WORKING PAPER 2022-32

OCTOBER 2022

Gas definitions for the European Union: Setting thresholds to reduce life-cycle greenhouse gas emissions

Authors: Yuanrong Zhou and Chelsea Baldino

Keywords: Gas definition, EU gas package, biomethane, hydrogen, GHG emissions

Introduction

The European Climate Law sets a legal objective for the European Union (EU) to reach climate neutrality by 2050, with an interim target of reducing the EU's net greenhouse gas (GHG) emissions by at least 55% by 2030 compared to 1990 levels. Decarbonizing the gas sector is a key measure for reaching these targets. About 75% of the EU's total GHG emissions are from the energy sector (European Commission, 2022b), and natural gas alone accounted for 25% of total energy used in the EU in 2020 (Eurostat, 2022). Recognizing this, the EU is promoting the use of renewable and low-carbon gases. In December 2021, the European Commission (EC) proposed a suite of policies, collectively referred to as the hydrogen and decarbonized gas market package (referred hereafter as the "gas package"). This proposed gas package includes (1) a Regulation on the Internal Markets for Renewable and Natural Gases and for Hydrogen, (2) a Directive on Common Rules for the Internal Markets in Renewable and Natural Gases and in Hydrogen (referred hereafter as the "proposed gas Directive"), and (3) a Regulation on Methane Emissions Reduction in the Energy Sector. The goal of the gas package is to decarbonize EU's gas sector and incentivize the uptake of renewable and low-carbon gases.

The definition of low-carbon gas can be confusing, despite the term being used in multiple EU policies. The EU Taxonomy Regulation, published in 2020, aimed to provide a classification system with definitions for sustainable economic activities that the EU should pursue for meeting its climate targets. Under this Regulation, the use of renewable and low-carbon gases is counted as a sustainable activity; however, no definition of low-carbon gas is provided. In addition, low-carbon gases are eligible

www.theicct.org

communications@theicct.org

twitter @theicct

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

Acknowledgments: This work was generously supported by the European Climate Foundation. Responsibility for the information and views set out in this report lies with the authors. The European Climate Foundation cannot be held responsible for any use which may be made of the information contained or expressed herein. Thanks to Lena Moeller, Eamonn Mulholland, Nikita Pavlenko, and Stephanie Searle for reviewing this paper.

for financial incentives in the EU, such as under the State Aid guidelines for climate, environmental protection and energy, or the Connecting Europe Facility funding instrument. However, neither of these two incentive policies provide a definition of low-carbon gas.

The proposed gas Directive under the gas package provides definitions of low-carbon hydrogen, low-carbon gas, and renewable gas, and the proposed gas Regulation on the Internal Markets references these definitions; however, the definitions are vague. The original texts from the proposed gas Directive and our interpretations are listed in Table 1. The proposed gas Directive separates renewable gas from low-carbon gas based on feedstocks. Specifically, renewable gases refer to those produced from renewable feedstocks, such as biomass and renewable electricity, while low-carbon gases refer to those produced from non-renewable feedstocks, such as coal and fossil gas. The proposed gas Directive also references Article 2, point 36 of the recast Renewable Energy Directive (RED II), which defines renewable gases derived from renewable sources other than biomass as renewable fuels of non-biological origin (RFNBOs). An example of a RFNBO is electrolysis hydrogen made from renewable electricity, such as solar and wind. In addition, the proposed gas Directive also sets different GHG reduction thresholds for low-carbon hydrogen or gas and renewable gas. Specifically, the definitions of low-carbon hydrogen and low-carbon gas include a 70% GHG reduction threshold; however, it does not specify a comparator for that GHG reduction. In contrast, the definition of renewable gas does not include a GHG reduction threshold. However, Article 8 of the proposed gas Directive requires the certification of renewable gas following Articles 29 and 30 of the RED II. Those two articles include a 50%–80% GHG reduction threshold for biogas depending on the sector and facility installation year, but do not have a reduction threshold for RFNBOs, which can be found in Article 25 of the RED II. Unlike the proposed gas Directive, the RED II specifies a fossil comparator for GHG reductions for renewable gases, which is 94 grams of carbon dioxide equivalent per megajoule (gCO_2e per MJ).

Table 1. Definitions of low-carbon hydrogen, low-carbon gas, and renewable gas in the European Commission's proposed gas Directive on Common Rules for the Internal Markets in Renewable and Natural Gases and in Hydrogen.

	Definition in Article 2	**Feedstocks**	**Example gas pathways**	**GHG reduction threshold**
Low-carbon hydrogen	*"...hydrogen, the energy content of which is derived from non-renewable sources, which meets a greenhouse gas emission reduction threshold of 70%"*	Non-renewable feedstocks, including fossil fuels and nuclear energy	Hydrogen made from fossil gas or coal	70%; No comparator specified
Low-carbon gas	*"...part of gaseous fuels in recycled carbon fuels as defined in Article 2, point (35) of Directive (EU) 2018/2001, low-carbon hydrogen and synthetic gaseous fuels the energy content of which is derived from low-carbon hydrogen, which meet the greenhouse gas emission reduction threshold of 70%"*	Non-renewable feedstocks, including fossil fuels and nuclear energy; Recycled carbon, such as plastics	Hydrogen and synthetic methane made from fossil gas or coal; Synthetic methane made from waste plastics	70%; No comparator specified
Renewable gas	*"...biogas as defined in Article 2, point (28) of Directive 2018/2001, including biomethane, and renewable gaseous fuels part of fuels of non-biological origins ('RFNBOs') as defined in Article 2, point (36) of that Directive"*	Biomass; Non-biological renewable energy, such as renewable electricity	Biomethane and hydrogen made from biomass; Hydrogen and synthetic methane made from renewable electricity (RFNBO)	Article 8 of the proposed gas Directive: "Renewable gases shall be certified in accordance with Article 29 and 30 of Directive (EU) 2018/2001." Meaning: • 50%–65% GHG reduction for biogas consumed in the transport sector, compared to 94 gCO_2e/MJ • 70%–80% GHG reduction for biogas consumed in other electricity, heating and cooling sectors compared to a 94 gCO_2e/MJ fossil comparator • No threshold for RFNBOs

Note: Directive (EU) 2018/2001 is the RED II.

To achieve GHG reductions from the use of renewable and low-carbon gases, it is necessary to define the gases based on their life-cycle well-to-wheel emissions. A life-cycle analysis (LCA) would include GHG emissions (carbon dioxide, methane, and nitrous oxide) along the fuel's life cycle, including feedstock extraction and transportation, fuel production and transportation, and fuel combustion.[1] Estimating life-cycle GHG emissions can support a full understanding of the potential direct and indirect climate impacts from using a type of fuel. A previous ICCT study which evaluated life-cycle GHG emissions of gases in the EU found that there can be large variations in the GHG intensity of gases, even within the same production pathway (Zhou et al., 2021). Furthermore, uncertainties in some parameters used to calculate emissions could mean that certain gas pathways classified as renewable gas or low-carbon gas fail to provide GHG reductions as intended. Therefore, clear, detailed definitions of renewable gas and low-carbon gas that are consistent among EU policies are needed, not only for the purpose of identifying the gas pathways that qualify, but also to support the gas pathways that achieve deep decarbonization of the sector.

This study proposes definitions for renewable gas and low-carbon gas based on key parameters that impact the life-cycle GHG emissions for major gas pathways in the EU. Example key parameters include upstream methane emissions and carbon capture and storage (CCS) rates for fossil pathways, and the share of renewable electricity for electrolysis hydrogen. We include two GHG reduction categories for gas pathways in this analysis, one "low-GHG" category where the gas reduces GHG emissions by 80% relative to a comparator, and another "zero-GHG" category, where the gas pathway reduces GHG emissions by 100%. Defining gases by life-cycle GHG emission parameters would act as a sustainability safeguard to ensure true decarbonization in the gas sector. Results from this study can provide insights for policymakers during the co-decision and trilogue period for the gas package when they are able to suggest changes to the definitions of low-carbon hydrogen/gas and renewable gas in the proposed gas Directive.

Methodology

In this study, we consider two categories of life-cycle GHG emissions reduction for gases: (1) "low-GHG" gas that has at least an 80% GHG reduction compared to a comparator, which could be used to define low-carbon gas or renewable gas; and (2) "zero-GHG" gas that essentially has at least a 100% GHG reduction. We include a zero-GHG gas category to demonstrate which pathways may provide the greatest GHG reductions, since the EU is aiming to reach climate neutrality by 2050.

While the 80% GHG reduction category is seemingly more ambitious than the proposed gas Directive, which defines low-carbon gas as that which achieves 70% GHG reduction, the Directive does not specify which comparator to use. We chose a fossil comparator for our analysis based on the GHG intensities of fossil fuels that are already listed in EU legislation. Council Directive 2015/652 lists a GHG value of 65.9 gCO_2e per MJ for fossil natural gas,[2] but this value is not used at present as a comparator for GHG reductions in any existing EU policy (Council of the European

---

[1] Combustion emissions from hydrogen and biomethane, regardless of the end use, are considered zero. Combusting hydrogen results in only water vapor. For biomethane, combustion emissions are considered to be offset by carbon sequestration of the bio-feedstock.

[2] Council Directive (EU) 2015/652 of 20 April 2015 laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels.

Union, 2015). Instead, it is an input to estimate the GHG intensity of fossil gas-based fuels, such as hydrogen made from fossil gas steam methane reforming (SMR). If this value were referenced as a fossil fuel comparator, a 70% reduction would result in a 19.8 gCO_2e per MJ GHG reduction threshold. Alternatively, we could reference the fossil comparator in the RED II for the purpose of consistency among EU policies. In this case, a 70% reduction results in a 28.2 gCO_2e per MJ reduction threshold. However, a higher GHG reduction requirement, such as 80%, would mean low-carbon or renewable gas must be less than 18.8 gCO_2e per MJ, similar to the 70% reduction compared to fossil natural gas. A 19 gCO_2e per MJ threshold is also similar to the low-carbon hydrogen definition used in the United Kingdom for the British Energy Security Strategy (Department for Business, Energy & Industrial Strategy, 2022). We summarize the life-cycle GHG intensity from a combination of the comparators and GHG reduction thresholds in Table 2. In this study we set the GHG threshold as an 80% reduction from the RED II comparator.

Table 2. Life-cycle GHG intensity based on different comparators and GHG reduction thresholds.

Life-cycle GHG intensity (gCO_2e per MJ)	Fossil gas comparator (65.9 gCO_2e per MJ)	RED II comparator (94 gCO_2e per MJ)
70% GHG reduction threshold	19.8	28.2
80% GHG reduction threshold	13.2	18.8

Note: The fossil gas comparator is from the Council Directive 2015/652.

Our previous LCA study, Zhou et al. (2021), identifies key parameters that impact the life-cycle GHG emissions of six hydrogen pathways and three biomethane pathways produced in the EU. The study collected a possible range for those parameters, such as upstream methane leakage, from literature and conducted a sensitivity analysis on the impact that these parameters have on each pathway's life-cycle GHG emissions across their full range of possible values. In this study, we use the sensitivity analysis results to identify the most impactful parameters for EU gas policy and their necessary range in order for a gas to meet an 80% or 100% GHG reduction threshold. For each pathway, we adjust the parameters with the same degree of change, i.e., percentage of change, at the same time until meeting the threshold. However, we note that, in reality, the parameters could vary in their degrees of change.

The key parameters identified in Zhou et al. for each of the hydrogen and biomethane pathways are in Table 3. For the parameters that are not as impactful, the assumed default values in the 2021 study are shown. For the most impactful parameters, we also show the possible ranges identified in Zhou et al., which serve as the upper and lower boundaries during adjustment. For example, Zhou et al. found that for hydrogen produced from fossil gas combined with CCS, carbon capture rate and upstream methane leakage rate are most impactful. Thus, in this study, we adjust the carbon capture rate and methane leakage rate within their possible ranges, while keeping the production efficiency at default 71.9%.

Table 3. Key parameters impacting the life-cycle emissions, and their possible ranges, for hydrogen and biomethane.

Gas pathway	Key parameters	Range	Default value
RFNBOs, such as electrolysis hydrogen	Share of additional renewable electricity as the energy input	0%–100%	
	Hydrogen production efficiency		72%
Hydrogen from fossil gas SMR+CCS	Carbon capture rate at hydrogen production plant	39.2%–99.9%	54.6%
	Upstream methane leakage rate	0.2%–20%	0.52%
	Hydrogen production efficiency		71.9%
Hydrogen from coal gasification+CCS	Carbon capture rate at hydrogen production plant	39.2%–99.9%	54.6%
	Hydrogen production efficiency		55.1%
Hydrogen from biomass gasification	Hydrogen production efficiency	40%–60%	50.5%
	Biomass feedstock	Residual or non-residual (e.g., stemwoood) biomass	
Hydrogen and biomethane from biomass anaerobic digestion	Biomass feedstock	Residual (e.g., manure and wastewater sludge) or non-residual (e.g., silage maize) biomass	
Manure-based hydrogen and biomethane through anaerobic digestion	Methane leakage rate during anaerobic digestion	0.65%–10%	1%
	Methane leakage rate during gas upgrading	0.04%–5%	2%
	Percentage of generated methane that is flared at manure management facility		60%
	Temperature (this informs the methane conversion factor)		15°C
Wastewater sludge-based hydrogen and biomethane through anaerobic digestion	Methane leakage rate during anaerobic digestion	0.65%–10%	1%
	Methane leakage rate during gas upgrading	0.04%–5%	2%
	Percentage of volatile solid reduction (this informs methane yield)		Counterfactual case: 45.3% Alternative case: 63.7%
	Fertilizer replacement credit		50%

Note: SMR = steam methane reforming. CCS = carbon capture and storage.

The electricity source used to produce RFNBOs greatly impacts its life-cycle GHG emissions. In this study, we estimate the minimum percentage share of additional renewable electricity that is needed to produce RFNBOs in its total production process, such as electrolysis hydrogen, in order to reach the two GHG reduction categories. Additionality means that the renewable electricity used for hydrogen is from a new renewable electricity generator that would not have existed without the electrolysis hydrogen demand; that is, it would not have been built in a business-as-usual scenario.

For hydrogen made from fossil fuels, that is, using coal or fossil gas to produce hydrogen combined with CCS, the carbon capture rate at the hydrogen production site is a crucial input of its life-cycle emissions. For hydrogen produced from fossil gas, the upstream methane leakage from gas extraction and transmission also has a significant impact.

The GHG emissions for biogas, i.e., gases made from biomass, are impacted the most by the type of biomass feedstock used. Studies have found that non-residual biomass, such as stemwood and silage maize, have an adverse climate impact when used to produce biogas, while residual biomass, such as agricultural residues and wastes like livestock manure, generally enable relatively low GHG emissions (Searle & Giuntoli, 2019; Giuntoli, 2020).

For biogases produced from wastes, such as manure and wastewater sludge, life-cycle GHG emissions depend on not only the production of the fuel itself, but also on the assumed waste management practices when these wastes are not used for biogas production. This is because diverting wastes from their pre-existing waste management practices, i.e., the counterfactual case, to fuel production results in avoided GHG emissions. Therefore, for hydrogen and biomethane produced from waste feedstocks, the avoided emissions that result from shifting to fuel production need to be accounted for to determine the life-cycle emissions of the fuel.

Zhou et al. found that methane leakage rate during biomethane production, i.e., during anaerobic digestion of the waste feedstocks and biogas upgrading, is the most important parameter influencing the pathway's life-cycle emissions. Therefore, this study evaluates the allowable maximum leakage rate for these pathways to reach the 80% or 100% GHG reduction thresholds, while also considering the minimum possible leakage rate reported in the previous study. We do not adjust other parameters that can also affect the GHG emissions, such as the percentage of generated methane that is flared at manure management facility, because these parameters are not as impactful, and they are not factors that the biogas producer could control or easily verifiable. For these unadjusted parameters, we show the default assumptions in Table 3.

Similar to Zhou et al., we use the GREET model,[3] updated to use EU fossil gas and electricity GHG intensity, to evaluate the life-cycle GHG emissions. We use a projected GHG intensity of an average EU grid mix at 136 gCO_2e per kilowatt hour (kWh). This intensity, which is required to meet the EU's net 55% GHG reduction target by 2030, has an average share of 67% renewable electricity, based on projections by EEA (2020) and European Commission (2020). In addition to the default assumptions in Table 3 that are pathway specific, we assume the same default downstream emissions for all hydrogen or biomethane pathways as in the GREET model, i.e., pipeline transportation for both hydrogen and biomethane. We also include emissions from compressing hydrogen to 700 bar, which is required by fuel cells combusting gaseous hydrogen. The default energy source for hydrogen compression is electricity, with the assumed carbon intensity cited above, which we then further adjust for pathways to qualify as zero-GHG. Results in this study are presented using the 100-year global warming potentials (GWP) from the Intergovernmental Panel on Climate Change Assessment Report 4 (Intergovernmental Panel on Climate Change, 2007) to be consistent with the RED II.

---

[3] The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model is a U.S.-based life-cycle model that can estimate GHG and air pollutant emissions from different types of transportation fuels.

Results and Discussion

In this section, we present the GHG parameter thresholds required for hydrogen and biomethane to meet an 80% or 100% GHG reduction relative to the 94 gCO_2e per MJ fossil fuel comparator. We also discuss the implications of these results for EU policy. The thresholds presented in this paper are designed for gases produced within the EU. Imported gases are likely to have different GHG intensities due to, for example, different fuel transportation and waste treatment, which means they would require different thresholds to meet these GHG reduction criteria. While thresholds for imported gases is outside the scope of this study, the threshold criteria in this study could also be applied to imported gases to achieve greater GHG reductions compared to a case where there are no threshold criteria at all.

Table 4 divides the six hydrogen pathways and three biomethane pathways into three categories: (1) a zero-GHG category where gases have ≥ 100% life-cycle GHG emission reduction compared to the 94 gCO2e per MJ fossil comparator in the RED II; (2) a low-GHG category where gases have ≥ 80% GHG reduction from the same comparator, which could be utilized for the renewable gas and low-carbon gas definitions in the proposed gas Directive; and (3) a third category where gases fail to meet the 80% GHG reduction threshold. Table 4 shows the combination of parameter thresholds needed for each gas pathway to qualify for each of the three categories.

Table 4. Definitions of renewable and low-carbon gases based on life-cycle GHG thresholds.

	≥ 100% GHG reduction	**≥ 80% GHG reduction**	**< 80% GHG reduction**
RFNBOs, such as electrolysis hydrogen	• 100% additional, renewable electricity used for electrolysis & • 100% renewable electricity used for all other processes, such as hydrogen compression and methanation	• Produced using ≥ 90% additional, renewable electricity in the total process	Produced using < 90% additional renewable electricity in the total process
Hydrogen from fossil gas SMR+CCS	N/A	• Carbon capture rate ≥ 83.5% & • Upstream methane leakage rate ≤ 0.34%	• Carbon capture rate < 83.5% & • Upstream methane leakage rate > 0.34%
Hydrogen from coal gasification+CCS	N/A	Carbon capture rate ≥ 94.4%	Carbon capture rate < 94.4%
Hydrogen from biomass gasification	• From waste biomass, such as agricultural residues & • 100% renewable electricity used for hydrogen compression	From waste biomass, such as agricultural residues	From non-residual biomass, such as stemwood
Hydrogen from manure anaerobic digestion	• Methane leakage from digester ≤ 4.4% • Methane leakage during upgrade ≤ 2.2%	• Methane leakage from digester ≤ 5.7% • Methane leakage during upgrade ≤ 2.85%	• Methane leakage from digester > 5.7% • Methane leakage during upgrade > 2.85%
Hydrogen from wastewater sludge anaerobic digestion	• Methane leakage from digester ≤ 6% & • Methane leakage during upgrade ≤ 3%	• Methane leakage from digester ≤ 7.3% • Methane leakage during upgrade ≤ 3.7%	• Methane leakage from digester > 7.3% • Methane leakage during upgrade > 3.7%

	≥ 100% GHG reduction	≥ 80% GHG reduction	< 80% GHG reduction
Biomethane from manure anaerobic digestion	• Methane leakage from digester ≤ 4.5% • Methane leakage during upgrade ≤ 2.25%	• Methane leakage from digester ≤ 6% • Methane leakage during upgrade ≤ 3%	• Methane leakage from digester > 6% • Methane leakage during upgrade > 3%
Biomethane from wastewater sludge anaerobic digestion	• Methane leakage from digester ≤ 6.2% • Methane leakage during upgrade ≤ 3.1%	• Methane leakage from digester ≤ 7.6% • Methane leakage during upgrade ≤ 3.8%	• Methane leakage from digester > 7.6% • Methane leakage during upgrade > 3.8%
Biomethane from silage maize anaerobic digestion	N/A	N/A	Falls in this category

Note: Renewable electricity refers to electricity produced from solar and wind.

Hydrogen made from electricity

Electrolysis hydrogen can only meet an 80% GHG reduction threshold when at least 90% of the electricity source is from renewable, such as solar, wind, or hydropower, in its total production process. The projected renewable share in the average EU grid mix is 67% in 2030 in order to meet the 55% GHG reduction target by that year, which means that hydrogen made from EU grid electricity could not meet an 80% GHG reduction threshold unless the Member States are able to meet the threshold of 90% renewable electricity in their national grids. For electrolysis hydrogen to be defined as zero-GHG, 100% renewable electricity needs to be used throughout its life cycle, not only during its total production process, but also for hydrogen compression.

Another critical factor in electrolysis hydrogen's GHG impact is that the renewable electricity being used must be additional; otherwise, grid electricity would be used, leading to substantial GHG emissions. To ensure additionality, an electrolysis hydrogen producer could have a power purchase agreement (PPA) with a renewable electricity generator, to be combined with a certificate showing the renewable electricity installation does not receive any other financial subsidy (Timpe et al., 2017; Malins, 2019). This ensures that the renewable electricity is not displaced from another use, which would likely be replaced with grid electricity. In 2022, the European Commission proposed a delegated regulation that supplements the RED II with detailed rules for RFNBOs (European Commission, 2022a). This proposal addresses the requirement of additional renewable electricity for RFNBOs, including electrolysis hydrogen.

Hydrogen made from fossil gas or coal

For the two fossil-based hydrogen pathways, it is unrealistic for them to be truly zero-GHG; even reaching an 80% GHG reduction threshold would be difficult given technology and economic barriers. Particularly, at least 84% and 95% of CO2 generated during hydrogen production from fossil gas or coal, respectively, has to be captured. However, as described in Zhou et al., the typical carbon capture rate at the hydrogen production plant is only 55% and reaching a higher carbon capture rate would be significantly more expensive (Kandziora et al., 2014). For fossil gas-based hydrogen, upstream methane leakage is another key impacting parameter. The total upstream leakage rate from natural gas extraction, processing, and transportation must be capped at 0.34%. There is evidence methane leakage along the fossil gas supply chain can be around 0.2%–3% and may even be up to 20%, as shown in Table 3. This would require robust monitoring and tracking of methane leakage. The EU is taking measures to address this issue; the proposed Methane Emission Reduction Regulation within the gas package aims to reduce methane emissions in the energy sector through accurate estimation, measurement, and verification. Once implemented, this Regulation could be helpful in tracking the amount of methane leakage and defining gases accordingly.

Hydrogen and biomethane made from biomass

For hydrogen made from biomass gasification, the feedstock is the most critical parameter. If non-residual feedstock such as stemwood and silage maize are used, hydrogen made from biomass gasification cannot reach the 80% and 100% GHG reduction thresholds. This pathway can only meet the 80% threshold if the gas is produced from waste biomass, such as the majority of feedstocks defined in Annex IX, A of the RED II, which includes agricultural and forestry residues. However, pulp-quality stemwood is included in the category “other ligno-cellulosic material” in Annex IX, A. Stemwood is associated with lost carbon sequestration if used for biogas production and would be associated with high GHG emissions (Alessandro et al., 2014). For waste biomass hydrogen produced from gasification to be defined as zero-GHG, 100% renewable electricity must also be used for hydrogen compression.

Biomethane and hydrogen from manure and wastewater sludge can provide significant GHG reductions and can be zero-GHG as long as methane leakage during biogas production and upgrading is well regulated. In general, the average leakage rate at biogas facility would enable biomethane and hydrogen made from manure and wastewater sludge to meet the 80% and 100% reduction thresholds. However, this is only true when other parameters are the same as the default assumptions in this study (Table 3). For example, we assume half of the solid digestate, a residue of the anaerobic digestion process, from wastewater sludge digestion is used to replace conventional fertilizer in soil, which results in avoided emissions. If the fertilizer replacement rate is lower than 50%, the thresholds for methane leakage would need to be lower. Moreover, although the average leakage rate at a biogas facility would enable biomethane and hydrogen to be labelled zero-GHG, higher leakage rates of 10% during biogas production and 5% during biogas upgrading have been reported, as indicated in Table 3. Therefore, it is still crucial to have robust leakage monitoring and measurement at biogas facilities. While the proposed Methane Emission Reduction Regulation provides rules for the fossil energy sector, it does not have any methane measurement requirement for the biogas industries. Instead, biogas producers are allowed to simply use the default GHG emission values in the RED II. Lacking requirements and detailed rules of methane measurement for the biogas industry would be problematic when defining biogases.

While hydrogen and biomethane made from waste feedstocks, including forestry and agricultural residues, manure, and wastewater sludge, are able to reach deep decarbonization, a key barrier to these pathways is feedstock availability. Carraro et al. (2021) estimated that the total annual available agricultural residue and forest residue for biofuel production in the EU is about 83 million and 11 million tonnes, respectively. Further, these feedstocks will be needed to produce biofuels for the hard-to-decarbonize aviation and marine sectors, both of which have proposed regulations as a part of the Fit for 55 package. For biomethane made from manure and wastewater sludge, Baldino et al. (2018) found that not only is the feedstock availability limited, the intersectoral competition is also unavoidable since, without policy incentives, it is more economically viable to use biomethane for power generation than injecting into the pipeline for heating or transportation uses.

Silage maize, a feed crop, is the dominant feedstock for biomethane production in the EU (Kampman et al., 2016). However, as outlined in the Zhou et al., this pathway is nowhere close to reaching the 80% GHG reduction threshold due to its substantial emissions from direct and indirect land use change (ILUC) due to diverting biomass from existing use to biofuel production. While the vast majority of scientific literature recognizes the negative climate impacts from crop-based biofuels because of ILUC emissions, the typical value of silage maize biomethane in the RED II of 42 gCO2e per MJ does not include ILUC emissions, which would be an additional 21 gCO2e per MJ (European Commission, 2015). Nonetheless, even considering the uncertainties in GHG emissions, the lowest estimate from previous studies, even without ILUC emissions, far exceeds the 80% GHG reduction threshold (Zhou et al., 2021). This emphasizes the necessity to define renewable gas based on GHG reduction threshold, which is currently lacking in the proposed gas Directive.

Certification of gases

While having clear and detailed definitions for gases in EU legislation is one important step towards ensuring the gas sector is decarbonized, it is just as important to have a means to accurately label and certify gases. One mechanism that could be useful for certification is guarantees of origin (GOs), which provide evidence regarding the sources of the energy supplied and could be issued to the gas producer by a third-party verifier. The main purpose of GOs is to provide disclosure and transparency in the energy market and facilitate decarbonizing the energy sector from the use of renewable and low-carbon feedstocks. The RED II directs and provides rules for EU Member States to adopt GOs for electricity and gases, including hydrogen. The Annexes to the proposed gas Directive also require gas suppliers to disclose the share of renewable gas and low-carbon gas purchased by the final customers and specifies that the disclosure of renewable gas shall be done through GOs, as a part of the billing requirements for gas suppliers.[4]

Although the RED II requires GOs for gases, this mechanism has been mostly practiced in the power sector for certifying renewable electricity. Particularly, the RED II references a GO standard, CEN – EN 16325, which only covers electricity. Given that renewable and low-carbon gases are gaining increasing importance in EU's energy sector and are able to receive incentives, it is of crucial urgency to adopt clear rules for GOs for gases. Recognizing this, the CEN – EN 16325 standard is under revision to extend its scope to include gases, including biomethane and hydrogen (Association of Issuing Bodies, 2020). Besides progress in standard making, there have been projects experimenting with GOs for gases. The European Commission initiated and financed the CertifHy project to create an EU-wide system of GO certification schemes for renewable and low-carbon hydrogen, which is compliant with CEN – EN 16325 and rules for RFNBOs in the RED II (CertifHy, 2022). The REGATRACE (REnewable Gas TRAde Centre in Europe) project, funded by the EU's Horizon 2020 program, aims to establish a system for issuing and trading biomethane GOs. This project, with the participation of ten Member States, will develop harmonized rules and procedures for biomethane GOs, set up national GO issuing bodies, explore the integration of GOs among biomethane, hydrogen, and electricity, and provide policy recommendations (REGATRACE, 2022).

Nonetheless, caution is necessary regarding a GOs system. One particular risk is double counting of the same energy source to two different end-users, which could happen in two ways. First, since GOs are traded separately from the physical energy market, it is

---

[4] Article 2 of the proposed gas Directive defines final customer as "a customer purchasing gases for his own use".

necessary to make sure the same amount of energy tracked using GOs is subtracted from the energy market, i.e., the grid electricity or gas mix. This can be especially tricky when GOs and energy are imported or exported between countries (Hamburger, 2019; Snoeck, 2019). Second, as GOs can be freely traded among different stakeholders, including energy suppliers, traders, and end users, it is also necessary to make sure the same GO is not sold to two different buyers.

Besides the above-mentioned inherent challenges of GOs, there are several potential issues when applying GOs to gases, particularly those that fall into either 80% GHG reduction or 100% GHG reduction categories. For low-carbon or renewable gases to achieve true GHG emissions reductions, their performance must be defined in terms of life-cycle GHG emissions, which means the GOs must also include this information. However, such requirements might be missing from the current GO design. For example, CertifHy only covers emissions from upstream and from hydrogen production but leaves out downstream emissions from hydrogen transport and compression (CertifHy, 2022). In the case of electrolysis hydrogen, information must be included that the gas was produced with additional renewable electricity. The GHG parameter thresholds for defining gases that we provide in this study could help set the foundation for such a certification scheme.

Lastly, as the EU will continue to rely on imported biomethane and hydrogen to meet its domestic energy demand (European Commission, 2022c), EU policymakers need to provide more detailed and clear guidance on certification of gases that are imported from countries outside of the EU. Such rules would need to be consistent, not only domestically among EU Member States, but also with countries outside the EU.

Conclusions

Clear definitions of renewable gas and low-carbon gas based on life-cycle GHG emissions are necessary for the success of EU climate and energy policies for meeting decarbonization target. This study provides policymakers and the gas industry with details in terms of how gas pathways could qualify.

This study defines how different gas pathways could meet an 80% life-cycle GHG reduction compared to the fossil comparator of 94 gCO_2e per MJ in the RED II, which is equivalent to 18.8 gCO_2e per MJ. We evaluate the threshold needed for each key life-cycle parameter in order for hydrogen and biomethane pathways to meet the GHG threshold. Particularly, for hydrogen made from fossil energy, such as fossil natural gas and coal, a minimum carbon capture rate during hydrogen production is defined to meet the same GHG threshold. For biomethane and hydrogen made from fossil natural gas or biogas, upstream methane emissions is a crucial parameter, and this study identifies the maximum allowable leakage rate for each of these gas pathways. In addition, this study also defines zero-GHG gases using the same approach, which could provide some implications for future policy making.

While the parameter thresholds provided in this study can be helpful for defining gases based on life-cycle GHG emissions, the implementation would require policy support from EU policymakers. Specifically, strong monitoring of methane leakage at different stages of a gas's life cycle is needed. Robust and transparent certification of the gas origins and GHG emissions of gases is necessary, and GOs can be a useful measure. However, such a certification system needs to be well-designed to prevent risks such as double counting and assure additionality. As the EU continues to design gas policies, results and discussions from this study can provide some insights.

References

Alessandro, A., Guintoli, J., & Aikaterini, B. (2014). *Carbon accounting of forest bioenergy: Conclusions and recommendations from a critical literature review.* Publications Office. https://data.europa.eu/doi/10.2788/29442

Association of Issuing Bodies. (2020). FaStGO. https://www.aib-net.org/news-events/aib-projects-and-consultations/fastgo

Carraro, C., Searle, S., & Baldino, C. (2021). *Waste and residue availability for advanced biofuel production in the European Union and the United Kingdom*. International Council on Clean Transportation. https://theicct.org/publication/waste-and-residue-availability-for-advanced-biofuel-production-in-the-european-union-and-the-united-kingdom/

CertifHy. (2022). Certification schemes. https://www.certifhy.eu/go-definition/

Council of the European Union. (2015). Council Directive (EU) 2015/652 of 20 April 2015 laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC of the European Parliament and of the Council relating to the quality of petrol and diesel fuels. *Official Journal of the European Union, L107*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0652&from=DE

Department for Business, Energy & Industrial Strategy. (2022). *UK Low Carbon Hydrogen Standard: Emissions reporting and sustainability criteria*. https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria

European Environment Agency. (2020, December 8). *Greenhouse gas emission intensity of electricity generation* [Data Visualization]. https://www.eea.europa.eu/ds_resolveuid/7e1d0edbc6b4488a89fb1686d8239858

European Commission. (2015). *The land use change impact of biofuels consumed in the EU*. https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

European Commission. (2020). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 climate ambition*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0562&from=EN

European Commission. (2022a). *Commission delegated regulation supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council*. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/7046068-Production-of-renewable-transport-fuels-share-of-renewable-electricity-requirements-_en

European Commission. (2022b). *Energy and the Green Deal* [Text]. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/energy-and-green-deal_en

European Commission. (2022c). *REPowerEU* [Text]. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

Eurostat. (2022). *Energy statistics—An overview*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview

Giuntoli, J. (2020). *Forest bioenergy and Canada's Clean Fuels Standard: Potential carbon impacts*. International Council on Clean Transportation. https://theicct.org/publication/forest-bioenergy-and-canadas-clean-fuels-standard-potential-carbon-impacts/

Hamburger, Á. (2019). Is guarantee of origin really an effective energy policy tool in Europe? A critical approach. *Society and Economy*, 41, 487–507. https://doi.org/10.1556/204.2019.41.4.6

Intergovernmental Panel on Climate Change. (2007). *Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 996). https://archive.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf

Kampman, B., Leguijt, C., Scholten, T., Tallat-Kelpsaite, J., Brückmann, R., Maroulis, G., Lesschen, J. P., Meesters, K., Sikirica, N., & Elbersen, B. (2016). *Optimal use of biogas from waste streams: An assessment of the potential of biogas from digestion in the EU beyond 2020*. European Commission. https://energy.ec.europa.eu/optimal-use-biogas-waste-streams-assessment-potential-biogas-digestion-eu-beyond-2020_en

Kandziora, C., Lamb, K., & Shahani, G. (2014). CO2 Capture from Steam Methane Reformers—Understanding the Options. *Ammonia Technical Manual*, 10.

Malins, C. (2019). *What does it mean to be a renewable electron?* International Council on Clean Transportation. https://theicct.org/publication/what-does-it-mean-to-be-a-renewable-electron/

REGATRACE. (2022). *Work packages*. https://www.regatrace.eu/work-packages/

Searle, S., & Giuntoli, J. (2019). *Does bioenergy improve forest management?* International Council on Clean Transportation. https://theicct.org/publication/does-bioenergy-improve-forest-management/

Snoeck, M. (2019). *Understanding the Guarantees of Origin and their impacts on the electricity value chain: A comparative case study of Norway and Germany.* Université catholique de Louvain. https://dial.uclouvain.be/memoire/ucl/en/object/thesis%3A19124

Timpe, C., Seebach, D., Bracker, J., & Kasten, P. (2017). *Improving the accounting of renewable electricity in transport within the new EU Renewable Energy Directive* (p. 40). Institute for Applied Ecology (Öko-Institut e.V.). https://www.oeko.de/fileadmin/oekodoc/Improving-accounting-of-renewable-electricity-in-transport.pdf

Zhou, Y., Swidler, D., Searle, S., & Baldino, C. (2021). *Life-cycle greenhouse gas emissions of biomethane and hydrogen pathways in the European Union*. International Council on Clean Transportation. https://theicct.org/publication/life-cycle-greenhouse-gas-emissions-of-biomethane-and-hydrogen-pathways-in-the-european-union/