spectrum, there might be new and innovative CCU products or applications, where the identification of a fossil counterpart might prove difficult. One example would be proteins from CO_2. In these cases, it should be identified which products the CCU product might replace (here, other food or feed proteins) and whether this substitution can be considered desirable.

Should CO_2 prices rise to a sufficiently high level and CCU processes receive full ETS deductibility, it might happen that products containing CO_2, especially direct applications, will become so cheap that they displace other technologies from the market, with different positive or negative environmental effects, depending on the substituted product. This is an important aspect and should be considered when evaluating direct CO_2 applications (blacklist, see criterion 1).

The substitution of fossil carbon sources through the use of CO_2 is the most important climate advantage of CCU. In the beginning of the project, it was considered to what extent the substitution can be quantified and justify deductibility. A combination with criterion No. 2 (actually bound % carbon) was assumed to be a sensible approach, where the overall efficiency of the CO_2 utilisation can be factored in to fully capture the amount of substituted fossil carbon.

Excursus: Discussions with the mineralization industry

For further discussion on CO_2-use for mineralisation processes, a meeting with the limestone industry (more precisely, the Forschungsgemeinschaft Kalk und Mörtel e.V.) was held on the 27th of February 2018.

During this meeting, criterion 4 regarding the substitution of fossil CO_2 was still regarded as critical for the decision tree. Although the criterion has been removed, the discussion brought some considerations into light: The substitution in the then presented decision tree referred to the replacement of products that "under common industrial practices" would have been produced from fossil resources. It became apparent that limestone producers capture their own carbon dioxide emissions to produce precipitated calcium carbonate, which has its own range of applications. Thus, under the original terminology, the "common industrial practice" referred in case of PCC to the use of recycled CO_2. This would have resulted in a "No" for the substitution of fossil carbon and appears to be problematic in general: If only fossil-based processes were allowed to count as substitution, already existing CO_2 recycling receives no credit even though they use synergetic and environmentally advantageous solutions.

During the project discussion on the 5th of July 2018, it was once again emphasized that the substitution character is one of the key aspects and advantages of CCU and that every additional recycled carbon is principally welcome. Nonetheless, it was agreed upon that, due to the universal applicability of substitution to all CCU processes, this criterion is not critical for a final yes/no decision in regards to ETS deductibility. The use of CO_2 is always associated with considerable costs, which is why CCU processes are only carried out if it results in a marketable product. Usually, this product substitutes other products based on fossil raw materials. From here, it is difficult to further differentiate the fate of the carbon through the ETS monitoring system because it is often not possible to follow the exact process chain. Instead, the project agreed that the amount of CO_2 used and how much of it is bound in the CCU product/material are essential parameters for judging a CCU process. Therefore, the substitution criterion has been removed from the decision tree, but remains a key argument in favour of CCU.

2.1.5 Criterion 5 – Chemical stability and lifetime duration: How long will the carbon be stored in a product and how stable are the chemical products won by CCU?

According to the ECJ judgement on Schaefer Kalk, the binding of CO_2 in a "chemically stable product" is decisive for determining that the transferred CO_2 is not classified as an emission. Despite this legal situation, from a climate mitigation perspective it might be more relevant how long the CO_2-binding product is actually used, before the stored carbon is released back into the atmosphere in the form of CO_2 – e.g. through incineration. Liquid fuels, such as methanol or kerosene won through CCU, are completely stable from a chemical point of view, but have a very short duration of use and release their carbon into the atmosphere quite quickly. However, this aspect is also cause for controversy with many LCA experts arguing which lifetime is actually beneficial enough for the climate in order to justify a more positive evaluation for some products compared to others in LCA methodology. This will be further discussed in the background paper produced in WP2.

Similar to the discussion of other criteria, it needs to be considered that the usage and life cycle of materials won from CO_2 cannot be traced in practice. Often, chemicals and materials are being processed through many different stages and it cannot be tracked, whether methanol, for example, is used as a platform chemical for fuels, for solvents or for polymers. It was discussed whether the criterion "further transformation of the CO_2" itself could also be included in the decision on deductibility, but this approach was rejected as unfeasible. A transformation per se is not something positive or negative; climate impacts depend on utilisation pathways and overall energy balances.

Again, different solutions are conceivable:

a) Ranges could be determined as 'typical' life time durations for a basket of materials that can be made from CO_2-based chemicals. It needs to be discussed whether such a method is scientifically feasible and doable, as well as implementable in the monitoring system.

b) The aspects chemical stability and life time duration could be treated with secondary focus only. Instead, the criteria could focus on the aspect that all CCU processes should substitute virgin fossil carbon. That would mean that criterion No. 4 (substitution of fossil carbon) in combination with criterion No. 9 (energy source) would play a central role in the evaluation. This would, however, also mean that in contradiction to applicable law, chemical stability is not the decisive aspect for deductibility. Because even the use of CO_2 won from CCU dry ice production or fire extinguishers – both a direct use of CO_2 and with dry ice having a very short life time – would replace virgin carbon from fossil sources (natural gas) and thus contribute to climate mitigation.

Based on the discussions within the project, it has been concluded that chemical stability is of high relevance as a criterion due to the prevailing legal situation. The criterion, laid down by the ECJ, states that "CO_2 needs to be stably bound in a chemically stable product". Since most CCU processes reduce the CO_2 and only bind the carbon, this definition should be expanded to include the carbon stemming from a CO_2 stream if it is bound in a chemically stable product. After further discussion, it was noted that this is actually not against the ECJ judgement, as it was explicitly targeted at the Schaefer Kalk case. It does not exclude the possibility for further criteria when judging other cases next to the Schaefer Kalk PCC production. Because of this flexibility, the criterion is removed in order to simplify the final decision tree and avoid potential difficulties with tracking chemicals and materials. Approach a) regarding the lifetime duration of products will furthermore be discussed in WP2.

Excursus: Applying the criteria to direct CO_2 utilization

It can be difficult to define the borders for this criterion because the term chemical stability is not clearly defined: In principle, CO_2 is a stable product in itself, but following the ECJ judgement the CO_2 needs to be bound (in a chemically stable product). In the case of direct use this does not happen, albeit CO_2 from other sources still gets substituted. As of today, CO_2 for direct use largely comes from fossil sources (methane). If the definition would be changed to carbon instead of CO_2, the carbon becomes stably bound in the carbon dioxide molecule. For now (and following the ECJ judgement definition), the chemically stable bound criteria cannot be strictly applied for direct CO_2 utilization, but it still supports the overall intention of substituting fossil carbon.

2.1.6 Criterion 6 – Proof of carbon source: How can the type of carbon stored in a product (CCU-based or non CCU-based) be verified?

In principle, it is possible to differentiate biogenic or atmospheric carbon from fossil carbon through ^{14}C analysis. However, it is not possible to differentiate virgin fossil carbon and recycled carbon won through CCU from fossil CO_2, even if it is processed via biological processes (algae, biotechnology or even plant cultivation in greenhouses fed by industrially produced CO_2). This criterion does not seem to be helpful to decide on deductibility and will not be elaborated on in the following discussions. This means that all sources of carbon will be accepted in the scope of this project.

2.1.7 Criterion 7 – Other greenhouse gases: Will other greenhouse gases be used or destroyed, such as N_2O?

Aside from the use of CO and CO_2, new technologies could also enable the usage of other greenhouse gas emissions. At the moment and in the nearer future, especially the use of nitrous oxide (N_2O, also called laughing gas) could be relevant. Emitting installations obligated to report and surrender allowances for N_2O emissions are producers of nitric acid, adipic acid and glyoxal. A potential use of N_2O emissions could be the synthesis of urea and nitrogen-based fertilizers, which are so far being won from airborne ammonia (NH_3).

However, after further discussions it became apparent that the fate of other greenhouse gases cannot constitute a separate criterion; they need to be treated the same as CO_2 and other emissions. But it should be considered that there might be CCU processes that lead to the production of other relevant GHGs, for example methane emissions through anaerobic processes. To avoid that processes with such negative end up in the ETS, they could similarly to CCU processes be put on the "blacklist" discussed in 2.1.1, if there is reasonable doubt or proof.

2.1.8 Criterion 8 – Double counting: How can it be ensured that no double counting occurs under the ETS and RED systems? How can it be ensured that fossil emissions deductible due to potential future CCU regulations do not disappear completely from the accounting system?

In general, **double counting** refers to the faulty practice of counting the value of a good more than once. In this project, it should be differentiated into two different issues:

On the one hand, double counting is relevant for national greenhouse gas inventories. These inventories have to be drawn up under the United Nations Framework Convention on Climate Change (UNFCCC) commitments on reporting on inventories of anthropogenic emissions of greenhouse gases. The Intergovernmental Panel on Climate Change (IPCC) produced inventory methodologies that are regularly revised and updated. The latest version are the 2006 Guidelines (IPCC, 2006) which cover not only technical methodologies but the whole system required to produce regular, high-quality inventories with quality assurance and quality control, documentation and reporting. These IPCC guidelines also make recommendations to avoid double counting of emissions, for example between biomass combustion and energy statistics (volume 2 "Energy", chapter 2 "Stationary combustion", segment 2.3.3.4 "Treatment of biomass") , the non-energy use of fuels (volume 5 "IPPU, chapter 5 "non-energy products from fuels and solvent use", segment 5.1 "introduction" and segment 5.2.2.4 "completeness"), and waste as a potential fuel (volume 5 "Waste", chapter 5 "Incineration and Open Burninf of Waste", segment 5.5 "completeness" and segment 5.8.2 "reporting and documentation). Similar recommendations would be necessary for CCU in the ETS, to avoid that an emission gets counted twice, first in the ETS and again outside of the ETS realm.

On the other hand, it can become a potential pitfall of crediting the avoidance of GHG emissions more than once, which can become reality when political instruments overlap or have impact on different parts of the value chain of a resource or material. For CCU technologies this can become a reality because they act within the spheres of both the Renewable Energy Directive (RED) and the ETS system.

In light of the proposed revision called RED II, CO_2-based fuels are included as a potential option that might count into the 14% renewable energy quota for transport. In practice, the term CCU fuels is not included in the RED II, instead the directive talks about two potentially CCU-based fuels:

- renewable liquid and gaseous transport fuels of non-biological origin (ReFuNoBio)
- recycled carbon fuels

ReFuNoBio is defined as "liquid or gaseous fuels which are used in transport other than biofuels whose energy content comes from renewable energy sources other than biomass". This definition only qualifies the energy source but not the carbon source, which only prerequisite is being non-elastic, i.e. it does not respond to increased or reduced demand from CCU processes. As a consequence, as long as renewable energy sources are used for transformation processes, all kinds of CO_2 sources can be accepted, so that for example atmospheric CO_2 or pure CO_2 waste gas streams from e.g. power plants could count as ReFuNoBio.

Recycled carbon fuels mean "liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin […] and waste processing gases and exhaust gases of non-renewable origin which are produced as an unavoidable and not intentional consequence of the production process in industrial installations". An example would be flue gases from steel or concrete production, where the exhaust gas can serve as the energy source for transformation processes.

Both classifications require verified GHG emissions savings, 70% for ReFuNoBios and a to be determined minimum threshold for recycled carbon fuels. Achieving these savings, ReFuNoBios count towards the 14% target of renewable energy in transport and member states can individually decide whether to also include the contribution from recycled carbon fuels into their renewable energy share of the transport quota.

It needs to be discussed how it can be ensured that fossil emissions do not completely disappear from the accounting system. For example, in the light of future CCU regulations in ETS a power plant might capture their CO_2 emissions and transfer them to a biodiesel producer, so that it would not have to surrender allowances within the ETS. The ReFuNoBio producer purchasing this CO_2 in order to create fuel through a power to liquid process, might count the fuel towards the renewable fuel targets of the revised RED II, even though the CO_2 originated from fossil sources. As a result, the fossil carbon will be released to the environment, but the emission is neither accounted for by the plant operator nor the fuel producer – it "vanishes" from the system because the CCU process receives a credit both in the ETS and the RED. Double counting occurs.

Double counting is a potential issue also recognized by the EU, as is indicated by the statement that by "31 December 2021, the Commission shall adopt delegated acts[...] by specifying the methodology for assessing greenhouse gas emission savings from renewable liquid and gaseous transport fuels of non-biological origin and from recycled carbon fuels, which shall ensure that credit for avoided emissions is not given for carbon dioxide the capture of which has already received an emission credit under other provisions of law" (European Parliament, 2018). Therefore, one should be aware of the potential of double counting. But within the scope of this project and a simple system of "yes/no" decision regarding deductibility, the problem could only be highlighted and not further elaborated on. As indicated by the above citation, it is much more likely that these aspects will be incorporated in a wider political process on a higher level.

2.1.9 Criterion 9 – Energy source: Will energy be needed in the CCU process, and if yes, what are the energy sources?

For every CCU process' climate balance, it is crucial whether the utilisation of the CO_2 requires energy, and, if yes, which kind of energy source and how much energy is used. In earlier versions of this report, the term "additional energy" was used, but during the project discussion in July 2018 it was removed in order to improve clarity. Originally, the idea was that any external energy required to transform CO_2 into a CCU product would have to be taken into account. However, this did not properly reflect some particular use cases. A gas stream can e.g. already contain useable amounts of fossil-based energy and therefore require less or no further energy input. Simply put, this criterion therefore considers whether a CCU process requires energy for the reduction of CO_2, and if so, from which sources the energy is provided.

It is important that the entire energy consumption of the CCU project must be calculated and accounted for. This involves the capture of the gas, the purification and the transport from supplier to user, expressed in the following formula:

$$E_{capture} + E_{purification} + E_{transport} + E_{utilisation} = E_{CCU}$$

The following two kind of CO_2 transfers can be distinguished:

a) **Fossil energy contained in a used waste gas stream needs to be offset with renewable energy:** Some emission streams do not just contain CO_2 but also relevant amounts of carbon monoxide (CO) and hydrogen (H_2). Those waste gases are for example emitted by installations in the steel or chemical industries. These gases often contain considerable amounts of energy besides CO_2 and can thus be processed without requiring further energy input. This is also true for processes where CO_2 reacts with other educts with high energy content like epoxides via a catalysed process for e.g. polyols. For the criterion itself, it is not relevant whether such CO and hydrogen-containing emissions are avoidable or not. But nowadays, when originating from fossil resources such as coal or natural gas, waste gas emissions are a fossil energy carrier. If this energy is used for a CCU process, it is at the same time not available for other purposes it was used for before. To account for the fact that the energy contained in the waste gas is fossil based, it would have to be offset through alternative solutions. For example, the same amount of energy could be generated in a renewable way and this renewable energy can be used wherever the energy might be missing after the CCU implementation.
Forward-looking, for e.g. the steel industry, there are alternative routes for steel production (direct reduction and electric arc furnace), which can already be run with significantly less C and, in the medium term, potentially almost without fossil C. However, if the valuable gases of the steel industry are used in the chemical industry, the incentives to switch to low-carbon or non-fossil production routers are lower. Such lock-in effects of current technologies are to be avoided.

   In this regard, the blacklist could become a viable tool where processes can be added when feasible low-carbon alternatives for those are available. This extends the scope of the blacklist to not only remove CCU processes that directly have undesirable environmental side effects, but also remove politically undesirable CCU processes, e.g. in order to avoid lock-in effects.

b) **Additional energy for usage needs to originate from renewable sources:** When using only CO_2, it is usually necessary to deploy additional energy to reduce the molecule and use the carbon. From a climate perspective, it would be absolutely counterproductive to use high emission energy sources for this process, since e.g. for every amount of CO_2 which is made usable via electricity from coal, four or five times as much CO_2 will be emitted (own estimations by nova-Institute). The use of renewable energy sources is therefore essential to design CCU processes in a climate-friendly way.

Either a), b) or a mix of both needs to be fulfilled in order to recognise the deductibility of CO_2 transferrals to CCU processes. It needs to be discussed how fulfilment can be proven, but at this stage it should already be highlighted that an entirely on renewable energy based, 100% clean CCU process is unrealistic – For example, it seems hard to guarantee that the transport energy $E_{transport}$, if required, could be fully renewable. A CCU process that is mostly (e.g. 95%) based on renewable energy will only be allowed to recognise the deductibility to that degree, but still support the overall goal of decreasing emissions.

A final point of consideration is the definition which energy sources can be considered as renewable energy. The following options were considered as theoretically feasible:

1. Certified renewable energy

2. Energy already covered under the ETS

While the first item is rather straight-forward, the second point stirs considerable discussion. Following ETS logic, an installation covered by the ETS scope is also covered by the absolute ETS cap. Its emissions are limited and need to be reduced with the linear reduction factor or other installations need to mitigate more emissions than the linear reduction. Energy used for any step of a CCU process originating from an ETS installation would therefore already be covered by the same system in which deductibility shall be checked. This would also include energy sources like H_2 from industrial processes in e.g. the steel sector.

Building on this, electricity from the grid is an interesting case, as it is the most readily available source of electricity. But the grid mix in Europe includes both fossil ETS and fossil non-ETS energy sources, so while emissions subject to the ETS are accounted for, fossil non-ETS installations could lead to additional emissions that are not covered by any system[1]. Fossil grid electricity emissions are in large parts (assumed at least 90%, likely even much higher) covered under the ETS. Therefore, it could be argued that ETS covered energy and the electricity grid mix might represent acceptable energy sources for CCU under the ETS scheme.

That being said, supporting CCU of fossil energy sources is a precarious position, as it would provide incentives to continue or prolong fossil-based industries. It especially conflicts with the political goal of increasing the share of renewable energy in Europe. Furthermore, with a rising environmental consciousness of society, it would also be difficult to convey to the public.

As a consequence, it is recommended that for the energy of CCU processes, only renewable energy should grant deductibility within the ETS. This decision would also be well aligned with the current revision of the RED II and an approach similar to the RED II proposal for using electricity can be envisioned:

1. When grid electricity is used for CCU processes, the average share of electricity from renewable energy sources in the country of production, as measured two years before the year in question, may be used to determine the share of renewable energy.
2. Electricity obtained from a direct connection to an installation generating renewable electricity can be fully counted as renewable electricity if the installation
   a. comes into operation after or at the same time as the CCU installation
   b. is not connected to the grid or is connected to the grid but can provide evidence that respective electricity has been provided without importing electricity from the grid.
3. Electricity imported from the grid may be counted as fully renewable if the electricity is produced exclusively from renewable energy sources, the renewable properties and other appropriate criteria have been demonstrated and the renewable properties are claimed only once in one end-use sector.
4. As mentioned before, there are industry gases that contain inherent energy that could be utilized for CCU processes. Such sources, for example waste gases in the chemical industry, would have to be compensated by the above options.

Excursus: Energy use under Schaefer Kalk judgement

We have pointed out the importance of renewable energy for CCU processes. Under the existing Schaefer Kalk judgement, the kind of energy source was never considered, which means that the use of fossil energy for CCU processes is allowed even if it is unfavourable from a climate perspective. While, in case of the PCC production, the additional energy is only a marginal amount (required for stirring the calcium hydroxide slurry by a high shear mixing agitator and the addition of water at temperatures of 30-50°C), it is indeed common practice to use fossil energy for the process. This is an important issue: If the

[1] E.g. a <20 MW turbine

judgement were valid for chemical or fuel CCU processes, the CO_2 capture and recycling might lead to higher emissions than the simple release of the gas (cf. chapter 2.1.9b). In these cases, the Schaefer Kalk judgement would be in direct conflict with the EU ETS goal to reduce greenhouse gas emissions.

2.2 Interim conclusion: Revised list of criteria

Based on the early discussions in the project, a preliminary ranking of criteria was carried out, which resulted in three principal groups of criteria:

1) Criteria which seem feasible for a yes/no decision with regard to deductibility (priority 1)

2) Criteria which will be considered with a secondary focus; perhaps for qualitative discussions or a quantification of deduction after a yes decision has been taken (priority 2)

3) Criteria which seem unfeasible for a yes/no decision which will not be considered further (priority 3)

Based on conclusion of the project meeting in July 2018 and consequent discussions, the ranking of criteria was updated and finalized. From the classification and project discussions – with all reasons explained in detail in chapter 2.1 – the following list of criteria and priorities emerges:

Table 1: Revised list of criteria for a yes/no decision including prioritization

Criterion No.	Criterion	Priority	Comment
1.	Life Cycle Assessment	**1**	only relevant for CCU processes on the future “blacklist”. In these cases, highly relevant
2.	Percentage of CO_2 actually being bound	**2**	not relevant for yes/no decision; only quantification of deductible emissions after yes decision based on other criteria
3.	Non-avoidable GHG	**3**	not relevant for yes/no decision; avoidability cannot be finally answered
4.	Substitution of fossil carbon	**0**	Crucial, but is assumed to be always the case
5.	Chemical stability and lifetime duration	**3**	chemical stability important due to legal situation of Schaefer Kalk, but ECJ judgement allows additional criteria for other CCU measures; lifetime duration will not be considered
6.	Proof of carbon source	**3**	Excluded, not possible to differentiate virgin fossil CO_2 from CO_2 of CCU process
7.	Other greenhouse gases	**3**	not relevant for yes/no decision; all GHG must be treated the same
8.	Double counting	**3**	unfeasible for yes/no decision; must be answered in further political process
9.	Energy source	**1**	relevant; complete energy demand has to be covered by accepted sources

The substitution of fossil carbon has been given priority “0”, as it constitutes the key argument for allowing CCU into the ETS. Because it is relevant for all CCU processes, it is at the same time not feasible to differ between individual CCU processes. The criteria ranked as priority “1” are included in the decision tree (see Figure 1) as concrete input to the yes/no decision on deductibility of CO_2 emissions. This is on the one side the LCA for the blacklist, on the other side the energy source. “Lifetime duration” as a sub-aspect of chemical stability will not be included due to the monitoring restrictions explained above. Criteria ranked with priority “2” are reflected in the decision tree, but are not concrete inputs to the yes/no decision. Instead, the percentage of CO_2 actually bound is important for calculating the final deductibility of transferred GHG for CCU process. For a few criteria (substitution, chemical stability and lifetime duration, energy source) some background information is provided in chapter 3 to give further context to the debate. Criteria ranked with priority “3” will not be assessed further in WP2.

Throughout the development of criteria to evaluate CCU technologies, the six underlying principles of monitoring, as defined in the monitoring regulation[2], GHG emissions have always been considered. Operators of installations within the EU ETS are asked to follow those six principles when monitoring their GHG emissions, which includes emissions used in CCU processes:

1. Completeness
2. Consistency and comparability
3. Transparency
4. Accuracy
5. Integrity of methodology
6. Continuous improvement

The first principle of **completeness** refers to a comprehensive coverage of all process and combustion emission source streams of an installation. This also includes any smaller source streams as long as the threshold of any of the other activities is exceeded. Secondly, over the years monitoring and reporting needs to be **consistent and comparable.** Arbitrary changes of the monitoring approach are to be avoided. Thirdly, **transparency** of data collection, compilation and calculation is key to ensure that the verifier and the authority comprehend the monitoring approach of the operator. **Accuracy** as the fourth guiding principle requires due diligence by the operators and the adherence to required accuracy levels. To avoid unreasonable costs, the required level of accuracy is defined in a tiered approach depending on the amount of annual emissions. Accuracy is closely connected to the fifth principle of **integrity of methodology**. It obligates the operator to implement a monitoring system that achieves reasonable assurance when being tested. In particular the verifier must be able to conduct an intensive test of the data and methodology to ensure reporting was done correctly. Finally, any operator should strive for **continuous improvement** in the monitoring approach. If higher levels of accuracy are achievable under reasonable costs, the operator is encouraged to improve his/her monitoring system.

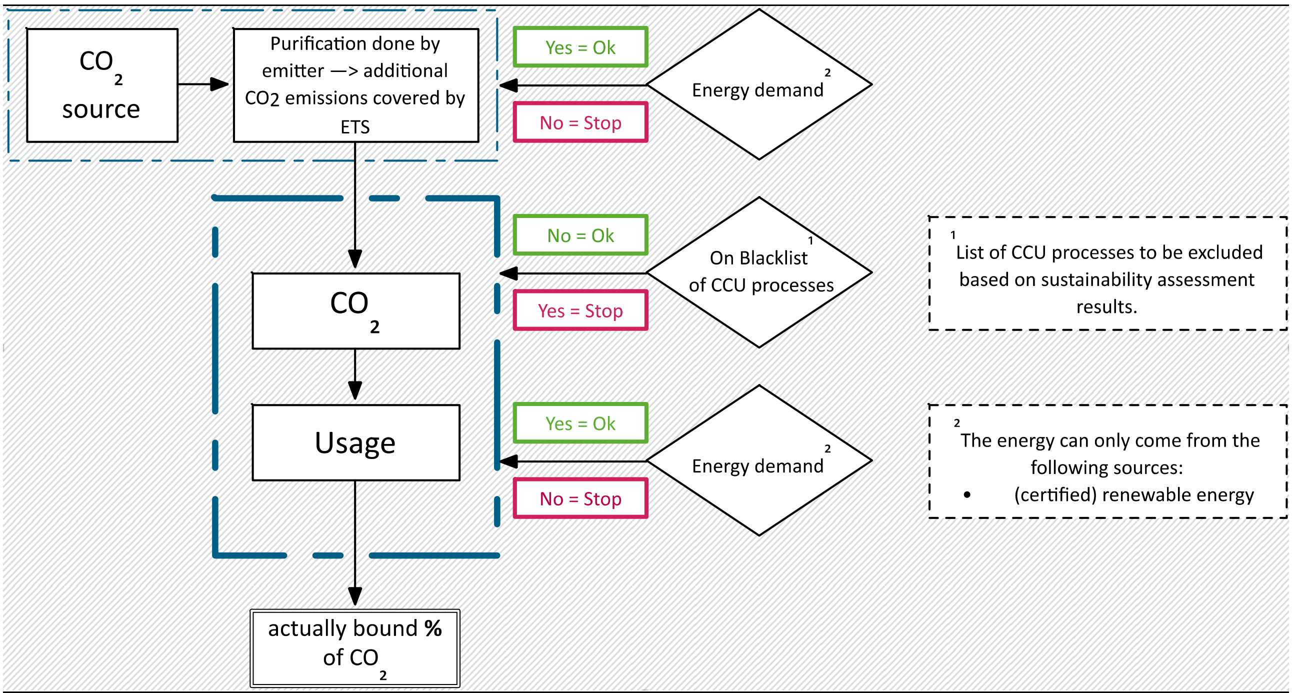
Monitoring the CCU supply chain in, from and to ETS-installations will have to adhere to above six principles. Each step in the decision tree shown in Figure 1 needs a check considering those principles. E.g. the assessment of additional energy in the CCU process requires to be proven in a transparent and accurate way based on an integer methodology.

[2] Commission Regulation (EU) No 601/2012 of 21 June 2012 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council.

2.3 Decision tree

From the classification carried out in chapter 2.2, a decision tree can be drawn to support a decision regarding deductibility of CO_2 emissions which are transferred to CCU installations:

Figure 1: Decision tree regarding deductibility of CO_2 emissions



The figure shows the decision tree to be followed to support the deductibility decision of a CCU process

Source: Original drawing by the nova-Institute and Navigant

The decision tree starts at the top left of the figure, at the CO_2 source. Here, at the emitter, the CO_2 gets captured and purified up to a level that allows further utilization. Afterwards, the CO_2 is transferred to the user, who will use it for a specific process, product or function. Both at the emitter and the user, any energy demand to utilize the CO_2 has to be checked whether and to what extent it fulfils the renewable energy criteria. Additionally, the blacklist of CCU processes has to be checked to ensure that the process is not on that list. If it is blacklisted, or if the energy demand is not saturated by the accepted sources, the process has to be rejected in regards of ETS deductibility. If the process is not rejected, in the end the actually bound percentage of CO_2 can be deducted from the emissions accountable under the ETS.

Example: 20% of E_{CCU} comes from fossil sources of an incineration plant, the remaining 80% is covered directly by renewable energy. The actually bound CO_2 in the final product amounts to 75%. The factor for the deduction of the forwarded CO_2 quantity is therefore:

0.8 (energy) * 0.75 (actually bound CO_2) = 0.6 or 60%

The decision tree has been internally discussed and tested for CO_2-based chemicals and fuels mainly from the area of organic chemistry. For these materials, the tree is feasible and applicable within the EU ETS framework.

In conclusion, the existing ECJ judgement does not consider some aspects that are critical for a comprehensive approach towards CCU technologies. Different pathways towards a viable solution have to be discussed: Can the existing legislation be adapted to include renewable energy sources as obligatory? It was discussed whether it might make sense to design two decision trees: One valid for chemicals and fuels and a second for mineralisation, with the only difference in the renewable energy requirement. This would allow to be consistent with the Schaefer Kalk judgement for mineralisation processes, while ensuring the realisation of EU ETS goals for as many CCU processes as possible. The idea was finally rejected because Schaefer Kalk and mineralisation processes in general would also have to meet the energy criteria.

3 Work Package 2: Technologies and background information

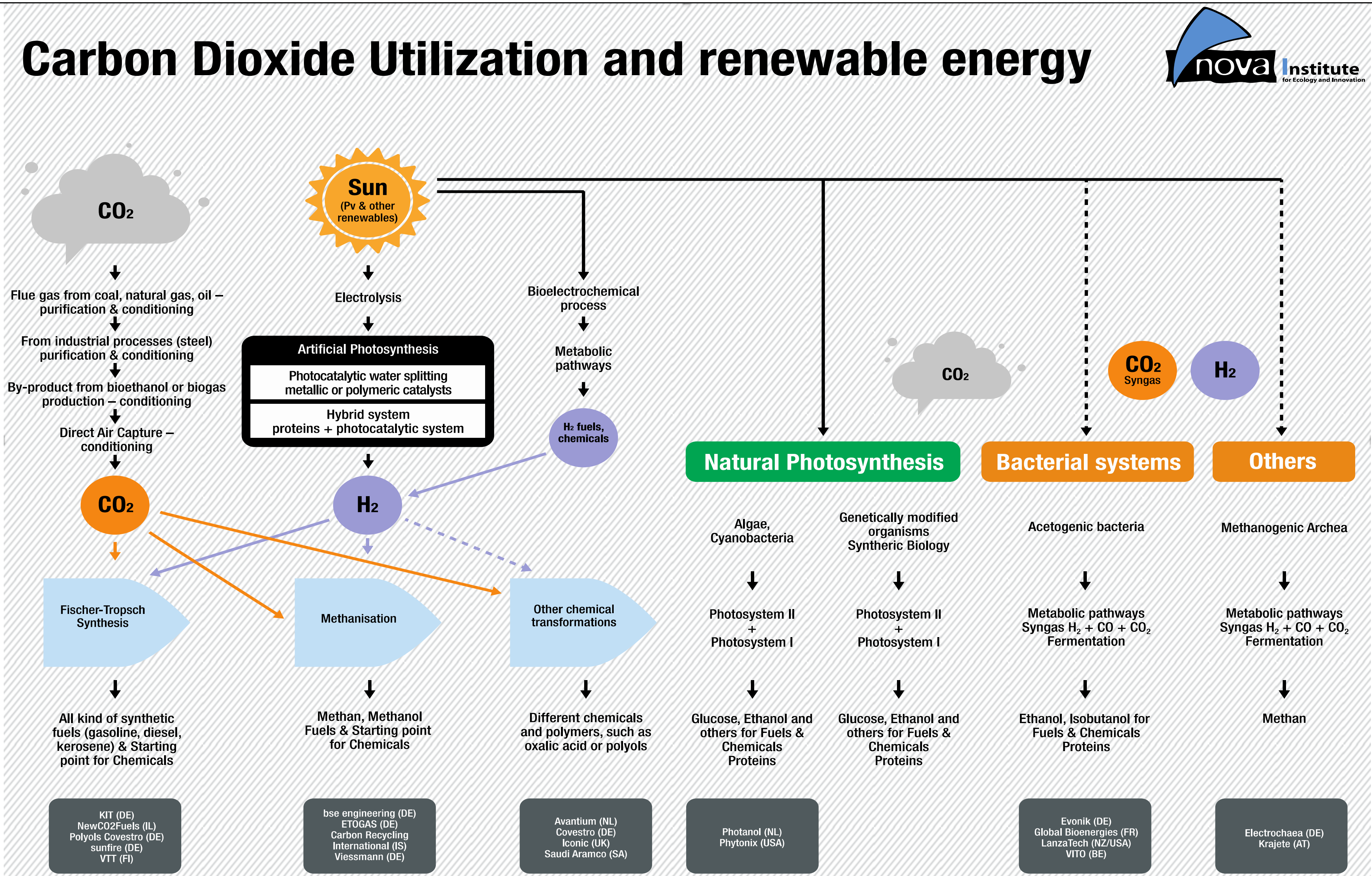
The list of technologies in the focus of the project, supposed to give an overview for further discussion, is as follows:

1. Direct usage for greenhouses, dry ice, beverages, solvents (e.g. for decaffeination), Enhanced Oil Recovery (EOR), textile cleaning and other applications
2. Methanisation of CO_2 – Power to Gas (PtG)
3. Methanol production and further processing (Dimethyl ether (DME), Oxymethylene dimethyl ether s (OME), etc.)
4. Fischer-Tropsch-Technology to produce synthetic naphtha („Blue Crude“) and kerosene – Power to Liquid (PtL)
5. Urea synthesis
6. Mineralisation through production of carbonates (calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), also PCC) as alternative construction materials, for neutralisation of waters and for other applications
7. Usage for the production of polyols and polymerisation other than from biogenic oils to produce polycarbonates and polyurethanes
8. Biotechnological CO_2 usage through algae, cyanobacteria and acetogenic bacteria (for sugars, ethanol, butanol, lactic acid, oils, proteins and other products)

Because only a few criteria of WP1 ended on the final list, the originally intended ranking of CCU technologies was no longer feasible. Instead, this chapter now focuses on background information on a number of topics that are relevant for understanding and assessing CCU technologies. Chapter 3.1 gives background information on the substitution argument for CCU processes, chapter 3.2 briefly touches upon the term chemically stable and chapter 3.3 takes a closer look at the energy source. Table 3 summarizes the first 3 chapters. Then, chapter 3.4 takes a brief look at average life time duration of CCU products, chapter 3.5 is about LCA in the context of CCU processes and chapter 3.6 talks about the importance of considering only the actually bound amount of CO_2.

To give a first orientation, Figure 2 provides an overview of CCU technologies currently in use or in development, including options for the CO_2 feedstock and renewable energy supply.

Figure 2: Overview on CCU technologies with combination of CO_2 feedstock and energy source (nova 2017)



The figure illustrates the available technological and natural pathways for utilizing carbon dioxide

Source: Original drawing by nova-Institute, 2017

This list can be further structured into three main categories of use types, for which the application of decision criteria determined in WP2 need to be interpreted and evaluated slightly different. These categories are direct uses, organic chemistry and inorganic/mineral uses.

Table 2: Overview of established CO_2 uses

Direct uses	Organic chemistry	Inorganic / mineral uses
Greenhouses	Methanisation – Power to gas (PtG)	Production of carbonates for construction materials (mineralisation)
Fire extinguishers	Methanol and further processing (DME, OMEs, etc.)	PCC for paper colours, dyes, and others
Dry ice	Fischer-Tropsch technology to produce synthetic naphtha ("Blue Crude") and kerosene – Power to Liquids (PtL)	Water neutralisation and buffering
Beverages	Urea synthesis from ammonia	Cement curing
Sterile packaging atmospheres	Carbamates, lactones, acetylsalicylic acid (ASA), formic acid and other fine chemicals	Bauxite residue treatment
Solvents (supercritical CO_2), e.g. for decaffeination	Polyols, polycarbonates and polyurethanes	
Heat transfer materials	Biotechnological pathways to produce ethanol, butanol, lactic acid, Polyhydroxybutyrate (PHB) and other products (algae, cyanobacteria and bacteria)	
Enhanced Oil and Gas Recovery (EOR, EGR)	Power to Proteins – production of proteins based on CO_2 utilisation (PtP)	

One special case in this direction is the production of alternative proteins based on CO_2-based fermentation processes and the use of algae/cyanobacteria for feed and food applications (PtP – Power to Proteins). In this case no substitution of "a product which otherwise would be made from fossil resources" exists even if the CCU process replaces CO_2- or generally GHG-intensive processes like livestock-based meat production, agricultural protein production (esp. soy bean production) or conventional fish feed production based on fished fish from the oceans.

The processes for the three categories – while of course different for each specific product within each category – have some commonalities which should be considered when evaluating the deductibility of CO_2 emissions going to any of these categories.

3.1 Background information: substitution of fossil carbon

In nearly all cases, a given product made from a CCU process substitutes another product which is otherwise made via the use of virgin carbon from fossil sources. This is true especially for products from organic chemistry, where fossil carbon is used as the main feedstock.

In case of the direct uses and for the state-of-the-art production of urea and methanol, CO_2 usually is produced from the fossil resource natural gas (methane) together with hydrogen via a steam reforming process and water-gas shift reaction. This means that in these cases, fossil carbon can be directly substituted by CCU processes using CO_2 from emissions together with hydrogen produced via electrolysis of water using renewable energy instead of utilising the virgin resource methane. This also is the base for a PtG process where CO_2 is processed to methane and directly substitutes methane from natural gas.

The Fischer-Tropsch process (FT) is used to produce a mixture of organic products called naphtha from syngas. Syngas consists of CO_2, CO and hydrogen and can be produced either from natural gas, coal gas, gasified biomass or from hydrogen enriched CO_2 from flue gases. The resulting product mixture – naphtha – can be used as a direct substitute of fossil naphtha (from crude oil) or the resulting products such as fuels (benzene, diesel and kerosene) and chemicals used as base chemicals in the chemical industry (e.g. to produce ethylene and propylene in a cracker process) and even asphalt.

In the polyol production, the CO_2 reacts with epoxides, mainly ethylene oxide (EO) and propylene oxide (PO), to polyols. These can then be used for a polymerisation to CO_2-based polymers like polypropylene carbonate (PPC), polyethylene carbonate (PEC), polyurethanes (PUR) and other materials. In these cases, the CO_2 used in the CCU process substitutes educts based on fossil carbon or the resulting materials substitute conventional petro-based polymers and plastics. The same is true for polymers produced via biotechnology processes such as polyhydroxybutyrate (PHB) or polylactic acid (PLA) (based on lactic acid), which can also be produced e.g. by fermentation of glucose or from corn starch, but where the main idea is that these plastics can replace fossil-based alternatives like polyethylene (PE) or polystyrol (PS). In other cases of biotechnologically produced molecules petro-based chemicals can be directly substituted or substituted by functionalities. And finally, CCU mineralisation processes for mineral carbonates are under development and might play a role in the future construction sector.

3.2 Background information: Chemically stable products

All products resulting from the above shown processes can be classified as chemically stable. This means that the CO_2 or the carbon stemming from the CO_2 is bound in a product and not released directly to the atmosphere. The lifetime duration of the utilization can differ between these products from very short periods, as we can expect from fuels or CO_2 in beverages, to longer periods, for example when bound in solvents or packaging atmospheres. However, lifetime duration is not mentioned as an aspect in the Schaefer Kalk judgement, only the binding of CO_2 and chemical stability of the product – which is given for all these products from a chemical-technical point of view.

3.3 Background information: Energy source

As already described above, conversion processes for CO_2 require energy that may come from different sources. In some cases, the energy content of flue gases already brings in enough energy for the conversion process (e.g. in syngas) or the additionally needed energy is produced by reaction partners (e.g. epoxides). Often times, this energy is already utilized in other processes and thus not readily available for CCU processes. In other cases, especially in biotechnological and biochemical conversion processes, the required energy is produced by organisms using sunlight in a photosynthesis process (crops in greenhouses, algae, cyanobacteria). Alternatively, the direct use of sunlight is possible in artificial systems with photocatalytic devices (artificial photosynthesis). Other microorganisms can also use other forms of energy such as sugar, heat or electricity which can be won from renewable sources.

In most of the conversion processes hydrogen is a key energy provider to react with CO_2 to valuable products. This is true for all PtG and PtL processes as well as for the bacterial conversion of CO_2. In these cases, the hydrogen production can be based on water splitting or on steam reforming from natural gas. For sustainable CCU processes it is crucial not to produce and release a higher amount of CO_2 through the energy required for the reduction of the CO_2, than what is actually utilized in the CCU process. This means that only a hydrogen production with an optimized water splitting system (electrolysis) based on renewable energies like solar, wind, water, geothermal or tidal energy use is suitable. Also, one should always be mindful that potentially electricity or water could be used directly to achieve the same product or service that the CCU process under consideration would deliver.

Table 3: Classification of CCU process and general description

Product	Process	Substitution of	Chemical stability	Add. energy required?
Direct usage	-	Fossil carbon (mainly natural gas)	Stability depends on usage, CO_2 not chemically bound	None to Very Low
Syngas	Hydrogen enrichment	Fossil carbon (coal, natural gas)	No	High
Urea	Haber-Bosch process	Fossil carbon	Yes	Medium to High
Methanol, DME, OME	Methanol production process	Fossil carbon	Yes	High
Naphtha / Blue Crude	Fischer-Tropsch synthesis based on syngas	Fossil naphtha and resulting products	Yes	High
Polyol, PPC, PUR	Epoxide reaction	Educts based on fossil carbon	Yes	None
Polymers like PHB or PLA	Biotechnological processes	Fossil-based polymers	Yes	Medium to High
Fine chemicals (e.g. carbamates)		Fossil-based alternatives	Yes	Medium to High
Carbonates and construction material	Mineralisation	cement & concrete (energy-intensive production)	Yes	Low to Medium
	Water neutralisation and buffering		Yes	Very Low to Low
Proteins	Biotechnology	Animal and plant proteins	Yes	Medium to High

3.4 Background information: Lifetime duration of products from a climate perspective

For the lifetime duration of a CCU-based product, the captured and re-used carbon will not be released into the atmosphere and therefore does not contribute to global warming. After end of life, the carbon dioxide is nonetheless released into the atmosphere, for example when the product gets incinerated for thermal energy. As mentioned in 2.1.5, the usage and life-cycle of materials won from CO_2 cannot be tracked in practice and thus considering the lifetime duration of products does not appear to be a feasible criterion for a clear yes/no decision in regards to ETS eligibility.

In this regard, the different CCU technologies bind captured CO_2 based on the lifetime durations of the products and materials they are applied for. The following table gives an overview of available CCU products and information about their average lifetime or the usual time until the bound CO_2 gets released again. It should give an indication how long the final release of emissions can be delayed.

Table 4: Average lifetime durations of CCU products/materials

Product or Material	Average lifetime duration	Comments
Dry ice	A few days	Sublimates, even when stored properly, around 5 to 10 pounds per 24 hours. Lifetime is therefore dependant on block size, but usually not longer than a couple days. (University of Rochester, 2017)
Fire extinguishers	max. 20 years	The general lifetime of a fire extinguisher is usually around 20 years. According to DIN 14406-4, fire extinguishers have to be examined and maintained every 2 years, with possible replacement of the extinguishing medium and propellant (Gloria, 2015)
Beverages	6-9 months	Carbonated beverages usually have an average shelf life of 6-9 months, largely based on the barrier properties of the packaging material.
Solvents		Durability of solvents can vary greatly and is based on the chemical/material/product they are added to.
Chemicals and plastics	Weeks to years	Packaging materials and chemical auxiliaries have on average short life times. Plastics in consumer goods could last for several years.
Fertilizers	1-10 years	Granular fertilizer has an extensive shelf life, while liquid fertilizers usually last around 8-10 years with proper storage. It can be assumed that most fertilizers are used shortly after purchase.
Fuels	Around 2-3 months	Most fuels have a recommended shelf life of less than 6 months. Based on this value, the average lifetime duration is an assumption.
Precipitated calcium carbonate	Depending on usage	PCC is mainly used in the paper industry, where it increases the life time of paper to an average life time of 500 years. (Sezer, 2013)

3.5 Background information: Life Cycle Assessments of CCU processes

Life cycle assessments are a powerful tool for comprehensive environmental footprint calculations, which not only include GHG balances, but also further impact categories such as non-fossil energy requirements, the eutrophication and acidification potential, photo smog, etc.

Using CO_2 as a resource offers potential to utilize CO_2 from point sources and the atmosphere, follows the Circular Economy thinking and can be an alternative raw material for low carbon fuels, chemicals and materials. As one of its key advantages, CCU substitutes fossil raw materials and their CO_2 emissions.

For years now there have been intensive discussions on how CCU processes should be treated methodically in LCAs. Various international organizations and projects have announced to publish specific recommendations in autumn 2018 that, presumably, endorse "system expansion" as the preferred method of choice. LCA standards such as from the International Organization for Standardization, in short ISO (ISO 14040 and ISO 14044, 2006), and the International Reference Life Cycle Data System, in short ILCD (JRC, 2010), deliberately leave considerable room for maneuver, depending primarily on the goal and scope.

When utilizing CO_2, there are some particularities that lead to a reignition of the old discussion about choosing the correct method (Fehrenbach et al., 2017):

- CO_2 is both a raw material and an impact category.
- CO_2 can come from different sources, fossil or biogenic point sources, the atmosphere or even from natural gas.

In order to compare entire **production systems**, e.g. comparing fossil-based traditional production with CO_2-based production, system expansion[3] is the ideal solution. With this method, you can identify whether a production system is better or worse for different impact categories without distortion through allocations or credits. Moreover, a cross-sectoral shift of burden is not possible here. In addition, it avoids the risk that each sector, supplier and user, will claim arbitrarily calculated CCU bonus for itself. System expansion is particularly important on a political level, and the results are solid and hardly assailable.

There are ongoing activities such as projects, workshops or committees working on a suitable and joint methodology for CCU processes on national, European and world level. For the evaluation of CCU measures the recently released LCA Guidelines of the Global CO_2 initiative sould be considered, where results shall be interpreted based on a system expansion scenario. The overall results compared to the reference scenario need to show significant global warming potential (GWP) savings, no additional fossil resource consumption, and only insignificant increases in other environmental categories.

Over the past few years, experts have calculated the environmental footprint and GHG balances of CO_2-based methanol, kerosene and other fuels as well as that of plastic components such as polyols and polyurethanes. Depending on their respective product or process path and applied methodology, GHG savings amounted to 20 to 90 percent compared to their fossil counterparts (cf. Table 5).

It has to be noted that the results cannot be compared directly because methodological differences between the calculations exist. Especially the allocation of GHG emissions onto different co-products can distinguish between various approaches, looking at energy (for fuels), mass (for products) or economic values – or following the RED methodology for fuels (no allocation of emissions to waste streams such as CO_2). Direct comparisons should therefore be

[3] This means expanding the product system to include the additional functions related to the coproducts.

restrained to deriving general trends. Still, the following table gives an overview of GHG emission reductions for different CO_2-based products.

Table 5: GHG reductions for various products on the basis of CO_2 in combination with renewable energies, based on different methods and sources.

Product/Material	GHG emission reduction in percent compared to its fossil counterpart	Load allocation methodology, source
Methanol derived from industrial CO_2 in combination with geothermal energy (Iceland)	90% (this value was never matched by any bio-fuel when the same calculation method was used)	Allocation: energy, methodology according to the EU Renewable Energy Directive (RED), CO_2 load-free, as it is an emission/waste. Source: ISCC, 2016
Methanol and electricity (CCU based on flue gas vs. fossil)	58%	System expansion, Von der Assen et al., 2014
Kerosene via Fischer-Tropsch or methanol route	ca. 90%	Allocation: energy, methodology according to the EU Renewable Energy Directive (RED), CO_2 load-free, as it is an emission/waste. Source: DBFZ, 2016
Power-to-Liquid with direct air capture (DAC) CO_2 vs fossil diesel	40 to 95% (depending on the power and heat source)	Allocation: energy, methodology according to the EU Renewable Energy Directive (RED), CO_2 load-free, as it is an emission/waste, but: all loads for the capturing/provision allocated to CO_2, source: Stuttgart University, 2015
Power-to-Liquid biogas CO_2 in combination with wind power vs fossil petrol, after 200,000 km	85%	CCU process gets load-free CO_2, emissions remain with the power plant, source: Audi, 2015
CO_2-based polyols with a 20-30% share of CO_2 vs fossil polyol	Up to 20%	System expansion, Von der Assen and Bardow, 2014
Polypropylene carbonate (PPC) vs PE and PET	50% (vs PE) and 60% (vs PET)	Source: SK Innovation, 2012

3.6 Background information: Percentage of CO_2 actually being bound

Today, there is an estimated global CO_2 demand of 220 Mt per year, with nearly 180 Mt being used in the chemical and fuel industries, while the remaining 40 Mt are used directly. The established production of urea is responsible for the largest part of CO_2-usage, responsible for an annual input of 114 Mt (IASS 2016). Urea is mostly used for fertilizers or the production of melamine, where large parts of the bound CO_2 are usually released again.

Depending on the process, a varying amount of carbon dioxide will be actually bound in the resulting product or material. As discussed in 2.1.1, this is not applicable for deriving a clear yes/no criterion, but it is nonetheless a critical factor when considering the overall environmental impact of a CCU technology and needs to be taken into consideration, if CCU technologies were to be deductible according to the EU ETS. In order to reliably identify the climate benefit a CCU technology offers, it is therefore necessary to quantify the amount of carbon dioxide bound in relation to the overall carbon dioxide that went into a process.

Excursus: Intermediaries in CO_2 trade

The traceability of CO_2 amounts that are transferred from one installation to another and then actually being bound in a product is of course made even more difficult if an intermediary is involved in buying and selling the gas. This is often the case if industrial gases are transported over longer distances and pipelines are not economically feasible. There are several big players on the market dealing with industrial gases, most prominently Linde (currently attempting to merge with Praxair) and Air Liquide.

Often, the CO_2, which is being bought and sold by such intermediaries is very pure and used for food or beverage applications. As such, it requires intense purification, is quite expensive and therefore not very probable to be transported over long distances only to be emitted to the atmosphere. The economic incentives that would be necessary to make such a business model of simple trade and emit the CO_2 worthwhile would probably need to be much stronger than the current ETS. However, since misuse can also not be completely ruled out, it is suggested to apply conservative estimations of the amount of CO_2 being bound in a given product, e.g. 30%. This practice is not unusual in ETS monitoring and as explained above, it is quite unlikely that the valuable CO_2 will not really be utilised (see chapter 4.2.3).

4 Work Package 3: Field test to evaluate feasibility and practicability

For work package three the final decision tree was tested for its practicability and feasibility. Two important considerations emerge for the deductibility of transferred CO_2 to CCU processes:

(1) Is the decision tree actionable in practice for operators and verifying authorities?

(2) What additional effort from both verifying authorities and operators of ETS installations is required?

Both considerations were scrutinized based on the experience and knowledge of the ETS implementation team of Ecofys, a Navigant Company. Given their large scope of projects in which ETS installation operators are supported in their reporting obligations the feasibility of the decision tree could be tested with practitioners. Furthermore, interviews were conducted with several verifying authorities to get their view on practicability and additional effort. In particular, questions such as an extended audit scope for the verification and additional documentation needed as evidence were discussed. This was done with the help of three case studies, which were selected to test the decision tree under varying CCU applications.

In the following, section 4.1 introduces the three cases, section 4.2 shows the main results of the practicability test, section 4.3 adds further case specific elements and general remarks of the verifying authorities and section 4.4 concludes.

4.1 Introduction of three case studies

Three different cases were considered in the scope of this study to reflect operational differences in applications of captured carbon.

(1) **Direct use** (Figure 3)**:** Several options of direct use of sequestered CO_2 exist, mostly in industrial applications. Examples are fire extinguishers, pH-value regulation in the paper and cellulose production or inert gas metal arc welding.

(2) **Urea synthesis** (Figure 4)**:** Carbon emissions are captured in the ammonia production and transferred to a urea installation, currently the largest application of captured carbon.

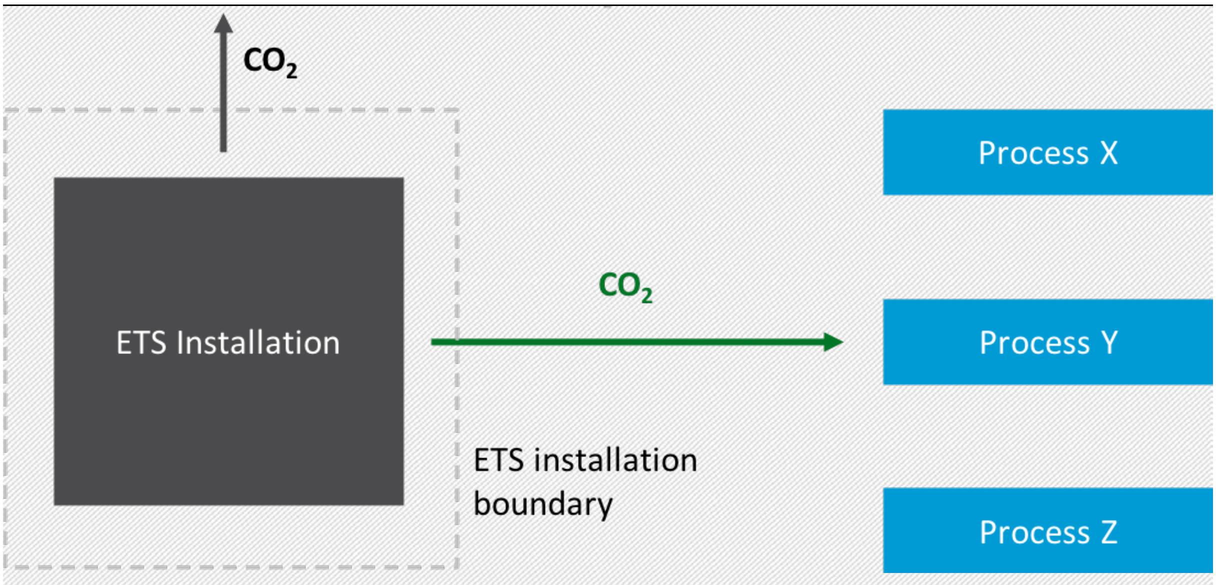
(3) **Inorganic carbonates** (Figure 5)**:** In the production of precipitated calcium carbonate (PCC) CO_2 from a calcination process is used. This was the key process of the Schaefer Kalk European Court of Justice decision.

4.1.1 Case 1: Direct use of CO_2 for mainly industrial applications

The first case study covers a range of direct applications of CO_2 in several contexts. Direct use applications are characterised by CO_2 being used in its original form taking advantage of its inherent molecular characteristics. Figure 3 shows a schematic representation of the direct use case of CO_2 from an ETS installation. Carbon capture and potentially purification can take place within or outside the boundaries of the ETS installation, capturing all or only parts of its CO_2 emissions. It could also be done by a third party. The key criterion at this stage concerns the energy use which has to be assessed in either case and either be offset with additional renewable energy supply or proven to be from renewable origin. The captured CO_2 would then be transferred either directly to the end-user or further processed via an intermediary, e.g. an industrial gas supplier.

End-users of CO_2 in this scenario are mostly companies outside the scope of the EU ETS. Applications can be found across several industries and sectors like the health sector, the food and beverage sector, the agriculture sector or the metal industry. One concrete example is CO_2 usage in fire extinguishers, where CO_2 is stored under pressure in a bottle or other container and released to block the fire's access to oxygen in case of emergencies. A second example is the usage in greenhouses, where a higher CO_2 -concentration of the air is aimed at accelerating and improving plants' growth. As a third example, CO_2 is directly used in the beverage industry to increase the shelf life of drinks (by removing oxygen) and to make them more sparkling.

Figure 3: Case Study 1/3 – Direct usage of CO_2 for mainly industrial applications



Transfer of CO_2 either directly to final application or via intermediary (e.g. industrial gas producer)

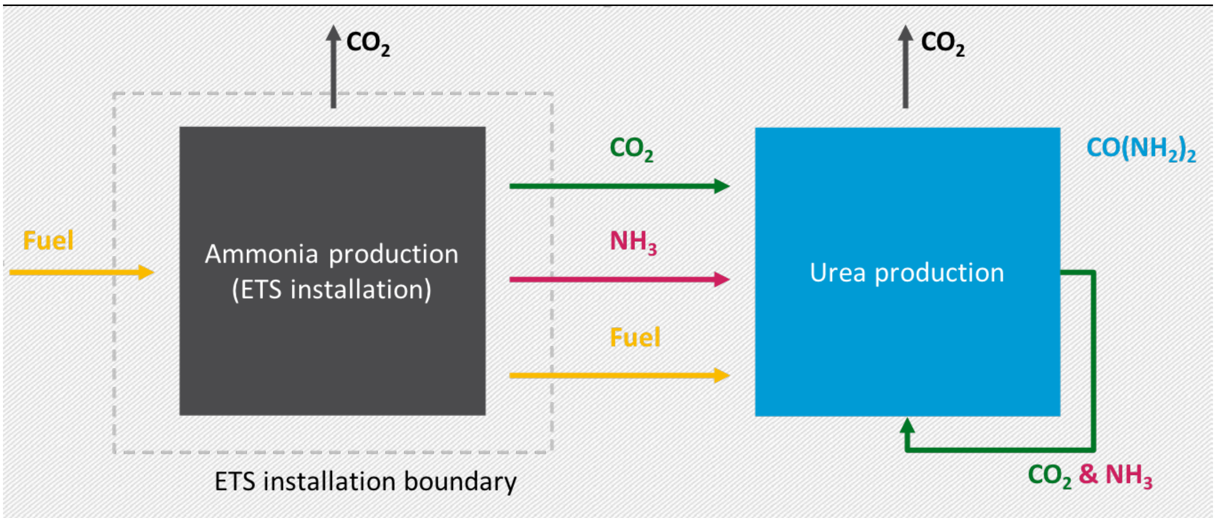
Source: Original drawing by Navigant and nova-Institute

4.1.2 Case 2: Urea synthesis

The second case study looks at the common CO_2 use in the urea ($CO(NH_2)_2$) production. Urea is made from ammonia (NH_3) and CO_2. The main use case for urea is fertilization, another significant part goes into the production of melamine and synthetic resin. Furthermore, albeit not in such large quantities, it is used as for de-icing at large airports or in cosmetics because of its moisture-binding properties. In most of the use cases CO_2 is finally released. Figure 4 sketches the production processes involved and its chemical equations. Within the ammonia plant, firstly natural gas is cracked in a steam reforming process to gain hydrogen for the ammonia synthesis. At the same time, high-purity CO_2 is being removed in a separate source stream as a co-product of the process. This CO_2 is transferred to the urea installation, in which ammonia and CO_2 are forced to react to urea under high pressure and high temperature. The resulting urea still contains unreacted ammonia and CO_2 which are fed back into the reactor in a circle.

Currently the (ETS) ammonia plant reports its transferred CO_2 to the (non-ETS) urea plant in its annual emissions report. The emissions are accounted for at the ammonia plant (see MRR, Annex IV, 17. B).

Figure 4: Case Study 2/3 – Urea synthesis



Steam	$CH_4 + H_2O \rightarrow CO + 3H_2$ $CO + H_2O \rightarrow \boldsymbol{CO_2} + H_2$	Carbamate	$2NH_3 + \boldsymbol{CO_2} \rightleftharpoons H_2N - COONH_4$
		Urea	$H_2N - COONH4 \rightleftharpoons (NH_2)_2CO + H_2O$
Ammonia	$N_2 + 3H_2 \rightarrow 2NH_3$		

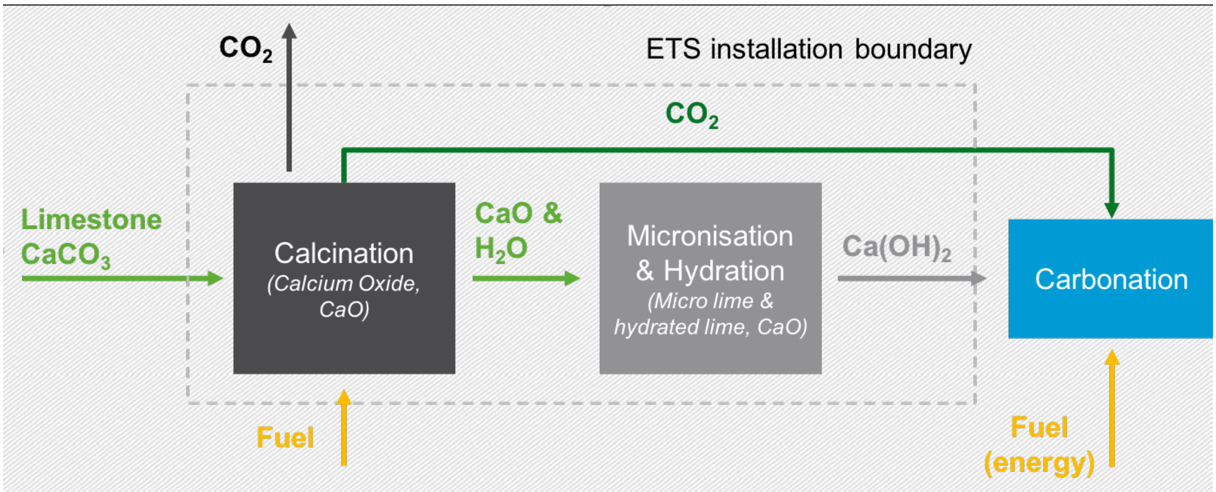
Source: Original drawing by Navigant and nova-Institute

4.1.3 Case 3: CO_2 use in inorganic carbonates such as precipitated calcium carbonate

In the third case study, CO_2 from a calcination process is used to produce precipitated calcium carbonate, $CaCO_3$, or PCC. Figure 5 illustrates the process schematically. Firstly, lime is processed to calcium oxide (quicklime). In this process, CO_2 is emitted. While the quicklime is further processed in the micronisation and hydration facilities, the CO_2 is transferred to a carbonation process (non-ETS facility), in which it reacts with slaked lime from the hydration process to PCC. Additional fuel input is required to ensure the necessary conditions for this reaction.

Key difference to the other two case studies is that it is ensured that all the CO_2 bound in PCC is not emitted to the atmosphere upon usage of the product. In the late Schaefer Kalk court case this was acknowledged by the European Court of Justice (ECJ) and Schaefer Kalk can deduct the emissions, although transferring CO_2 to a non-ETS installation.

Figure 5: Case Study 3/3 – Precipitated calcium carbonate (PCC)



Calcination $CaCO_3 \rightarrow CaO + CO_2$ Carbonation $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

Source: Original drawing by Navigant and nova-Institute based on Cales de Llierca, 2018

4.2 Results of testing the decision tree

Three elements of the decision tree are in need to be tested for practicability in their execution:

1. Comparison of process in place with blacklist of CCU processes and applications
2. Assessment of energy demand for capture and use process
3. Assessment of actually bound percentage of CO2 transferred in the final product

Those three elements were tested considering three main items of verification procedures in the EU ETS:

(A) System boundaries and scope of verification
(B) Evidence and documentation
(C) Specific challenges of verification

The resulting key overall findings are listed briefly and described more in-depth in the following paragraphs.

Key overall findings

a. The MRR needs to provide clear and unambiguous definitions for all new terminologies and monitoring concepts.
b. The major part of additional MRV obligations is seen at the receiving CCU facility that would not directly profit from deduction of CO_2 emissions in the scope of the EU ETS.
c. The obligation for documentation of evidence shall be with the entity claiming CO_2 deductions.

4.2.1 Comparison of process in place with blacklist of CCU processes and applications

As first part of a verification the operator would have to prove that the installation to which carbon is transferred is not using a use process on the blacklist as introduced in Criterion 1 (see section 2.3). The process run in the receiving installation would need to be compared against this blacklist, which reveals the first challenge of the new verification process as it broadens the audit scope of the verifying authority. All down-stream installations using the CO_2 of the ETS installation are relevant for the reporting. Today, the audit scope for emissions reporting is mainly limited to the site of the actual ETS installation. To be able to ensure that the downstream installation does not run technologies or processes on the blacklist, the operator of the ETS site would have to ensure access to the receiving facility and cooperation from its operator.

Taking into account the three cases presented in section 4.1, above approach seems realistic in practice for direct relationships between the ETS installation and the downstream receiving installation, i.e. for cases 2 and 3. In case 1, it is likely that an intermediary, such as a trader or industrial gas company plays a major role in capturing, sequestration and/or transport of the CO_2 for temporary storage or to its final user. This intermediary would have to prove to the ETS installation operator, and ultimately to the verifier, to whom the CO_2 is sold to, and what it is used for to ensure the process is not on the blacklist. To minimise the associated effort, this could be done via a registry including the intermediary's clients and their use cases. Each CO_2 buying customer would have to prove to the intermediary that his/her process is not on the blacklist. Such a register could be subject to a regular and independent verification itself, to the effect that the intermediary can attest that all CO_2 purchased from the ETS plant is eligible for deductions.

4.2.2 Assessment of energy demand for capture and use processes

In three steps of the CCU process additional energy input is required: Firstly, capturing and purification the CO_2, secondly transport of CO_2, and thirdly the actual use of the contained carbon to create a new product. In criterion 9 (see section 2.1.9) the following equation was introduced to show this:

$$E_{capture} + E_{purification} + E_{transport} + E_{utilisation} = E_{CCU}$$

Furthermore, two options to fulfil this energy demand were suggested:

a) The gas stream containing the carbon to be used already contains the energy necessary for further processing (with potential limitations if processes are on the blacklist).

b) The energy required for the CCU process has to originate from renewable sources.

For the first step ($E_{capture} + E_{purification}$) two cases arise: (1) capturing and purification happens within the boundaries of the ETS installation and thus any additional heat or electricity generated on-site is covered by the EU ETS. In this case only for energy imports the amount and sources have to be proven. (2) In case the capturing and sequestration facility is not included in the ETS installation's boundaries[4], its energy consumption needs to be monitored and the sources properly documented with a proof of origin.

In the second step, energy use in transport needs to be accounted for. As transport modes can vary from road transport in bottles to rail or maritime transport in tanks up to pipeline transport or a combination of all, a simple approach needs to be found. Again, conservative standard values for each transport mode could be a feasible solution. Verification can get very complicated in practice if transport modes and its related energy requirements had to be accounted for individually and with high precision. Nevertheless, an operator convinced that the transport method in place is better than the applied standard value should have the opportunity to provide evidence for this claim.

The third step, the actual use case of the sequestered carbon, will most likely not be under the scope of the EU ETS as many of the downstream companies using the carbon are non-ETS installations. Similar to step one, this requires a detailed monitoring of the energy consumption and documentation of the energy sources in line with the MRR.

From the perspective of a verifier another new field of verification apart from the enlarged audit scope already mentioned in section 4.2.1 arises: Electricity consumption has not played a role in direct ETS reporting so far and has thus not been in the scope of those verification processes for annual emission reporting[5]. With CCU processes most likely requiring electricity, this would be introduced to the auditing scope. However, some verifiers' organisations are likely to have experience with the verification of electricity related data and methodologies, as ETS related state aid processes such as the German electricity price compensation scheme need verification by auditors as well. Although those are different individuals, experience within the organisations is also useful.

For the final reporting both the amount and the source of energy required for the CCU process will need to be assessed. The first one requires known and available documentation and evidence of energy uses in those parts of the installation dedicated to the CCU process. To enable this, it might be necessary to install additional metering systems. The measuring results would be subject to the verifiers audit scope.

If the energy is purchased, the source of energy can be checked through e.g. contractual relationships of the installation with its energy suppliers. Those would need to contain certificates of origin for renewable energy provided to the sufficient amount in the relevant time frame. If those are not available, the national grid share of renewable energy is used, as was laid out in chapter 2.1.9. This could be applied for both electricity and natural gas. For heat obtained from a local heat network, the share of renewable energy can be obtained from the heat network operator.

If the energy is produced on-site, documentation has to be provided showing that operation of that unit started parallel to or after the CCU facility. Next to that, verifiers would need to inspect documentation that the energy produced by the unit covers the energy needs of the CCU process.

Criterion 9 furthermore includes the provision of offsetting fossil energy contained in the waste gas stream. Documentation of this energy amount would need to be presented as well as the

[4] e.g. it might have a separate official permit which in some MS leads to not being part of the ETS installation.

[5] Certain ETS installations qualify for compensation for indirect carbon costs under the EU State Aid Guidelines (2012/C 158/04). This also requires verification by external auditors. However, the verification needs to come from financial audit firms. EU ETS verification bodies are not authorized to do so.

prove of providing or purchasing the same amount of renewable energy. In case the additional renewable energy to offset the fossil amount is not required onsite, the operator will be asked to provide offsets elsewhere. It would have to be defined, which criteria these offsets would have to meet.

4.2.3 Assessment of actually bound CO_2 in the final product compared to transferred CO_2

The last item in the decision tree concerns the carbon actually bound in the final product compared to the CO_2 that was transferred by the ETS installation. Only that share shall be deductible in the end, including any subtractions that might be necessary e.g. due to the usage of grid electricity for the use process. This requires knowing the carbon content of the final product, the production figure of the receiving facility and any other carbon sources used apart from the CO_2 received from the ETS facility. Criterion 2 was introduced in section 2.1.2.

The practicability test primarily revealed the same complication as for the other two criteria: The verifier will require access to the receiving installation to verify carbon content, production figures and other carbon sources and their amounts. For the carbon content, the operator would have to provide analyses conducted. Verification of those includes the standard process as known for current ETS analyses verification, such as, among other things, a visit of the laboratory and retracing the data stream of the analyses' results. Since this is common practice in the EU ETS, it is judged to be feasible in practice.

Such a process can be simplified using standard values. For certain common, already widely practiced processes, such standard values could be issued by the competent authorities or directly included in the regulation. This approach is supported by the verifying authorities interviewed as it strongly simplifies the process. Again, exceptions should be allowed for if operators deem more effort to be justified.

Next to the carbon content of the final product, the production figures of the receiving facilities need to be verified, in order to ensure the correct amount is deducted. This is already common practice in the EU ETS in verification processes, however, the installation subject to verification is not the ETS installation but the receiving installation.

Thirdly, the verifier has to request evidence for other carbon sources and the carbon amounts used in the receiving installation. By doing so, it can be ensured that only the amount of carbon actually originating from the ETS installation subject to verification is taken into account.

4.3 Case specific elements and general remarks from verifying authorities

A number of case specific elements and challenges arose. These are discussed in the following. Next to that, verifying authorities provided general remarks to simplify the additional verification procedures needed.

Case specific elements

The percentage of CO_2 actually bound in the final product is a crucial criterion. For cases 2 and 3 as presented above both approaches using standard values or analyses seem feasible without large additional verification efforts. However, direct use cases as presented in case 1 can be challenging. Clear definitions of "bound" and "used" are required and to which effect they determine the deductibility. As was discussed in section 2.1.2, for some use cases it can be difficult to assess the amount of carbon actually bound. Also, very low values might render the effort of carbon capture financially unattractive. One example of a direct use case is the application of CO_2 in the atmosphere of a greenhouse. Greenhouse operators are keen to optimise the CO_2 concentration in their facilities, depending on the plants grown. This optimal CO_2 concentration will determine their additional CO_2 intake. However, the plants in a greenhouse might absorb only about 20% of the CO_2 inserted into the atmosphere. Most likely operators of the greenhouse will also not increase the concentrations above the optimum as this again decreases plant yields. In this case the required amount of CO_2 is higher than the amount of CO_2 that can be bound in the end-product. Comparing this to the example of the fire extinguisher, where no CO_2 is bound after the extinguisher has been used but 100% are required for its usage, the question remains whether this criterion remains useful for direct applications. Ultimately, this would imply that in the direct use case 100% of the CO_2 is eligible for deduction as 100% is needed for the application.

Another layer of complexity for the evidence of CO_2 actually bound in a final product arises with the inclusion of traders. If an ETS installation captures its carbon emissions and sells it to a trader, it cannot be determined with certainty today where this carbon will be used. To not exclude direct applications with too little consumption to justify a direct relationship with an ETS installation or not in proximity of an ETS installation, traders and other intermediaries should not be excluded from the system. However, requiring the trader to log all exact use cases of their customers is seen as too complex. Following the above logic of direct use cases "using" 100% of the CO_2 for their purpose, 100% of CO_2 sold to a trader shall be deductible for the ETS installation. This might lead to the concern that an incentive is created for operators to just sell CO_2 to a trader making them eligible for deduction, without further usage of the CO_2. However, the cost of sequestering CO_2 and the market price for liquid and gaseous CO_2 being much above the current EUA price make this no realistic scenario.

General remarks from verifying authorities

A key remark from verifying authorities was the recommended use of standard values. As can be seen above, in multiple steps of the verification, standard values would simplify the verification process. Interviewees stressed standard values in particular in the context of carbon content analyses. There they can help smoothen the process for both the verifier and the operator, the latter being the one obliged to gain access to evidence and documentation from the receiving installation. Legal complications of operators who expect their product or process to perform better than the standard value could get an option to apply for an exception.

One of the main challenges identified is the larger verification scope which is not limited to the ETS installation anymore but includes the capturing and sequestration facility, the transport and the receiving installation, all possibly operated by 3rd parties. Still the duty of information rests with the ETS installation operator. Although not common in the realm of ETS verification, it is not unknown to verifiers as for large, interconnected installations and also other regulations this is already common practice.[6]

4.4 Conclusion of the field test

Based on the regulations of the current MRR, the "producer" of GHGs is responsible for the emissions if they are transferred to an installation not subject to the EU ETS. This approach is simpler and results in a lower administrative burden than following the carbon down the chain. The Schaefer Kalk case, however, requests an approach for the deduction of CO_2 transferred to a CCU process not subject to the EU ETS.

Three case studies showed potential set-ups and the key differences of scopes and boundaries. Generally, verifying authorities estimate an additional effort of 30 % compared to a standard

[6] An example was given in the context of heat delivery contracts, where the verifier had to check receiving installations of heat streams, which were also outside the scope of the original installation.

verification process of emissions reporting. This estimate is based on the additional requirements of verifying data and methodologies related to the entire CCU process chain and can differ between installations depending on their set-ups and the number and complexity of CCU processes.

For the verifying authorities, the larger scope of their work could be reasonable and realisable in practice under specific conditions. One important condition are clear definitions and requirements in the MRR. The use of standard values wherever reasonable and possible can further decrease the MRV burden for operators. Capturing and purification are expected to require less effort as they are likely to occur on the ETS site. Energy requirements for transport, however, can be challenging and should be dealt with using standard values if possible. Furthermore, extending the scope of the verification process to another site is for most installations a new element and can lead to considerable additional efforts. Verifying that the CCU process in place is not on the blacklist and scrutinizing the energy use of that CCU process is likely to require the major part of the additional effort.

Such additional administrative effort could disincentivize operators to apply for deductibility of their CCU processes. Increasing interdependencies between installations (both ETS and non-ETS) result in higher additional transaction costs. Operators transferring carbon to smaller CCU projects could be discouraged by the suggested rules. Deductions for energy use and carbon bound can be expected to decrease the amount of actually deductible CO_2 and thus hamper implementation for many applications. Therefore, it is likely that with the suggested decision tree only larger CCU projects will claim deductions, go through the MRV processes and adhere to the additional obligations. Nevertheless, those pre-conditions accompanied by clear guidance could provide a framework needed for the implementation of emission reductions at ETS installations via transferred CO_2 to CCU processes.

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