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Working Paper

Challenges for the accounting of emerging negative and zero/low emission technologies

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Abstract

The present paper investigates challenges for the reporting and accounting of negative emission technologies (NETs) and zero or low emission technologies (ZLETs) in GHG emissions inventories, under the EU Directive on the promotion of renewable energies (RED II) and under the EU Emissions Trading System (EU-ETS). Technology-wise we focus on NETs/ZLETs based on engineered processes setting aside natural processes and natural process enhancers.

For GHG emission inventories, there are open questions how to address the intermediate storage of carbon in E-fuels based on fossil CCU, biomass (BECCU) or atmospheric origin (DACCU): The basic options are (1) to either calculate negative emissions for the recovery or removal of CO_2 for E-fuel production or (2) not to include the emissions of CO_2 from E-fuel combustion in national emission totals, comparable to the present treatment of CO_2 from biomass combustion, which is reported separately from national totals. Furthermore, international agreement should be sought on methodologies and inventory categories to be used for reporting permanent CO_2 removals (e.g. DACCS).

The definitions frameworks of the RED II and the EU-ETS are consistent and ensure that CO_2 recovery for production of E-fuels cannot be subtracted from CO_2 emissions in ETS installations, thus close to the 2^{nd} option discussed for E-fuels GHG inventories.

Zusammenfassung

Das vorliegende Papier untersucht Herausforderungen bei der Berichterstattung und Anrechnung von Technologien mit negativen Emissionen (NETs) und Technologien mit null oder geringen Emissionen (ZLETs) in Treibhausgasemissionsinventaren, im Rahmen der EU-Richtlinie zur Förderung erneuerbarer Energien (RED II) und im Rahmen des EU-Emissionshandelssystems (EU-ETS). Dabei konzentrieren wir uns auf NETs/ZLETs, die auf technischen Prozessen basieren und natürliche Prozesse außer Acht lassen.

Für THG-Emissionsinventare bestehen offenen Fragen, wie die Zwischenspeicherung von Kohlenstoff in E-Kraftstoffen auf der Grundlage von fossilem CO_2 (fossiles CCU), Biomasse (BECCU) oder atmosphärischem Ursprung (DACCU) behandelt werden soll: : Die grundlegenden Optionen sind (1) entweder die Berechnung negativer Emissionen für die Rückgewinnung oder Entfernung von CO_2 für die Herstellung von E-Kraftstoffen oder (2) die separate Ausweisung von CO_2-Emissionen aus der Verbrennung von E-Kraftstoffen außerhalb der nationalen Emissionssummen, vergleichbar mit der derzeitigen Behandlung von CO_2-Emissionen aus der Verbrennung von Biomasse, die außerhalb der nationalen Emissionssummen berichtet werden. Darüber hinaus sollte eine internationale Einigung über Methoden und Inventarkategorien angestrebt werden, die für die Berichterstattung über den dauerhaften CO_2-Abbau (z. B. DACCS) verwendet werden sollen.

Die Definitionsrahmen der RED II und des EU-ETS sind kohärent und stellen sicher, dass die CO_2-Rückgewinnung für die Herstellung von E-Kraftstoffen nicht von den CO_2-Emissionen in ETS-Anlagen abgezogen werden kann, was der zweiten Option nahekommt, die für die THG-Inventare von E-Kraftstoffen diskutiert wird.

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1 Introduction

As an increasing number of parties to the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) are envisaging net zero greenhouse gas (GHG) emission targets, carbon dioxide removal (CDR) processes will be needed to balance remaining GHG emissions (most likely non-CO_2 emissions) which may be found too hard to abate. In that context, the development and deployment of new zero and in particular of negative emission technologies is gaining rising attention. While theoretical concepts for such technologies exist, practical experience is very limited.

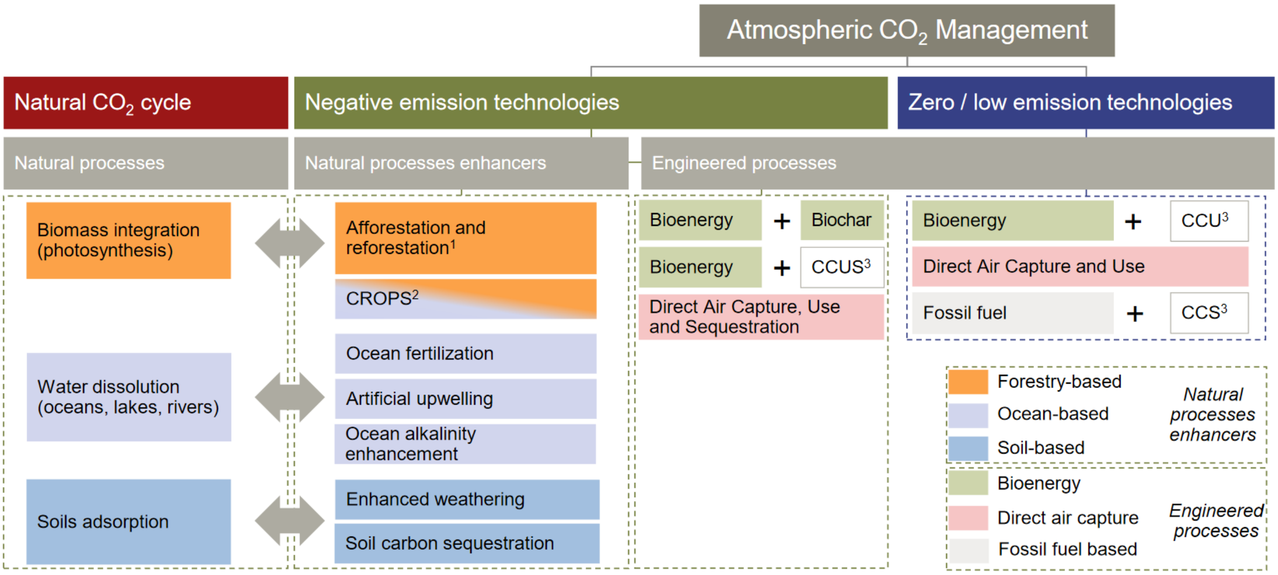
As the likelihood for future deployment of such technologies thus increases, this paper investigates challenges for accounting frameworks: Are our accounting frameworks fit to properly deal with such emerging technologies, and involved processes, products and trade? Are potential gaps or double-counting to be apprehended? Which challenges will have to be overcome in order to maintain environmental integrity of the accounting systems and to avoid unintended barriers to the deployment of emerging technologies?

Given the multitude of CDR and related technologies on one hand, and of potentially relevant accounting frameworks on the other hand, we limit the scope of this working paper in both dimensions for pragmatic reasons due to limited time and budget:

- Technology-wise we focus on engineered processes (Figure 1-1), setting aside natural processes and natural process enhancers.
- As accounting frameworks we consider in this working paper
  - GHG emission inventories as internationally standardised under the UNFCCC
  - The EU Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II), in particular relates to a variety of targets defined therein for EU Member States
  - Monitoring and compliance rules under the EU Emissions Trading System (EU-ETS)

While our choice of scope is of pragmatic nature due to limited resources in time and budget, we acknowledge that similar assessments would be useful both for excluded CDR-relevant processes (nature-based solutions, ‘geo-engineering’-type natural process enhancers) and for further accounting frameworks (e.g. baseline-and-credit certificate systems, GHG accounts on company or product levels).

Figure 1-1: Carbon dioxide removal technologies classification tree



1. Planting trees is classified as negative for the timescale studied, even if it is not fully permanent.
2. CROPS is crop residue ocean permanent sequestration
3. CCS refers to carbon capture and storage, which is usually capturing waste CO2 from point sources (power plant or factory) and storing it in geological formations; CCU refers to carbon capture and use; CCUS refers to carbon capture, use and sequestration; some of the uses release the carbon in the atmosphere (agriculture, beverage, etc.) making the process carbon neutral, and some store it (concrete, plastics, etc.) making the process carbon negative

Note: Other solutions such as wetland and coastal restoration (blue carbon) were not considered the study quoted for this figure.
Source: (Debarre et al. 2019)

In order to enable a specific discussion of relevant emerging technology choices we establish in chapter 2 the concept of ‘negative emission technologies’ (NETs) and ‘zero or low emission technologies’ (ZLETs). To that end we consider a broad range of fuels (including carbon-containing fuels and carbon-free fuels H_2 and NH_3) and of carbon-containing non-fuel products and we asses under which circumstances their use can be considered a NET or ZLET.

Subsequently we discuss the coverage of NETs and ZLETs in GHG emission inventories in chapter 3 and identify challenges. Similarly we discuss NETs/ZLETs under the RED II accounting rules in chapter 4 and under the EU-ETS in chapter 5.

Our conclusions are summarised in chapter 6.

2 Fuels and non-fuel products in the context of NETs and ZLETs

Carbon neutral are those processes that either do not emit CO_2 at all or release only the same amount of CO_2 that was absorbed in a short timeframe before.[1] A negative emission in that context is the process of either absorbing CO_2 from the atmosphere or preventing the emission of CO_2 that would else be considered part of a carbon neutral process.

Negative emission technologies (NETs) in the context of climate mitigation are technologies that either directly absorb CO_2 from the atmosphere or prevent CO_2 (or carbon) that is considered as carbon neutral from reaching the atmosphere.

Zero or low emission technologies (ZLETs) are technologies that produce either no CO_2 emissions at all, very few CO_2 emissions or only such CO_2 emissions that are considered as carbon neutral. However, some ZLETs produce emissions of methane (CH_4) and nitrous oxide (N_2O) which are also greenhouse gases. Examples:

- Combustion of biomass and biofuels is often considered as CO_2-neutral as only as much CO_2 is emitted as was absorbed before during growth of the plants. However, combustion of biomass not only emits CO_2 but also methane and nitrous oxide.
- Combustion of hydrogen with air produces no CO_2 but N_2O and (other nitrogen oxides) due to reactions of nitrogen and oxygen at high temperatures.

The focus of this paper is to describe and classify negative emission technologies (NETs) and zero or low emission technologies (ZLETs). It is not the aim of this paper to evaluate which technologies are better than others. To fully assess NET/ZLET not only the technologies and processes themselves are relevant but also the fuels and products used are important. For the analysis we distinguish between three general types of materials:

- Carbon containing fuels, see Table 2-1 and Table 2-2
- Non-fuel carbon containing products, see Table 2-3 and Table 2-4
- Fuels not containing carbon: H_2 / NH_3 (which would likely be produced from H_2), see Table 2-5 and Table 2-6

With fuels we mean here materials that are used in combustion or other oxidation processes to produce useful energy. Non-fuel products are products that or produced for other purposes than energy production. However, some non-fuel products can be combusted after the product use phase in waste incineration plants.

The construction and deconstruction of the plants and facilities implementing the described technologies and producing the respective fuel is not considered in the following section. One could also analyse whether the construction and deconstruction processes emit CO_2 and thus examine whether these processes fulfil the carbon neutrality definition above. However, this is beyond the scope of this paper. Also, we focus on engineered processes. Measures like compensating using certificates are not in the scope of this paper.

[1] This description is not intended as a legal definition. The length of the "short timeframe" is dependent on the processes and fuels involved and can range from days to years.

2.1 Carbon-containing fuels

Nine different types of carbon-containing fuels were identified. These can be classified by three different dimensions Table 2-1:

- The **fuel category** provides common names of these fuels and provides examples.
- Important for the further assessment is the **carbon source** of the fuels.
- The third dimension is the **classification in RED II** (Renewable Energy Directive (EU) 2018/2001), as discussed in further detail in chapter 4.

Table 2-1: Classification of carbon-containing fuels

No	Fuel category	Carbon source	Classification in RED II
#1	**Conventional fossil fuels (coal, petroleum products, natural gas etc.)**	Primary fossil resources	-
#2	**Conventional biomass fuels (firewood, biogas etc.)**	Biomass	biomass fuel
#3	**Fossil-based synthetic fuels (Coal to liquid etc.)**	Primary fossil resources	-
#4		Fossil waste	Recycled carbon fuel (RCF)
#5	**Biomass-based synthetic fuels**	Biomass	Biofuel (in transport), bioliquid (other sectors)
#6		Biowaste (including RED II annex IX feedstocks)	Advanced biofuel, bioliquid
#7	**E-fuels / CO_2-based synthetic fuels (Power-to liquid)**	CO_2 from bioenergy combustion	Renewable transport fuel of non-biological origin (RFNBO), if used in transport sector
#8		CO_2 from direct air capture (DAC)	
#9		CO_2 from fossil fuel combustion	

Note: RED II: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (European Union 2018)
Source: own presentation

Both conventional fossil fuels and conventional biomass fuels (#1 and #2 in Table 2-1) are easy to classify. As the carbon contained in conventional fossil fuels like coal, petroleum products and natural gas is from primary fossil resources (underground deposits of fossilized organic matter) these fuels are not classified in the RED II. Similarly, the carbon in all conventional biomass fuels originates in the biomass that was produced naturally by plants during their growth. Thus, conventional biomass fuels are classified in the RED II as biomass fuels.

For synthetic carbon-containing fuels, the classification is more complicated, and the carbon source is decisive. In the group of fossil-based synthetic fuels only those fuels that are produced from fossil waste as carbon source (#3 in Table 2-1) are classified as recycled carbon fuel (RCF) while all fossil-based synthetic fuels like coal-to-liquid fuels or syngas produced from natural gas are not classified in the RED II.

Biomass-based synthetic fuels that are produced directly from biomass (#4 in Table 2-1) are classified in the RED II as biofuel in the transport sector and bioliquids in all other sectors. Advanced biofuels according to the RED II are only those biomass-based synthetic fuels that are not produced from (primary) biomass but from biowaste (including RED II annex IX feedstocks, #5 in Table 2-1).

E-fuels, also called CO_2-based synthetic fuels, are fuels that are produced using a power-to-liquid or power-to-gas process from CO_2 and hydrogen. The hydrogen is produced from water by electrolysis using electrical energy (thus the “E” in E-fuels). The CO_2 used for production can originate in different sources: either from biomass combustion (#7 in Table 2-1), from direct air capture (#8) or from fossil fuel combustion (#9). In all these three cases, these E-fuels are classified in the RED II as renewable transport fuel of non-biological origin (RFNBO), if used in transport sector.

Not only the carbon source but also use of the carbon-containing fuels determines and the fate of CO_2 from combustion determines whether a process is a NET, a ZLET or leads to significant CO_2 emissions. This shows Table 2-2 which has the following columns for classification:

- The first two columns (**Fuel category** and **Carbon source**) follow Table 2-1.
- The two last columns show the NET / ZLET assessment resulting from the **fate of CO_2 from combustion**, differentiated between CO_2 emission or no emissions in the long term.

Table 2-2: NET / ZLET assessment of production and use of carbon containing fuels

No	Fuel category	Carbon source	Fate of CO_2 from combustion: **CO_2 emission:** immediately or after intermediate CCU (fuel or non-fuel) cycle(s)	Fate of CO_2 from combustion: **no emission, long-term:** CCS, solid C / C compounds, possibly including intermediate or ‘endless’ carbon capture & fuel use cycles
#1	**Conventional fossil fuels**	Primary fossil resources	Emission	ZLET
#2	**Fossil-based synthetic fuels (CtL etc.)**	Primary fossil resources	Emission	ZLET
#3	**Fossil-based synthetic fuels (CtL etc.)**	Fossil waste	Emission (ZLET-like carbon recycling if considering the carbon in fossil waste / the CO_2 captured for fuel use as bound to be emitted anyway)	ZLET
#4	**Fossil E-fuels / CO_2-based synthetic fuels (Power-to liquid)**	Fossil fuel combustion	Emission (ZLET-like carbon recycling if considering the carbon in fossil waste / the CO_2 captured for fuel use as bound to be emitted anyway)	ZLET
#5	**Conventional biomass fuels**	biomass	ZLET	NET
#6	**Biomass-based synthetic fuels**	biomass	ZLET	NET
#7	**Biomass-based synthetic fuels**	biowaste (including RED II annex IX feedstocks)	ZLET	NET
#8	**BEC-based E-fuels / CO_2-based synthetic fuels (Power-to liquid)**	bioenergy combustion (BEC)	ZLET	NET
#9	**DAC-based E-fuels / CO_2-based synthetic fuels (Power-to liquid)**	DAC (direct air capture)	ZLET	NET

Notes: NET: Negative emission technology; ZLET: zero/low emission technology, CtL: Coal to liquid
ZLET & NET assessment is subject to sustainability criteria for biomass use and/or use of renewable energy sources for involved CCU

cycles.
Source: own presentation

If conventional fossil fuels (#1 in Table 2-2) combusted and CO_2 is emitted immediately or after intermediate CCU cycle, then emission is relevant for climate change. If combustion of conventional fossil fuels is combined with carbon capture and storage (CCS), then this is a ZLET. The same holds true for fossil-based synthetic fuels based on primary fossil resources like Coal-to-Liquid fuels (#2 in Table 2-2).

For fossil-based synthetic fuels produces from fossil waste (#3 in Table 2-2) and fossil E-Fuel / CO_2-based synthetic fuels that are produced from fossil fuel combustion (#4 in Table 2-2), there are emissions, but these emissions are ZLET-like carbon recycling if considering the carbon in fossil waste / the CO_2 captured for fuel use as bound to be emitted anyway). If these fuels however are combined with CCS or other forms of permanent carbon storage, then the use of these fuels are ZLET.

Conventional biomass fuels (#5), biomass-based synthetic fuels (regardless of the carbon source being biomass or biowaste, #6 or #7), and E-fuels / CO_2-based synthetic fuels that use carbon release in bioenergy combustion (#8) are all ZLET without further abatement. In all these cases, only as much CO_2 is emitted during combustion as was absorbed during growing of the biomass. If these fuels are combined with CCS or other forms of permanent carbon storage, then the use of these fuels are NET.

The assessment of E-fuels based on direct air capture (#9) is the same as the various biomass and biomass-based fuels (#5 to #8). Also, in the case of DAC-based fuels, while combustion only as much CO_2 is released as previously captured from the air. Thus, combining direct air capture with CCS is a net emission technology. DAC-based e-fuels can be interpreted as mimicking production of a fuel by replacing the natural process of absorbing CO_2 from the air and producing carbon compound that take place in plant with artificial processes (technology).

Fuel production and fuel use not necessarily have to take place at the same location, not even in the same country. If the fuels listed in #5 to #9 are produced in country A and combusted (with CCS) in country B, the fuels are still ZLET, but this has implications for the accounting in GHG emission inventories which is described in section 3.

2.2 Non-fuel carbon-containing products

A wide range of current and non-fuel products contain carbon. With non-fuel products we mean here products that contain carbon that but are not intended for combustion or other oxygenation process to obtain useful energy. Table 2-3 classifies these products into a **carbon storage product category** and further by their **carbon sources**.

Table 2-3: Classification of non-fuel carbon-containing products

No	Carbon storage product category	Carbon source
#1	**Harvested wood products (HWP)**	Biomass / wood
#2	**Other (biomass-based) carbon storage products** (construction material, fibres / polymers etc, as addressed in 2021 COM proposal for revision of LULUCF-Regulation)	Biomass / biowaste
#3	**Fossil plastics / organic compounds**	Fossil fuel
#4	**CCU-based synthetic organic non-fuel carbon storage products**	CO_2 from bioenergy combustion
#5		CO_2 from direct air capture (DAC)
#6		CO_2 from fossil fuel combustion
#7	**Solid C (conventional black carbon)**	Fossil fuel
#8	**Solid C (biochar)**	Biomass / biowaste
#9	**Solid C (synthetic, CCU)**	CO_2 from bioenergy combustion
#10		CO_2 from direct air capture (DAC)
#11		CO_2 from fossil fuel combustion
#12	**Conventional carbonates / other inorganic C-compounds**	(fossil) geological resources
#13	**CCU-based carbonates / other inorganic C-compounds**	CO_2 from bioenergy combustion
#14		CO_2 from direct air capture (DAC)
#15		CO_2 from fossil fuel combustion
#16	**Captured CO_2**	CO_2 from bioenergy combustion
#17		CO_2 from direct air capture (DAC)
#18		CO_2 from fossil fuel combustion

Note: Carbon monoxide (CO) not considered as unlikely storage use.
Source: own presentation

In both harvested wood products (#1 in Table 2-3) and other biomass-based carbon storage products (#2), the carbon contained originates in biomass (wood or biowaste). In contrast fossil plastics and other organic compounds produced from fossil fuels have a fossil carbon source (#3).

There are various carbon-containing products that are produced from CO_2: With carbon capture and utilisation processes (CCU) CO_2 can be captured and transformed either into synthetic organic products (#4 to #6 in Table 2-3) or transformed into carbonates or other inorganic carbon compounds (#13 to #15). A third option is to convert CO_2 to solid carbon (#9 to #11). Also captured CO_2 can be directly used as product (#16 to 18). In all these cases the source of the CO_2 used as input is important for the further assessment: It can be CO_2 from bioenergy combustion (#4, #9, #13, #16), from direct air capture (#5, #10, #14, #17) or from fossil fuel combustion (#6, #11, #15, #18).

Solid carbon can have different carbon sources: Conventional black carbon (#7) is produced from fossil fuels. Biochar (#8) is produced from primary biomass or biowaste. As mentioned before, solid carbon can also be produced synthetically with CO_2 from CCU (#9 to #12). Carbonates and other inorganic carbon compounds are conventionally produced from geological resources (#12) and thus the carbon contained is fossil-like.

The classification of non-fuel carbon-containing products itself leads to the NET / ZLET assessment of the production and use of these products in Table 2-4. The classification in that table uses the following columns:

- The first two columns (**Carbon source** and **Carbon storage product category**) follow Table 2-3.
- The two last columns show the NET / ZLET assessment resulting from the **fate of carbon after produce use**, differentiated between CO_2 emission or no long-term emissions.

Table 2-4: NET / ZLET assessment of production and use of non-fuel carbon-containing products

No	Carbon source	Carbon storage product category	Fate of carbon after product use:	
			CO_2 emission: Upon industrial use or decomposition / combustion in waste stage possibly including intermediate CCU (fuel or non-fuel) cycle(s)	**no emission, long-term:** CCS, solid C / C compounds, possibly after waste incineration / waste treatment / landfilling; possibly including intermediate or 'endless' CCU (fuel or non-fuel) cycles
#1	Fossil fuel	Solid C (conventional black carbon)	Emission	ZLET
#2		Fossil plastics / organic compounds		
#3	(fossil) geological resources	Conventional carbonates / other inorganic C-compounds		
#4	CO_2 from fossil fuel combustion	synthetic organic non-fuel carbon storage products	Emission (ZLET-like carbon recycling if considering the carbon in CO_2 captured for non-fuel use as bound to be emitted anyway)	
#5		Solid C (synthetic, CCU)		
#6		CCU-based carbonates / other inorganic C-compounds		
#7		Captured CO_2		
#8	CO_2 from direct air capture (DAC)	synthetic organic non-fuel carbon storage products	ZLET	NET
#9		Solid C (synthetic, CCU)		
#10		CCU-based carbonates / other inorganic C-compounds		
#11		Captured CO_2		
#12	Biomass / wood	Harvested wood products (HWP)		
#13	Biomass / biowaste	other (biomass-based) carbon storage products		
#14		Solid C (biochar)		
#15	CO_2 from bioenergy combustion (BEC)	synthetic organic non-fuel carbon storage products	ZLET (NET-like carbon removal if considering the CO_2 captured for non-fuel product use as bound to be emitted anyway)	
#16		Solid C (synthetic, CCU)		
#17		CCU-based carbonates / other inorganic C-compounds		
#18		Captured CO_2		

Notes: Carbon monoxide (CO) not considered as unlikely storage use.
NET: Negative emission technology; ZLET: zero/low emission technology
ZLET & NET assessment is subject to sustainability criteria for biomass use and/or use of renewable energy sources for involved CCU

cycles.
Source: own presentation

The use of non-fuel carbon products from fossil fuels (#1 and #2 in Table 2-3) or from (fossil) geological resources (#3) leads finally to CO_2 emissions if the products are combusted after their product use life. This holds also true for products that were produced using CO_2 from fossil fuel combustion (#4 to #7). However, these products can be interpreted as ZLET-like carbon recycling if considering the carbon in CO_2 captured for non-fuel use as bound to be emitted anyway.

In contrast, the use of products containing carbon from either direct air capture (#8 to #11) or biomass, wood or biowaste (#12 to 14) are ZLET even if the carbon contained in these products is finally emitted as CO_2 after the product us. Products containing CO_2 from bioenergy combustion (#15 to #18) are also ZLET. But these can also be interpreted as NET-like carbon removal if considering the CO_2 captured for non-fuel product use as bound to be emitted anyway.

The picture changes, if the use of non-fuel carbon-containing products does not lead to emissions in the long-term. This can be achieved by e.g. by forms of carbon fixation (CCS, conversion to C or stable compounds, depositing in permanent landfills) or by endless cycles of carbon capture and use (CCU). These cycles do not necessarily mean direct recycling but can involve intermediary steps and the carbon can be used at different stages for fuel and non-fuel products if the cycle is endless. Then products contain fossil carbon (#1 to #7) are ZLET and products that contain carbon either from direct air capture (#8 to #11) or from biomass (#12 to 18) with any intermediate processes, fixating CO_2 is a negative emission technology.

2.3 Non-carbon fuels

The assessment so far dealt with carbon containing fuels and products. But there are also non-carbon fuels. Hydrogen (H_2) and ammonia (NH_3) are the most widely discussed non-carbon fuels. As production of ammonia always needs a hydrogen source, the classification of ammonia depends on its hydrogen source. Non-carbon fuels can be classified by five different dimensions Table 2-5:

- The **hydrogen source** specifies where hydrogen atoms used in the H_2, or ammonia production process originates.
- Relevant for the assessment of the renewable or fossil origin of a non-carbon fuel is the **energy source for H_2 generation**.
- Relevant for the classification of non-carbon fuels is the **fate of carbon in the hydrogen source**.
- In recent years, a classification of **H_2 and NH_3 into 'colours'** was established. These 'colours' abbreviation-like classify the involved pre-processes.
- The last dimension is, parallel to the carbon-containing fuels, the **classification in RED II** (Renewable Energy Directive (EU) 2018/2001, see chapter 4).

Table 2-5: Classification of non-carbon fuels H_2 and NH_3

No	Hydrogen source	Energy source for H_2 generation	Fate of carbon in H source	H_2 / NH_3 'colour'	RED II classification
#1	H_2O / other non-C substances	Renewable	-	green	RFNBO, if used in transport sector
#2		Fossil	-	grey	-
#3	Conventional fossil fuels	Fossil	CCS	blue	-
#4			solid C for long-term storage	turquoise	-
#5			CO_2 emission	grey	-
#6	Fossil waste	Fossil	CCS	blue (waste-based)	recycled carbon fuel (RCF)
#7			solid C for long-term storage	turquoise (waste-based)	
#8			CO_2 emission	grey (waste-based)	
#9	Biomass / biowaste	Renewable / bioenergy	CCS	orange / green with carbon sink	RFNBO, if used in transport sector
#10			solid C for long-term storage		
#11			CO_2 emission	orange / green	

Note: RED II: Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (European Union 2018)
RFNBO: Renewable transport fuel of non-biological origin; CCS: Carbon capture and sequestration
Source: own presentation

If the hydrogen source is water or any other non-carbon substance, then the classification of the non-carbon fuels only depends on the energy source for the H_2 generation. If a renewable energy source was used for H_2 generation (#1 in Table 2-5) then the produced fuel is "green" hydrogen or ammonia and according to the RED II a renewable fuel of non-biological origin (RFNBO), if used in the transport sector. In contrast, if the energy source for H_2 generation is fossil (#2 in Table 2-5) then the produced fuel is a "grey" hydrogen or ammonia and classified as non-renewable in the RED II.

If the hydrogen source is a conventional fossil fuel, then it is always classified as non-renewable in the RED, regardless of the fate of the carbon of the hydrogen source. The 'colour' of the H_2 or NH_3 depends on the treatment of the CO_2. If the CO_2 is captured and stored, then the non-carbon fuels are "blue" (#3 in Table 2-5). If the CO_2 is converted to solid carbon for long-term storage (#4 in Table 2-5) then the non-carbon fuels are called "turquoise". However, if CO_2 is emitted (#5 in Table 2-5), then the non-carbon fuels are grey.

For fossil waste as hydrogen source the classification of non-carbon the classification into 'colours' is like conventional fossil fuels as hydrogen source (#6 to #8 in Table 2-5). But different to conventional fossil fuels, non-carbon fuels using fossil waste as hydrogen source are classified as recycled carbon fuels (RCF) in the RED II.

Non-carbon fuels produced from biomass or biowaste as hydrogen source and using renewable energy or bioenergy are called "green" or "orange" H_2 or NH_3 (#11 in Table 2-5). If CCS is applied to the produced CO_2 or if the CO_2 is converted into solid carbon for long-term storage, then the 'colours' remain but an additionally carbon sink is generated (#9 and #10 in Table 2-5). In all three cases, the non-carbon fuels are classified in the RED II as RFNBO, if used in the transport sector.

Sometimes different hydrogen sources are combined. One important example is the Haber Bosch process which consists of various steps. In a first step methane (usually from natural gas) and water are chemically converted in a steam reforming process to hydrogen and carbon dioxide. In a second step, hydrogen reacts with nitrogen to form ammonia as final product. The Haber Bosch process therefore combines #2 and #5 of Table 2-5 (or #2 and #3 if CCS is added).

The classification of non-carbon fuels itself leads to the NET / ZLET assessment of the production and use of these fuels in Table 2-6. The classification in that table uses the following columns:

- Four columns (**Energy source for H_2 generation**; **Hydrogen source**; **fate of carbon in H source**; and **H_2 / NH_3 'colour'**) follow Table 2-5.
- The last column **NET / ZLET assessment** shows the final assessment.

Table 2-6: NET / ZLET assessment of production and use of non-carbon fuels H_2 and NH_3

No	Energy source for H_2 generation	Hydrogen source	Fate of carbon in H source	H_2 / NH_3 ‘colour’	NET / ZLET assessment
#1	fossil	H_2O / other non-C substances	-	grey	Emission
#2	fossil	Conventional fossil fuels	CO_2 emission	grey	Emission
#3	fossil	Fossil waste	CO_2 emission	grey (waste-based)	Emission (ZLET-like carbon recycling if considering the carbon in fossil waste used for H_2 generation as bound to be emitted anyway)
#4	fossil	Conventional fossil fuels	CCS	blue	ZLET
#5	fossil	Conventional fossil fuels	solid C for long-term storage	turquoise	ZLET
#6	Renewable / bioenergy	Biomass / biowaste	CO_2 emission	orange / green	ZLET
#7	Renewable / bioenergy	H_2O / other non-C substances	-	green	ZLET
#8	fossil	Fossil waste	CCS	blue (waste-based)	ZLET (NET-like carbon removal if considering the carbon in fossil waste used for H_2 generation as bound to be emitted anyway)
#9	fossil	Fossil waste	solid C for long-term storage	turquoise (waste-based)	ZLET (NET-like carbon removal if considering the carbon in fossil waste used for H_2 generation as bound to be emitted anyway)
#10	Renewable / bioenergy	Biomass / biowaste	CCS	orange / green with carbon sink	NET
#11	Renewable / bioenergy	Biomass / biowaste	solid C for long-term storage	orange / green with carbon sink	NET

Notes: NET: Negative emission technology; ZLET: zero/low emission technology
ZLET & NET assessment is subject to sustainability criteria for biomass use and/or use of renewable energy sources for involved CCU cycles.
Source: own presentation

Regardless of their hydrogen source, “grey” hydrogen and ammonia (#1 and #2 in Table 2-6) have always relevant emissions due to the fossil energy source. The same applies if fossil waste is used as hydrogen source (#3 in Table 2-6). However, non-carbon fuels produced with hydron from fossil waste can be assessed as ZLET-like carbon recycling if considering the carbon in fossil waste used for H_2 generation as bound to be emitted anyway (i.e. if the fossil waste would have been combusted if not used as hydrogen source).

The use of non-carbon fuels that are produced from conventional fossil fuels where carbon capture (either CCS or conversion to solid carbon for long-term storage; #4 and #5 in Table 2-6) is applied, then this is assessed as ZLET. In the same way the use of non-carbon fuels produced from renewable energy / bioenergy and either biomass / biowaste without further CO_2 abatement or H_2O and other non-carbon substances as hydrogen source are ZLET. In the case of biomass/biowaste as hydrogen source (#6 in Table 2-6) only as much CO_2 is released than was absorbed previously by plants. In the case of water or other non-carbon substances (#7 in Table 2-6), no CO_2 is involved in the whole process chain.

If production of non-carbon fuels from fossil waste as hydrogen source and fossil energy as energy source are combined with further CO2 abatement (either CCS or solid C for long-term storage; #4 and #5 in Table 2-6), then these technologies are ZLET. However, the use of such fuels can also be interpreted as NET-like carbon removal if considering the carbon in fossil waste used for H2 generation as bound to be emitted anyway.

The only true NET involving non-carbon fuels are if production if hydrogen or ammonia is produced from biomass or biowaste, the energy used is renewable or from bioenergy and some kind of further CO_2 abatement is applied (either CCS or solid C for long-term storage; #4 and #5 in Table 2-6).

2.4 Conclusion of NET / ZLET assessment of fuels and products

We show that the assessment of fuel and product use as NET or ZLET largely depends

- on one hand the carbon source (fossil, biomass, atmospheric), or the energy source in case of non-carbon fuels, and
- on the other hand on the final fate of contained carbon after use (emission into atmosphere or capture and storage, possibly after use cycles), or of carbon in the hydrogen source for non-carbon fuels.

For waste-based fuels and products, the NET/ZLET assessment depends on the accounting choice whether related carbon is considered as bound to be emitted anyway.

3 Coverage of NETs / ZLETs in national GHG inventories

National greenhouse gas (GHG) inventories under the United Nations Framework Convention on Climate Change (UNFCCC) provide information on emissions from sources and removals by sinks in line with methodologies developed by the Intergovernmental Panel on Climate Change (IPCC). NETs and ZLETs pose challenges to the accurate representation of emissions and removals in greenhouse gas inventories, and careful consideration is needed to ensure that emissions and removals associated with NETs and ZLETs are neither over- nor underestimated.

This chapter provides background information on GHG inventories and discusses for NETs and ZLETs how their production, transport and consumption is represented in GHG inventories. This chapter also points out the main related challenges.

3.1 Background on GHG inventories

Parties to the UNFCCC are required to report national inventories of anthropogenic greenhouse gas emissions by sources and removals by sinks (UNFCCC 1992, Article 12). The requirement for Parties listed in Annex I to the Convention (developed country Parties) are more comprehensive than those for developing countries. Under the Paris Agreement, the obligations for all countries have been largely harmonised, and from 2024 onwards, all Parties are required to report national GHG inventories biennially (Annex I Parties will continue reporting their inventories annually). In this section, we focus on the reporting requirements under the Paris Agreement, because almost all Parties to the UNFCCC are also Parties to the Paris Agreement.

Under the enhanced transparency framework of the Paris Agreement (United Nations Framework Convention on Climate Change (UNFCCC) 2015, Article 13), Parties submit information on climate action and support, including a national greenhouse gas inventory. As part of their biennial transparency report, they submit a national inventory report, which consists of a national inventory document (NID) and common reporting tables (CRTs). The outline for the NID and the templates for the CRTs were agreed at the climate change conference in Glasgow in November 2021 (UNFCCC 2021). The CRTs are very similar to the Common Reporting Format (CRF) tables which are currently used by Annex I Parties for inventory reporting. Minor differences exist, e.g. in the way recovery of emissions is reported (Moosmann und Herold 2022). The CRTs also provide rows for some categories additional categories, such as hydrogen production.

The methods for GHG inventory compilation are developed by the IPCC. Under the transparency framework, all Parties shall use the ‘2006 IPCC Guidelines for National Greenhouse Gas Inventories‘ (IPCC 2006). In the decision on the operationalisation of the transparency framework (UNFCCC 2021) it was agreed that Parties may use on a voluntary basis the ‘2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories’ (IPCC 2019). The 2019 Refinement introduced updated methods for many source categories and the methods for fugitive emissions from fuels were updated, among others. However, the methods for combustion emissions remained unchanged.

According to the 2006 IPCC Guidelines, national inventories cover emissions and removals taking place within the national territory. Emissions associated with the production of fuels or goods are reported by the producing country, while emission associated with use or disposal are reported by the country where the fuels or goods are consumed and/or disposed.

Greenhouse gas inventories under the UNFCCC and the Paris Agreement are organised in five categories[2]:

- (1) Energy
- (2) Industrial Processes and Product Use (IPPU)
- (3) Agriculture
- (4) Land Use, Land-use Change and Forestry (LULUCF)
- (5) Waste

Other emissions or removals can be reported in the category (6) 'Other'.

Greenhouse gas emissions are assigned to the category where they occur – emissions from one fuel or feedstock can occur in several categories. As an example, if a fuel is used for energy generation, the related emissions are reported in the energy category, while they are reported in the IPPU category if the fuel is used as a feedstock for an industrial process.

3.2 Reporting principles for CO_2 from biomass

In the context of CO_2 emissions in national GHG inventories, biomass is organic matter consisting of or recently derived from living organisms excluding peat, and includes products, by-products and waste derived from such material (IPCC 2006, Glossary). The combustion of biomass is treated differently from the combustion of other fuels in greenhouse gas inventories. In the energy category, only those CO_2 emissions which originate from the combustion of non-biomass fuels, e.g., from the combustion of natural gas, oil, coal or peat are included in total emissions.

The overall national balance of emissions and removals of biogenic CO_2 are addressed in the LULUCF category: CO_2 emissions and removals are estimated using changes in carbon stocks over time. Increases in total carbon stocks[3] are equated with a net removal of CO_2 from the atmosphere, whereas decreases in total carbon stocks are equated with net emissions of CO_2 (IPCC 2006, Vol. 4, chapter 1). Such a decrease in carbon stock occurs if biogenic carbon stored in wood or wood products is emitted into the atmosphere for example as part of a combustion process in the energy sector. The related emissions are reported in the LULUCF category, rather than in the category where biomass is combusted, transformed or decomposed.

Harvested wood products

Not all biomass is combusted, transformed or decomposed. Significant amounts are harvested and remain in products for differing lengths of time. The 2006 IPCC Guidelines provide several methods[4] for estimating the contribution of Harvested Wood Products (HWP) to CO_2 emissions and removals. Under the so-called production approach, emissions and removals are estimated from net changes in carbon stocks in the forest and HWP carbon pools and attributed to the producing country. The stock change approach focuses on changes in carbon pools within the country; emissions from the oxidation of exported HWP are not included. Finally, the atmospheric flow approach addresses all

[2] While the inventory categories are often referred to as ‚sectors' we stick to the wording 'category' in order to avoid confusion with 'sectors' differently defined under other statistics or legislation.

[3] Land managers' practices targeted to increase the carbon stock are discussed as 'carbon farming' e.g. in European Commission (EC) 2021b. Such 'nature-based solutions' are outside the scope of the present paper focussing on engineered 'technology-based' solutions.

[4] For an overview see Sato und Nojiri 2019.

removals of carbon in the producing country and all emissions from the oxidation of HWP in the country where the oxidation occurs.

If various countries use differing approaches to report CO_2 emissions and removals from harvested wood products, the global emissions and removals from this pool may be over- or underestimated. Under the transparency framework of the Paris Agreement, Parties may use different approaches for reporting emissions and removals from HWP, but all are required to provide (supplementary) data on emissions and removals from HWP estimated using the production approach (UNFCCC 2018, paragraph 56). This requirement ensures that comparable information is available from all countries.

Agricultural biomass

Biomass may be harvested from forests, but also from croplands. Such 'agricultural' biomass is also addressed in the LULUCF category. It is not part of the inventory category 'agriculture' – this category mainly covers emissions of CH_4 and N_2O.

According to the IPCC Guidelines, crops which are harvested from croplands are assumed to be oxidised without delay. This is a good approximation in most cases, e.g., if crops are converted into foodstuff of biofuels. However, if crops are converted into long-lived products such as building materials, they can store carbon for several decades, while the GHG inventory assumes instantaneous oxidation. Hence, according to current inventory rules, the storage of carbon in products from agricultural biomass does not show up in GHG inventories.

In its proposal for a new LULUCF Regulation (European Commission 2021, Article 9), the European Commission introduced the concept of 'carbon storage products'. While the current LULUCF regulation requires the accounting for harvested wood products, the proposal for the new regulation includes the accounting for additional products, such as fibres or polymers which have a carbon sequestration effect.

CO_2 emissions from the combustion of biomass

Although CO_2 emissions from the combustion of biomass are not included in total emissions from the energy category, they are reported in the GHG inventory as a memo item. If a country switches from fossil to biogenic fuels, this will show up in the inventory through a decrease of fossil CO_2 emissions and an increase of biogenic emissions. Total energy-related emissions will decrease because only the non-biogenic part is included in the total in the energy category.

In case of international trade of wooden biomass, the loss of CO_2 will show up only in the LULUCF balance of the exporting country. For traded agricultural biomass, possibly effects of indirect land use change (ILUC)[5] could show up in the exporter's LULUCF balance.

Fugitive CO_2 emissions from biomass

In addition to combustion processes, fuel transformation processes lead to CO_2 emissions. These are reported as fugitive emissions in subcategory 1.B of the energy category.[6] Biogenic CO_2

[5] ILUC effects could e.g. possibly comprise losses in carbon stocks due to the conversion of forests into agricultural land.

[6] Besides fugitive CO_2 emissions, fugitive emissions of CH_4 and N_2O are reported under subsector 1.B. Unlike CO_2, the emissions of CH_4 and N_2O from biogenic fuels are included in total emissions. Biogenic CH_4 emissions may be relevant, e.g., as fugitive emissions from the transport of biogas, as

emissions from fuel transformation may also occur, e.g., CO_2 emissions from charcoal production. A footnote in CRT table 1.B.1 explains that such CO_2 emissions are biogenic and should not be included in the national total. The logic is the same as with CO_2 emissions from fuel combustion.

CO_2 emissions from biomass in the IPPU category

Biomass may also be used as feedstock for industrial processes. Similar to the energy category, CO_2 emissions of biogenic origin are not included in total emissions of the IPPU category, and the 2006 IPCC guidelines focus on CO_2 emissions of fossil origin. Unlike in the energy category, there is no space for reporting emissions of biogenic CO_2 as a memo item. Only the CO_2 emissions from non-biogenic sources are reported. They are added to total emissions. However, the CRT provides for the reporting of recovery/capture of biogenic CO_2, as further explained in section 3.3, below.

CO_2 emissions from biomass in the waste category

CO_2 emissions from the combustion of waste are reported in the CRT for the waste category. In Table 5.C, emissions from biogenic and non-biogenic sources are reported. Footnote (1) to this table specifies that CO_2 emissions from combustion of biomass materials should not be included in the national totals. This approach is the same as the one used in the energy category. It has to be noted that if waste is combusted for energy use, emissions are reported in the CRT for the energy category, rather than in the CRT for the waste category.

Challenges

The question arises whether synthetic fuels, if made from CO_2 captured from the combustion or use of biomass (see #7 in Table 2-1 / #8 in Table 2-2), also constitute biomass under the inventory biomass definition quoted above. More specifically: Are BEC-based E-fuels 'derived' from biomass? As the main purpose of biomass combustion, preceding CO_2 recovery for E-fuel production in such cases, is direct energy or feedstock use rather than the generation of CO_2 for E-fuel production, we also consider that **BEC-based E-fuels do NOT meet the inventory definition for biomass**.[7] However, as the interpretation of the IPCC biomass definition in this context has significant consequences for consistent reporting both of CO_2 emissions from the combustion of such BEC-based E-fuels and of preceding CO_2 removals from bioenergy combustion processes, we suggest that consensus should be explored EU-wide and internationally among GHG inventory experts.

The absence of GHG inventory methodologies to account for medium or long-term storage of biogenic carbon in non-wood 'carbon storage products' implies that any potential schemes for such activities would not have any direct visibility as carbon storage in the GHG inventories. (However, potential substitution effects, e.g. avoided emissions for steel or cement production, would be visible in the inventories.)

fugitive emissions from charcoal production, or as combustion emissions from the incomplete combustion of biogas.

[7] This assessment is consistent to our consideration whether BEC-based E-fuels meet the definition for biomass based fuels under the EU Emissions Trading System, which are supposed to be 'produced from' biomass (cf. chapter 5.1.1).

3.3 Capture and storage / use of CO_2

Carbon capture and storage is addressed in national GHG inventories as follows.

Reporting of CO_2 that is captured and transferred to long-term storage

If CO_2 from combustion is captured, the 'amount captured' is reported in a dedicated column in the CTR (Table 1.a(a)). In the same table CO_2 emissions are reported. They are lower – by the captured amount – than they would be if no capture occurred.

If CO_2 is captured from *biomass* combustion and transferred to long-term storage, the recovered amounts should be reflected in the total emission for the category, i.e. they contribute as a negative emission (footnote 4 in Table 1.a(a)). This is an example where negative emissions can occur in the energy category. The capture and storage of CO_2 from biomass combustion is known as Bio-Energy Carbon Capture and Storage (BECCS). It is a negative emission technology, provided that the negative emissions are not counterbalanced by emissions during biomass cultivation, production, transport, fuel production, CO_2 transport and CO_2 storage.

In that sense, CCS from biomass is different from CCS from non-biomass sources (fossil, peat): CCS from biomass can be a negative emission technology, while CCS from non-biomass sources can be a low-emission technology only. For BECCS based on wood products, however, the loss of carbon stored in the wood product is accounted as an CO_2 emission in the LULUCF category (see chapter 3.2). Thus, in the inventory logic focussing on a single year, only BECCS based on agricultural biomass constitutes a net sink.

Like in the energy category, CO_2 can also be captured in the IPPU category and transferred to long-term storage. As an example, hydrogen can be produced from fossil methane, and the by-product CO_2 can be captured and stored. This approach is known as 'blue hydrogen production'. In the CRT (Table 2(I).A-H), the recovery and any remaining emissions can be reported under the category 2.B.10 hydrogen production. Hydrogen production from fossil feedstock with CO_2 capture constitutes a low-emission technology.

Table 2(I).A-H provides separate rows for fossil and *biogenic* CO_2. It is explained in footnote (6) that if biomass is used as a feedstock and the resulting CO_2 emissions are captured from the process and transferred to long-term storage, the recovered amounts should be subtracted from the emissions of the category. Like in the energy category, the capture and storage of carbon from biomass is a negative emission technology, provided that these negative emissions are not counterbalanced by emissions during the life cycle from biomass cultivation to CO_2 storage.

Biochar

As discussed in chapter 2.2, the production of biochar from biomass and subsequent storage (insertion into soil) can be considered as a NET (#8 in Table 2-3, #14 in Table 2-4). While the 2006 IPCC guidelines do not specify how the production and subsequent insertion of biochar would be accounted in the inventories, specific guidance is provided in the 2019 refinement: The insertion of biochar in the soil should be reported as a carbon removal in CRT category 4 LULUCF. Any CH_4 emissions from the production of biochar, however, should be reported in CRT category 1.B.1.b.i (charcoal and biochar production)[8]. It should be noted that this convention may possibly lead to

[8] Biogenic CO_2 emissions from the production of biochar should not be reported as clarified in footnote 7 to Table1.B.1 of the CRT as agreed in November 2021 under the UNFCCC/Paris Agreement.

confusion as CO_2 removals reported in the LULUCF category are often summarised as 'natural sinks'.

Use of captured CO_2

Besides the long-term storage of CO_2, captured CO_2 can be used for various purposes. The capture and use of CO_2 is common in the industrial processes category. As an example, CO_2 can be captured from ammonia production and used in greenhouses or for urea production. According to the 2006 IPCC guidelines, the related emissions should be allocated to the category where the CO_2 was captured – in this case: ammonia production (IPCC 2006, Vol 1, chapter 8). This is because not all emissions from the use of CO_2 or urea are reported in GHG inventories.

Only if the related emissions are reported in other inventory categories, they do not need to be reported in the category where CO_2 is captured. The 2019 refinement clarified that 'if in the process of using captured CO_2, emissions (fugitive) occur, then such emissions should be reported where the use of CO_2 occurs (IPCC 2019, Vol. 1, chapter 8). The two typical examples where such emissions occur and are reported are categories 2.D.3 (emissions from urea use in selective catalytic reduction) and 3.H (urea application).

In some cases, CO_2 may be captured and used for the production of long-lived products, such as melamine. Emissions of CO_2 captured for the use in long-lived products are generally not reported where they are captured because the stored carbon is emitted as CO_2 only if these products are combusted. Once these products are combusted at the end of their life cycle, the related emissions are reported in the waste or energy category. Such capture of CO_2 for the use in long-lived products would constitute a ZLET and could be considered a NET only in case of permanent storage (CCS) after end-of life treatment (see #8 or #15 in Table 2-4).

Besides the use in products, CO_2 may also be used for the production of synthetic fuels. This process is addressed in section 3.5, below

CO_2 emissions during transfer and storage

If CO_2 is captured and stored, part of it is emitted by leakages during its transport, injection into the long-term-storage site, and during storage. These emissions have to be reported in the CRT (Table 1.C). The higher these emissions, the lower the mitigation effect of CCS technologies.

According to footnote (4) of Table 1.C. there is no difference in the treatment of biogenic carbon and fossil carbon once captured. Emissions and storage of both biogenic and fossil carbon will be estimated and reported. The differentiation in reporting between biogenic and non-biogenic sources happens during the capturing process only (see above).

Challenges

National GHG inventories allow for the reporting of annual emissions and removals, but they provide some limitations when looking at long-term developments.

First, GHG inventories allow for the reporting of CO_2 emissions from storage in the reporting year only. This is the correct approach for an annual emissions inventory, but it does not provide information on long-term effects. As an example, if CO_2 from biomass is captured and stored, and the emissions associated with production, transport and storage are lower than the amount stored, this capture and storage appears to be a negative emission technology. However, if important amounts of CO_2 are emitted from storage in future years, or if biomass production leads to emissions from land use change in future years, CCS from biomass may no longer be regarded as a negative emission technology.

Second, the CRTs do not provide for the reporting of the recovery of CO_2 from the waste category. However, this is a minor issue because the waste category generates relatively small amounts of CO_2 emissions, and currently these are not recovered (e.g., open burning of waste, burning of clinical waste). If waste is incinerated for energy use, the associated emissions are reported in the energy category, and recovery can be reported there. What is of importance in the waste category is the recovery of CH_4. The recovery of this gas can be reported in the CRTs for solid waste disposal, biological treatment of solid waste, and wastewater treatment and discharge.

An open question remains how to report the CO_2 that is captured before it is used for synthetic fuel production. In Table 2(I).A-H there is guidance on subtracting biogenic CO_2 that is captured and transferred to long-term storage, but there is no guidance on how to treat biogenic CO_2 that is captured and used for synthetic fuel production. If such CO_2 is not subtracted, there may be an over-estimation of emissions. Non-biogenic CO_2 emissions would be reported when the synthetic fuel is combusted, although this fuel does not contain fossil carbon. A possible way forward could be to subtract biogenic CO_2 that is captured and used for synthetic fuel production. However, this would run counter the principles of the IPCC guidelines, which clearly state that CO_2 captured can only be reported if it is for long-term storage.

3.4 Direct air capture

Direct air capture (DAC) is a process which removes CO_2 from the atmosphere and therefore constitutes a greenhouse gas sink. Currently, DAC is not reported in national GHG inventories, but in the future, countries may want to include DAC as a sink category.

Reporting of removals from DAC

DAC could potentially be reported in the following categories:

- 1.B.2.d Other energy production (if it forms part of a fuel production process)
- 2.B.10 Chemical industry – other (if it forms part of a chemical industry process)
- 2.H.3 Industrial processes – Other

However, there is the difficulty that the CRT for these categories do not allow for the reporting of removals. They only allow for the reporting of recovery of emissions, which does not correctly describe the process of DAC.

In the CRT, removals can be reported in two categories: In category 4 (LULUCF) and in category 6 (Other). Removals can be reported in category 6 by entering negative values in the table ‘summary 1’ in the column for ‘net CO_2 emissions/removals’. Note that in category 1.C (CO_2 transport and storage), *emissions* associated with the transport and storage of captured CO_2 can be reported, but no *removals*.

Reporting of subsequent emissions

If CO_2 removals from DAC are reported in the GHG inventory, it is important to report any emissions which may occur subsequently. Such emissions may include emissions from CO_2 transport, emissions from injection and storage of CO_2, emissions from the use of CO_2, and emissions from the combustion of synthetic fuels made from the captured CO_2. Only if the CO_2 captured remains in long-term geological storage, DAC can be considered a negative emission technology.

Challenges

Currently, there are no guidelines on where to report direct air capture. The IPCC guidelines do not address this category, and they do not provide clear guidance how to report subsequent emissions. DAC-based fuels are neither biogenic nor fossil fuels, and it is unclear how to report them in GHG inventory.

It should be discussed whether the ‘recovery’ data field could be used to report direct air capture, or whether DAC could be reported as a new sink category under category 6. In any case, it will be important that clear guidelines will be developed well ahead of the revision of the GHG inventory reporting guidelines in 2028.

3.5 Combustion of E-fuels

Neither the 2006 IPCC guidelines nor the 2019 refinement do explicitly cover the production and consumption of E-fuels, involving CO_2 recovered from combustion processes (fossil CCU, see #4 in Table 2-2, or BECCU, see #8 in that table), or removed from the atmosphere (DACCU, see #9 in Table 2-2). Thus they do not provide clear guidance how the production and combustion of E-fuels should be accounted:

E-Fuels do not meet the definition for biomass – they are non-biogenic fuels or feedstocks, like fossil fuels or peat. In addition, biomass can be treated differently in inventories (memo item in the energy category; subtraction of captured CO_2 in the IPPU category) only because elaborate carbon balances are set up in the LULUCF category.

Thus, it has to be noted that e-fuels or other fuels or feedstocks derived from captured CO_2 cannot be treated the same way as biomass. Note that the CRT reporting format does not provide a dedicated fuel category for E-fuels. If E-fuels would not be reported as biomass the only sensible option would be 'liquid fuels' where CO_2 emissions are considered fossil and added to the national totals. If the CO_2 emissions from the combustion of E-fuels would thus be reported like CO_2 from conventional fossil fuels, the CO_2 recovered from waste gas streams for the production of the E-fuels (fossil CCU or BECCU), or removed from the atmosphere in case of DACCU, would necessarily need to be subtracted elsewhere in the inventory in order to avoid double counting.

On the other hand, the IPCC guidelines provide general guidance related to CO_2 capture that 'quantities of CO_2 for later use and short-term storage should not be deducted from CO_2 emissions except when the CO_2 emissions are accounted for elsewhere in the inventory' (IPCC 2006, Vol. 2, section 2.3.4). Such exceptions noted in the 2006 guidelines and the 2019 refinement are the production of urea and methanol. However, the use of CO_2 recovered for the production of E-fuels is not mentioned in the guidelines. Hence, this would support an interpretation of the IPCC guidelines, that CO_2 emissions associated with the combustion of e-fuels should be reported in the category where the CO_2 used for e-fuel production originates. For E-fuels produced from atmospheric CO_2 via direct air capture (see section 3.4) that would imply that no CO_2 removal should be reported.

While both approaches would be fit to avoid double counting, there are challenges in case of international trade of E-fuels. On one hand an international consensus for one of the two possible approaches would be required in order to avoid gaps or double-counting related to E-fuels produced in one country and combusted in another country. On the other hand, the allocation of related CO_2 emissions to either the producing or the consuming country (and possibly the allocation of removals to the producing country in case of BECCU- or DACCU-based E-fuels) entails differing incentives for the producing and the consuming countries to invest in CO_2 capture for E-fuel production (producing country) or to purchase costly E-fuels in the consuming country: While the first approach (to fully report CO_2 emissions for the combustion of e-fuels and subtract CO_2 recovered/removed for the production) would appear particularly attractive to the producing country, the second approach (to treat e-fuels combustion like biomass combustion) provides a direct incentive to the consuming country as purchases of costly e-fuels are reflected as lower emissions in the own inventory. In case the first approach for the treatment of e-fuels in GHG inventories would be chosen, the consuming countries would have an incentive only if there would be some mechanism to account for E-fuel trade in national GHG targets.

3.6 Summary of inventory challenges

The following challenges were identified when addressed NET and ZLET in GHG inventories:

Even if negative emissions are reported for a certain technology in a given inventory year, this does not mean that this technology constitutes a NET. If emissions from CO_2 storage, or from land use change related to this technology, occur in future years, these do not show up in the current GHG inventory. Hence, GHG inventory methods are not suitable in all cases for estimating the overall mitigation impact of a NET or ZLET. Life cycle approaches as used e.g. for sustainability and energy savings criteria in the EU Renewable Energies Directive context (see section 4.1.2) may be more appropriate in these cases.

Second, current inventory rules address the case that carbon is captured and transferred to long-term geological storage, but they do not explicitly address the case that CO_2 is captured and used for synthetic fuel production. The current rules appear ambiguous, emissions could be reported in the category where CO_2 is released upon E-fuel combustion or in the category where the CO_2 is captured. In the case of international trade of such e-fuels, both inventory approaches at hand would imply strongly differing incentives for the producing and the consuming countries, respectively.

As explained above, neither BEC-based E-fuels nor E-fuels in general in our view do meet the inventory definition for biomass. However, we suggest that this definition should be discussed further, and consensus should be explored.

Another challenge in GHG inventories is that there are currently no GHG inventory approaches for addressing the storage of carbon in non-wood biomass-based products. Such storage of carbon does not constitute a sink in GHG inventories.

The rules for the reporting of GHG inventories have been agreed under the UNFCCC and under the Paris Agreement, and it is important that they do not change during an NDC implementation period. Hence, the methods for national GHG inventory methods will remain unchanged in the coming years. This is unproblematic as NET and ZLET do not yet have a large mitigation potential in the period up to 2030. However, once the discussion on post-2030 targets and mitigation measures starts it will be important to consider how the effects of measures such as NET and ZLET can be reflected accurately in GHG inventories.

The way forward should be for experts in mitigation measures and GHG inventories to consider how various NET and ZLET can be represented correctly in GHG inventories. This exercise should be completed well ahead of the first review and update of the modalities, procedures and guidelines for the transparency framework under the Paris Agreement, which is scheduled to start no later than 2028.

4 Coverage of NETs / ZLETs in the Directive on renewable energies

Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (recast) (RED II) is the main policy instrument that promotes renewable energies in the EU. It sets a minimum RES share for the EU and requires Member States to set national contributions towards the overall target. Targets for different sub sectors and how these shares are calculated are also defined. In addition, it sets the sustainability and eligibility criteria for alternative fuels and provides the basis for the treatment of biofuels in the ETS (see section 5.1.1) among other issues. In the context of this paper, questions of relevance are the rules to prevent double counting in terms of produced/used renewable energies and the definitions of renewable fuels.

In this chapter, we give an overview over the relevant definitions used in the RED II and the sustainability requirements (chapter 4.1). Building on this, we discuss potential challenges related to the double counting of renewable energies (chapter 4.2) and provide a short summary.

4.1 Intro / Background on RED II

4.1.1 Relevant definitions

Art. 2 of the RED II provides the definitions of the different types of renewable fuels already listed in Table 2-1 above. In total, there are three main categories of renewable fuels:

1. Biomass-based fuels: biomass is defined as the biodegradable fraction of products, waste and residues from biological origin including the biodegradable fraction of industrial and municipal waste. Biomass is then the feedstock for the production of
   - Biomass fuels: gaseous and solid fuels;
   - Biogas: gaseous fuels;
   - Bioliquids: liquid fuel for non-transport purposes (i.e. electricity generation or heating/cooling);
   - Biofuels: liquid fuels for transport; and
   - Advanced biofuels: biofuels that are produced from a subset of biomass listed in Part A of Annex IX of the RED II.
2. Recycled carbon fuels (RCF): liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations; and
3. Renewable liquid and gaseous transport fuels of non-biological origin (RFNBO): means liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass;

When calculating the share of renewable energy in the transport sector, there are special rules for certain fuels:

- Fuels produced from food and feed crops as well as those associated with a high risk of indirect land-use change can only be used to a certain maximum share (Art. 26);

- Advanced biofuels as well as biofuels from used cooking oil and some animal fats are accounted with a multiplier of two, i.e. their energy content is counted double (Art. 27(2)). In addition, there is an increasing minimum share for advanced biofuels. The proposal for the revised Directive as part of the Fit for 55 package, this multiplier is removed (European Commission (EC) 2021a).
- RFNBOs are multiplied with the share of renewable electricity used during production, i.e. only the renewable share of RFNBOs is counted (Art. 27(3));
- RCF can be accounted towards the minimum share of RES in the transport sector (Art. 27(1)).

RFNBOs under the RED II are only foreseen in the transport sector. In the proposed amendments to the RED, this limitation is removed but accounting rules for the production and usage of RFNBOs are changed (chapter 4.2).

4.1.2 Sustainability and emission savings criteria

Biomass-based fuels have a high potential of having unintended consequences and/ or little actual greenhouse gas savings. Depending on the type of feedstock, place of origin and agricultural/ forestry practices, they can impact negatively on food security, land-use and land degradation, biodiversity and have high implied emissions. The sustainability criteria in Art. 29 of the RED II intend to minimise these negative consequences. These criteria are applied to all biomass independently of the place of origin, i.e. also when biomass or derived products are imported from non-EU countries (Art. 29(1)). Only those biomass-based fuels, that comply with these criteria, can be accounted towards national and EU-wide RES targets and fuel supplier RES obligations. Eligibility for financial support and the accounting of biomass with an emission factor of 0 t CO_2/MJ also depend on meeting these criteria.

In particular, the criteria cover

- sustainability of biomass (Art 29 (2)-(7));
- minimum emissions savings compared to the fossil alternative (50% to 70% depending on the sector and year when an installation started operations) (Art 29 (10)); and
- restrictions on biomass use for electricity generation (Art 29 (11)).

The biomass sustainability criteria depend amongst others on the type of feedstock, the type of land, the biodiversity and legal status of the land from where the feedstock stems and rules to prevent deforestation.

In addition to the criteria in Art. 29 there is a minimum emission saving threshold of 70% for RFNBO in transport (Art. 25(2)). A draft delegated act proposes the same minimum threshold for RCF (European Commission (EC) 2022). In the proposed amendment under the Fit for 55 package, these minimum thresholds for RNFBOs and RCFs are extended to all usages in Art. 29.

4.2 Double counting

In the context of this paper, the main issue is a potential double counting/ omission of RES contributions towards the respective targets and contributions. This can take place potentially within a country but also between two countries if renewable energy is traded. Art. 7(1) requires that "gas, electricity and hydrogen from renewable sources shall be considered only once". Electricity used for RFNBO-production is accounted towards the targets whereas the usage of RFNBOs is not. Due to the energy conversion losses during the production of RFNBOs, the electricity supplied is at least twice as high as the energy content of the RFNBO (Searle 2021). In the proposal for an amendment (European Commission (EC) 2021a), this is changed: RFNBOs are allocated to the sector targets where they are used, renewable electricity used to produce RFNBOs is deducted from the total renewable electricity generated in the calculation of the RES-E target. Effectively, this means that RFNBO production is accounted in the sector and country where it is used, electricity used for generating these fuels is not accounted for.

Trade between countries is regulated in Art. 8(1). It requires the exporting country to deduct the transferred renewable energy from the calculation of the national RES targets. The same quantity of renewable energy is added in the importing country. This can be a purely statistical transfer not physically linked to actual quantities (e.g. in the electricity sector typically the grid mix is exported). Both the transferring as well as the receiving Member State need to notify the Commission to conclude this statistical transfer and be allowed to reflect it in their calculations. A risk of double counting exists with third countries outside of the EU: if an exporting country also has a RES target it is not ensured that exported quantities are not counted towards both the exporting country’s and the importing Member State’s target achievement.

4.3 Summary of RED II challenges

There was some discussion around potential double counting of RES quantities under the current RED II but these concerns have been addressed in the proposal under the Fit for 55 package. The only potential issue regarding double counting could be with third countries that export RES to the EU. If these countries have RES targets based on RES production and do not deduct exported quantities, double counting would occur.

5 Coverage of NETs / ZLETs in the EU-ETS

In this chapter, first some basics on the monitoring rules are explained how ETS operators have to report their CO_2 emissions (section 5.1). Subsequently, the implications of those monitoring rules are discussed for CO_2 emissions / CO_2 generation (section 5.2) and CO_2 recovery / capture / transfer / sequestration (section 5.3) in the context of NETs and ZLETs. A summary of identified ETS monitoring challenges which may become relevant with an increased uptake of NETs/ZLETs is given in section 5.4.

5.1 Basics on ETS Monitoring

While the legal basis of the EU emissions trading system (ETS) is set out in the ETS Directive 2003/87/EC[9], most relevant definitions affecting the accounting for the production and/or use of fuels and non-fuel products considered in chapter 2 for NET/ZLET are set out in the Monitoring and Reporting Regulation (MRR) of 2018 (European Commission 2018) for the 4th phase of the EU-ETS starting 2021. In 2020 the MRR was amended by (European Commission 2020) with some definitional updates in order to maintain consistency with the 2018 recast of the EU Renewable Energy Directive (RED II) (European Union 2018).

5.1.1 Definitions related to biomass use

The MRR definition of biomass and biomass-based fuels (i.e. 'biomass fuels' as solid or gaseous fuels, 'biofuels' as liquid fuels in the transport sector and 'bioliquids' in other sectors) is fully aligned with respective definitions under the RED II, as explained in section 4.1.1.

Differing from the approach in emission inventories (see section 3.2), however, an emission factor of zero for the calculation of CO_2 emissions from biomass is permitted under the EU-ETS only for those cases of biomass use where the sustainability and emissions savings criteria as set out in the RED II (see section 4.1.2) are complied with. In cases where the sustainability and emission savings criteria are not complied with, CO_2 emissions are to be considered as fossil CO_2 (MRR, Art 38).

In the context of NET/ZLET discussed in chapter 2, synthetic fuels or non-fuel products based on CO_2 recovered from bioenergy combustion (BEC) may play a role in ETS installations: BEC-based E-fuels (#8 in Table 2-2) or BEC-based non-fuel carbon storage products (#4, #9, #13 & #16 in Table 2-4) may be used as source streams. We consider that **BEC-based fuels/products do NOT meet the MRR definitions for 'biomass'**[10]. We also consider that **BEC-based E-fuels do NOT meet the MRR definitions for 'biomass fuels', 'biofuels' or 'bioliquids'**, which are defined to be "produced from biomass"[11], as the downstream recovery and use of CO_2 generated during bioenergy combustion can hardly be considered 'production from biomass' while bioenergy combustion is primarily carried out for energy use[12] and for the purpose of generating and recovering CO_2.

Thus, under the present MRR accounting rules, the combustion of BEC-based E-fuels or the emissive use of other BEC-based products in EU-ETS installations is NOT incentivised by an

[9] See EU 2021 for consolidated text, including the latest available amendments of 2021.

[10] Definition in MRR Art 3 (21) 'biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin

[11] See definitions in MRR Art 3 (21a), (22) and (23).

[12] Next to energy use, possibly the use as reductive agent is likely to be the objective of bioenergy combustion.

emission factor of zero. The same would be likely to hold for BEC-based E-fuels (among 'RFNBOs' under RED II nomenclature, see section 4.1.1) placed on the EU market under a fuel ETS as proposed by the European Commission in its 2021 proposal (European Commission (EC) 2021c) to amend the EU-ETS Directive.

5.1.2 CO_2 transfers and inherent CO_2

The MRR provides for rules avoiding the double-counting of CO_2 emissions in cases where CO_2 is transferred from one ETS installation to another installation subject to the ETS as part of a source stream ('inherent CO_2' as defined in MRR Art 3 (41)): According to MRR Art. 48 such amounts are subtracted from the transferring installation and counted only for the receiving installation.

However, where fossil CO_2 is transferred out of the installation to entities not covered by the ETS Directive, it shall be counted as emissions of the installation where it originates (MRR Art. 48). Only two distinct exemptions for this rule are defined in MRR Art. 49:

1. **CCS:** fossil CO_2 amounts transferred to a capture installation for the purpose of transport and long-term geological storage in a storage site permitted under the EU CCS Directive 2009/31/EC[13] can be subtracted from the CO_2 account of the ETS installation generating the CO_2. The same holds for CO_2 captured in the ETS installation itself and directly fed into a dedicated CO_2 transport network or permitted storage site.
2. **precipitated calcium carbonate** (PCC)**:** fossil CO_2 may also be subtracted from an ETS installation's account if it is used (outside the ETS scope) for the production of precipitated calcium carbonate, in which the used CO_2 is chemically bound.[14]

In other cases, inherent CO_2 and carbon-containing products transferred from ETS installations to other entities are accounted as CO_2 emissions under the ETS although emissions do not physically take place directly at the ETS installation. The reasonable background of such a rule is the consideration that respective CO_2 emissions will in any case take place at a timescale of months or years[15].

Thus, under the present MRR accounting rules, the recovery of CO_2 for other purposes, including the production of E-fuels or of durable non-fuel carbon storage products, is NOT incentivised by allowing subtraction from the CO_2 account.

Note, however, that the 2023 revision of the EU-ETS Directive[16] will bring some changes. We refer to the proposal by the European Commission (European Commission (EC) 2021c) because the revised directive has not been published at the time of writing:

The new para 3b of the proposal will specify that no obligation to surrender ETS allowances arises for '**CO_2 emissions permanently bound in a product so that they do not enter the atmosphere under normal use'**. On this basis, the exemptions of CCS and PCC mentioned above are likely to

[13] European Union (EU) 2009.
[14] This particular exemption was first added to ETS monitoring rules after a respective law-suit had been decided in 2017.
[15] The quantitatively most relevant example for such a situation are ETS production installations for ammonia, where a significant share of CO_2 generated is recovered and chemically bound in urea (ammonium carbonate). However upon use of urea (mostly as fertiliser or as reductive agent in DeNOx waste gas treatment) the urea will decompose, and CO_2 will be emitted.
[16] On 18 December 2022, an agreement between the European Parliament and the Council was reached (Council of the European Union 18.12.2022). Formal adoption of the negotiation outcome is pending, however.

be extended. Details, however, defining more closely e.g. what is to be understood as 'permanently' bound and as 'normal use' (possibly including end-of-life treatment in waste incineration) are yet to be worked out in subordinate legislation to the ETS Directive.

For E-fuel production from CO_2 recovered from ETS installations, however, recital 40 of the Commission's proposal reconfirms that in such cases the emissions shall be accounted for those installations where the CO_2 is released first and that CO_2 captured for fuel use cannot be subtracted. Subordinate legislation, however, is bound to specify that the combustion of such E-fuels in ETS installations is to be rated as zero emissions in order to avoid double-counting.

5.2 ETS accounting of CO_2 emissions for NETs / ZLETs

Given the ETS monitoring basics as discussed in section 5.1, the reporting on the emissive use of fuels or other carbon-containing products under the ETS is rather straightforward. For corrections for end-of-pipe CO_2 capture and transfers see sections 5.3 and 5.1.2:

- Clearly, CO_2 from the combustion of 'normal' fossil fuels[17] or from non-fuel use of fossil carbon, e.g. as reductive agent or carbonate feedstock[18] is accounted as an emission.
  - This includes the CO_2 from the combustion of waste-based fuels[19], which may qualify as 'recycled carbon fuels' (RCF) under RED II. The present MRR accounting rules do thus not incentivise the use of RCFs in ETS installations.
- Under the present monitoring rules, CO_2 from the combustion of E-fuels based on captured CO_2[20] or CCU-based non-fuel carbon-storage products[21] is also accounted as an emission, regardless of whether the carbon in the E-fuel / CCU-based non-fuel product stems from fossil CO_2, DAC or BEC: As BECCU-based E-Fuels and products are not considered biomass nor biomass fuel / bioliquid / biofuel (see discussion in section 5.1.1), respective CO_2 would be fully accounted as an emission. Given the revision of the ETS Directive as discussed in 5.1.2, however, the situation is going to change and the combustion of E-fuels under the ETS will be zero-rated, probably subject to GHG emissions savings and sustainability criteria yet to be defined in detail.
  - Future ETS monitoring rules are likely to incentivise ETS operators to replace the combustion of 'traditional' fossil fuels by the combustion of E-fuels, including E-fuels based on DAC and BEC and fuels qualifying as RFNBOs under RED II. However, this is not yet the case under the present MRR accounting rules.
- CO_2 from the combustion biomass-based fuels[22] or of non-fuel biomass use[23] (e.g. as reductive agent) are accounted with an emission factor of zero only if the respective sustainability and emission savings criteria set out in the RED II are complied with (see sections 4.1.2 and 5.1.1). Otherwise, such 'biogenic' CO_2 would be accounted as an emission under the ETS.
  - While this approach is designed to incentivise 'sustainable' biomass use and disincentivise 'non-sustainable' biomass use in ETS installations, there will be administrative challenges for ETS

[17] See #1, #3 & #4 of Table 2-1 / #1, #2 & #3 of Table 2-2.
[18] See #3, #7 & #12 of Table 2-3 / #1 - #3 of Table 2-4.
[19] See #4 of Table 2-1 / #3 of Table 2-2.
[20] See #7- #9 of Table 2-1 / #4, #8 & #9 of Table 2-2.
[21] For the time being, such emissive use of CCU-based non-fuel carbon-storage products (#4 - #6, #9 - #11 & #13 - #15 of Table 2-3 / #4 - #6, #8 - #10 & #15 - #17 of Table 2-4) is rather a theoretical option.
[22] See #2, #5 & #6 of Table 2-1 / #5 - #7 of Table 2-2.
[23] See #1, #2 & #8 of Table 2-3 / #12 - #14 of Table 2-4.

operators and competent national authorities to demonstrate and check compliance with these sustainability and emissions savings criteria.

– A persisting use of 'non-sustainable' biomass in ETS installations resulting in accounted ETS emissions from biomass would further challenge the comparability of ETS emissions data with GHG inventory data and distort Member States' compliance situation under the EU Effort Sharing Regulation 2018/842 where emissions are determined roughly by subtracting ETS emissions (including CO_2 from 'non-sustainable' biomass) from inventory totals (excluding CO_2 from biomass).

- Emissive use of CO_2 feedstock[24], possibly e.g. in food industry, in particular considering the ETS monitoring rules related to transfer of inherent CO_2 (see section 5.1.2) is also accounted as an emission under the ETS, regardless of the origin of the CO_2.

5.3 ETS accounting of CO_2 removals for NETs / ZLETs

Capture or transfer of CO_2 for underground sequestration (CCS)

Where CO_2 is captured for underground sequestration (CCS, see section in 5.1.2) respective CO_2 amounts are subtracted from the company's emission accounts in case of fossil CO_2[25]. For biogenic CO_2[26] captured for underground storage (BECCS) no additional amounts can be subtracted.

However, with the revision of the ETS Directive (European Commission (EC) 2021c, Recital 39 and draft amendment to para 14(1)), subordinate legislation is foreseen to specify how to account for storage of emissions from a mix of zero-rated sources (e.g. sustainable biomass) and sources that are not zero-rated (e.g. fossil CO_2).

Thus, under the present MRR accounting rules, the capture for underground storage of CO_2 from sustainable bioenergy use (BECCS), is NOT incentivised by allowing additional subtraction from the CO_2 account or balancing against other CO_2 emissions of the ETS operator. Details pending, however, subordinate legislation to the revision of the ETS Directive could possibly evolve into a framework where permanent storage of CO_2 from biomass would be incentivised.

Capture or transfer of CO_2 for E-Fuel production

Under the present MRR accounting rules, the capture of CO_2 for the production of E-Fuels[27], possibly comprising RFNBOs as defined under RED II, is NOT incentivised by allowing subtraction from the ETS operator's CO_2 account.[28] Where CO_2 recovered for E-fuel production is subtracted in the national GHG inventory (see section 3.5) and E-fuels would possibly be traded in large scales across country borders, the present MRR approach would lead to inconsistencies between ETS and

[24] See #16 - #18 of Table 2-3 / #7, #11 & #18 of Table 2-4.

[25] See carbon-containing fuels #1, #3 & #4 of Table 2-1 / #1, #2 & #3 of Table 2-2 and carbon-containing non-fuel products #3, #7 & #12 of Table 2-3 / #1 - #3 of Table 2-4. Applies also to CO_2 from CCU-based fuels #7- #9 of Table 2-1 / #4, #8 & #9 of Table 2-2 and non-fuel products #4 - #6, #9 - #11 & #13 - #15 of Table 2-3 / #4 - #6, #8 - #10 & #15 - #17 of Table 2-4. Applies also to CO_2 from 'non-sustainable' (see section 5.1.1) biomass as quoted in footnote 26.

[26] See fuels #2, #5 & #6 of Table 2-1 / #5 - #7 of Table 2-2 and non-fuel products #1, #2 & #8 of Table 2-3 / #12 - #14 of Table 2-4 in case sustainability and emissions savings criteria sustainable' (see section 5.1.1) are met.

[27] See #7 & #9 of Table 2-1 / #4 & #8 of Table 2-2.

[28] An exception would apply where the E-fuel is produced within one ETS installation and supplied directly for use/combustion in other ETS installation. However, as E-fuels are expected to play a role particularly in the transport sector, the affected amounts are likely to remain insignificant.

inventory emissions and would possibly distort MS ESR compliance (like discussed for 'non-sustainable' biomass in section 5.2).

This situation is not expected to change with the 2023 revision of the ETS Directive

Capture or transfer of CO2 for the production non-fuel carbon storage products

Under present MRR rules, the same as for E-Fuels holds for the recovery of CO_2 for the production non-fuel carbon storage products[29], with the exception of CO_2 for the production of precipitated calcium carbonate (see section 5.1.2). Under the revision of the ETS Directive, however, criteria are likely to be developed to define further exemptions where CO_2 emissions are permanently bound in a product so that they do not enter the atmosphere under normal use.

5.4 Summary of challenges related to ETS monitoring

Under the present ETS monitoring rules as set out in the MRR[30], neither the removal of CO_2 from off-gases for the purpose of production of E-fuels nor the combustion of E-fuels is incentivised by allowing to subtract respective 'recycled' CO_2 amounts. This includes the production and combustion of E-Fuels which would comply with RFNBO[31] eligibility criteria to be set out under RED II, possibly including BEC[32]- & DAC[33]-based E-Fuels. In subordinate legislation under the revised ETS Directive, however, combustion of E-fuels is likely to be rated with zero emission, subject to eligibility criteria.

For the production of E-fuels based on fossil CO_2 captured in ETS-installations, however, the approach to fully allocate emissions from the later use of such fuels to the ETS installations ensures consistency with the RED II approach where the use of such fuels would be accounted as eligible for renewables quotas and thus communicated as 'emission-free'. However, that approach may possibly lead to inconsistency with GHG emission inventories (cf. section 3.2) in case respective CO_2 removals for E-fuel production would be turn out to be subtracted there. In that case and assuming large scale trade of E-fuels across borders, such an inconsistency between EU-ETS monitoring and GHG inventory approaches would distort EU Member State compliance under the EU Effort Sharing Regulation[34] (ESR) where ESR emissions are roughly defined as GHG inventory emissions minus EU-ETS emissions.

Like for RFNBOs, the ETS monitoring rules do not incentivise the combustion of carbon-containing recycled carbon fuels (RCF) which are promoted under the RED II, subject to eligibility criteria. The combustion of RCFs generated under the ETS, however, is likely to be rated with zero emissions in subordinate legislation under the revised ETS Directive.

[29] I.e. synthetic organic compounds (see #4 & #6 of Table 2-3 / #4 & #15 of Table 2-4), solid carbon (see #9 & #11of Table 2-3 / #5 & #16 of Table 2-4) or inorganic carbon compounds (see #13 & #15 of Table 2-3 / #6 & #17 of Table 2-4) or CO_2 for use as industrial gas (see #16 & #18 of Table 2-3 / #7 & #18 of Table 2-4).

[30] Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC

[31] RFNBO: Renewable transport fuel of non-biological origin, as defined under the RED II.

[32] BEC: bioenergy combustion

[33] DAC: Direct air capture

[34] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013

Furthermore, the recovery of CO_2 for the production of durable non-fuel carbon storage products, except geological sequestration, is presently not incentivised as respective CO_2 amounts are not allowed to be subtracted under the present MRR. In subordinate legislation under the revised ETS Directive, however, criteria are likely to be developed to define further exemptions where CO_2 emissions are permanently bound in a product so that they do not enter the atmosphere under normal use.

Finally, for ETS operators using biomass no credits are given for the capture of CO_2 from sustainable bioenergy use for underground storage (BECCS). In subordinate legislation under the revision of the ETS Directive, however, some bonuses for storage of CO_2 from biomass can be expected in the cases of a mix of zero-rated sources (e.g. sustainable biomass) and sources that are not zero-rated (e.g. fossil CO_2).

6 Conclusions

The major challenges related to consistently addressing NETs and ZLETs have been identified for ***national GHG inventories under the UNFCCC***:

- Explicit international agreement has to be sought related to the production and combustion of E-fuels based on fossil CO_2, biomass (BECCU) or atmospheric origin (DACCU): The two basic options, both fit to avoid gaps and double-counting, are

  1) Either account for CO_2 emissions in the CRT categories where E-fuels would be used (mostly CRT 1A 'fuel combustion') and at the same time allow subtraction of CO_2 amounts captured for fuel production in the categories where the respective CO_2 is recovered or removed (mostly CRT 1 'energy', 2 'IPPU', and/or CRT 6 'other'). Such an approach should be supported by the development of IPCC default CO_2 emission factors for E-fuels. ***In case of international trade of E-fuels, this approach would allocate emission reductions / removals to the countries where E-fuels are produced.*** Without a mechanism to account for e-fuel trade in national GHG targets, this approach would provide no incentive for the usage of e-fuels. The incentive would be for producing countries who could generate negative emissions in their national GHG inventories.

  2) Or confirm for E-fuels the exclusion of inventory reporting of CO_2 recovery for short-term storage. In that case explicit agreement should be sought that CO_2 from the combustion and process use of E-fuels should not be considered in national totals but rather reported as memo items, like biomass under the present guidelines. However, the CRT would be in need for amendments in some details in order to allow transparent reporting in that respect. ***In case of international trade of E-fuels, this approach would allocate emission reductions / removals to the countries where E-fuels are consumed.***

  – It should be noted that BECCU-based E-fuels do not meet the IPCC definition for biomass.

- For emerging CO_2 removal technologies an international agreement should be sought under the UNFCCC in which CRT category such CO_2 removals should be reported. Furthermore the development of respective standardised IPCC guidance for the quantification of CO_2 removal quantities would be beneficial. This relates to:

  – DACCS: Given the present CRT 6 'other' would be the most likely pragmatic option. For accounting under categories 1 (energy) or 2 (industrial processes and product use – IPPU) slight adaptation of CRT details would be necessary in order to facilitate reporting on CO_2 removals (from the atmosphere) next to CO_2 recovery (from waste gases).

  – Note that new reporting conventions would need to be agreed in case of the use of geo-engineering-type natural process enhancers aimed at increasing the amount of carbon stored in waters and soils, the likeliest options being CRT category 4 (LULUCF) or category 6 (other). If CO_2 removals from technology-based processes would be agreed to be accounted in the LULUCF category (as already the case for CO_2 stored in biochar) the lack of equivalence between 'natural sinks' and 'removals reported in the LULUCF category' would further increase.

- Support schemes for biogenic 'carbon storage products' (e.g. construction materials, fibres) are being discussed, which could possibly replace fossil-based products. Where such carbon storage products would not be wood-based, the lack of inventory methods which take into account related carbon pools would prevent visibility of such carbon storage in GHG inventories beyond substitution effects of replaced fossil-based products (e.g. cement, steel).

An appropriate forum for further EU-internal discussion of these inventory topics is the Working Group I under the Climate Change Committee. A first exchange related to direct air capture did already take place at the WG I meeting of 17 October 2022.

Related to accounting of NET and ZLET for renewables targets under the ***RED II*** no gaps or double-counting has to be apprehended. However, for international trade of fuels with non-EU countries, double counting of renewable energies may possibly occur in cases where the non-EU trade partners have own targets on renewable energies and exports into the EU would not be properly subtracted.

The definitions frameworks of the ***RED II*** and the ***EU-ETS*** are consistent and ensure that CO_2 recovery for production of E-fuels (that may be produced in or attached to ETS installations and may be eligible for renewables targets under the RED II) cannot be subtracted from CO_2 emissions in ETS installations.

In this context the incentives provided by presently valid ***EU-ETS accounting rules*** are limited to CCS of fossil CO_2. CCS of biogenic CO_2 and any CCU (beyond precipitated calcium carbonate as decided in a lawsuit in 2017) are not awarded under the EU-ETS and would need incentives from other regimes. In subordinate legislation under the revised ETS Directive, however, storage of 'CO_2 emissions are permanently bound in a product so that they do not enter the atmosphere under normal use' will be rewarded, details in definitions still pending.

The EU-ETS approach to CCU, including E-Fuel production, i.e. not to allow subtractions for CO_2 captured and stored in products for use outside the EU-ETS, is consistent with the 2nd option mentioned above for the coverage of E-fuel production and use in national GHG inventories. In case international consensus for E-fuels in GHG inventories would move towards the 1st option mentioned above, an inconsistency between the EU-ETS and the GHG inventory approaches would occur, comparable to the present inconsistency related to CO_2 recovered from ammonia production for urea production. In principle such an inconsistency affects the determination of GHG emissions subject to the EU Effort Sharing Regulation 2018/842 (ESR). In case of (large-scale) trade of E-fuels across Member States borders, net exporters of E-fuels would 'benefit' from "too" low ESR emissions while net importers would face "too" high ESR emissions.

Moreover, present EU-ETS accounting rules do not incentivise the use (combustion) in EU-ETS installations of emerging carbon-containing fuels meeting the criteria for RFNBO (renewable transport fuel of non-biological origin) or RCF (recycled carbon fuel) promoted under the RED II. This may become relevant after 2030 when RFNBO would turn-out applicable in other sectors beyond transport according to the Commission's proposal for a revised RED. In subordinate legislation under the ETS Directive, however, the combustion of RFNBO and RCF generated in ETS installations is likely to be zero-rated in order to avoid double-counting.

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