Relevance of Emission Accounting Methods for the Classification of Green Hydrogen

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Abstract:

The development of a regulatory framework for the transformation to a hydrogen-based economy is still in progress. Important markets, such as the United States and the European Union (EU) have provided first regulatory indications for when hydrogen can be considered “green” based on the hydrogen’s carbon footprint. This implies the necessity of a common methodology for greenhouse gas (GHG) emission accounting to calculate the carbon footprint. The EU taxonomy allows emission accounting on life cycle assessment (LCA) methodology or the methodology provided in the Draft of the Delegated Act (DA) complementing Articles 25 and 28 of the Renewable Energy Directive. A comparison of the results for hydrogen produced from electrolysis shows that the carbon footprint calculated in accordance with the DA methodology is lower than for the LCA methodology. In principle, a threshold for green hydrogen should be aligned with the corresponding methodology. This principle is not upheld by the EU taxonomy, because DA or LCA methodology can both be chosen. This has practical implications, since the carbon footprint of hydrogen produced from solar power can exceed the EU taxonomy threshold for green hydrogen depending on the methodology applied and the data source used. To conclude, standardization of both the methodology and data sources would enhance the comparability of green hydrogen criteria.

Keywords: hydrogen, emission accounting, life cycle assessment, Delegated Act

1 Introduction

To mitigate climate change, decarbonization is necessary. Low-carbon hydrogen is a key technology for certain industries and applications to decrease greenhouse gas (GHG) emissions. For hydrogen, a color code describes the production method and for electrolysis also the type of electricity used for production. Hence, the term “green” hydrogen is commonly used to describe hydrogen produced by renewable energies. Consequently, in the case of the electrolysis the electricity originates from renewables. While several stakeholders, such as the Green Hydrogen Organisation, CertifHy and others, have already developed private standards for green hydrogen, the regulatory framework is still evolving [1]. Despite rules regulating the renewable electricity source (e.g. additionality principle), also the overall carbon footprint or GHG emission savings can be subject to regulatory requirements. Hitherto, there is no universal definition of the term “green” hydrogen, not even within EU legislation. Hence, it is

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not entirely clear when hydrogen is "low-carbon", "sustainable" or "green", which might be an obstacle in the ramp-up of hydrogen. In the context of this work, green hydrogen is defined simultaneously by its carbon footprint and the renewable electricity used for production. A threshold for the carbon footprint of hydrogen ensures a reduction of GHG emissions compared to a fossil reference. However, this raises the issue of how emissions should be accounted for in a standardized way. Thus, also the emission accounting methodology must be defined. This is important because compliance with the criteria defined in legislation can determine for example the eligibility for government funding and for sustainable finance products.

Many countries currently strive for a regulatory framework for hydrogen. In the USA, the Inflation Reduction Act (IRA) defines and promotes "qualified green hydrogen" with tax credits [2]. Besides a GHG life cycle emission threshold, it also directly provides for the emission accounting method. In the EU, two different regulations define green hydrogen, which leads to less clarity in regulation. The Renewable Energy Directive regulates hydrogen in the context of transportation and is complemented by a delegated act (DA) that specifies an emission accounting methodology [3]. The EU taxonomy is the classification system that is used for sustainability reporting and sustainable financial products [4]. For emission accounting of hydrogen, it refers both to the methodology provided in the DA and the carbon footprint standard which follows the established life cycle assessment (LCA) methodology.

The paper aims at clarifying the differences in emission accounting methodologies for hydrogen that can be chosen according to the EU taxonomy and uses an example to discuss the carbon footprint thresholds. The carbon footprint of hydrogen produced from different electricity sources is calculated using both the LCA and DA methodology. The power source considered is the electricity grid mix and renewable electricity from solar and wind power. To conclude, the practical implications of the EU regulation and policy recommendations are discussed.

2 Method and Data

In this chapter, the carbon footprint thresholds for green hydrogen as defined in legislation are presented. Furthermore, the emission accounting methodology as suggested in the draft of the DA is presented and compared to the carbon footprint methodology based on LCA. Last, the data sources for the carbon footprint calculation used in this analysis are outlined.

In the EU, the two regulatory frameworks that define criteria for green hydrogen are the Renewable Energy Directive (Directive 2018/2001, RED II) and the EU taxonomy. The RED II regulates renewable liquid and gaseous transport fuels of non-biological origin (RFNBO), which include hydrogen in the application of transportation [5]. Article 25(2) and Article 28(5) refer to a DA that details a GHG emission threshold and accounting methodology. The draft of the DA was published in May 2022. It provides for a 70 % GHG emissions reduction for RFNBO to a fossil comparator (94 g CO_2e/MJ). Applied to hydrogen used as a fuel in the transportation sector, this yields a threshold of 3.4 kg CO_2e per kg H_2. The Climate Delegated Act of the EU taxonomy requires a higher GHG emission reduction, which results in a threshold of 3 kg CO_2e per kg H_2 [4]. In the USA, hydrogen is eligible for tax credits with a carbon footprint below 4 kg CO_2e per kg H_2 according to the IRA [2].

2.1 Comparison of Emission Accounting Methodologies

In general, LCA is a tool to analyze the potential climate and environmental impacts of a product, service or process along the entire life cycle. The methodology is defined in ISO 14040/14044, complemented by ISO 14067, which specifies carbon footprint calculations [6, 7, 8]. The assessment requires the definition of the system boundary and functional unit to which the results refer [6]. For the following comparison of hydrogen, the functional unit of 1 kilogram of hydrogen (kg H_2) is chosen. The system boundary includes all upstream chain emissions and emissions from hydrogen production. Yet, emissions from transportation, application and end-of-life are not considered. Thus, the carbon footprints calculated are lower than full life cycle emissions (cradle-to-grave). The chosen system boundary ends with the provision of hydrogen (cradle-to-gate) and hence omits the use phase. The impact category chosen to calculate the carbon footprint is the Global Warming Potential with a time horizon of 100 years (GWP 100a) using the life cycle impact assessment method from the IPCC 2013 [9]. The results are expressed in kilogram CO_2-equivalents (CO_2e) per kg H_2. For comparability, the functional unit, system boundary and impact category of the LCA also apply to the emissions assessment with the DA methodology. The system boundaries and differences for the methodologies, as well as the process steps included in this comparison, are depicted in Figure 1.

The draft of the DA details an emission accounting method for RFNBO which follows in general a life cycle approach. As mentioned above, emissions from transport and distribution are excluded in this assessment, as this would require additional assumptions, such as for example means of transport. Additionally, these emissions would not differ between the LCA and DA methodology and hence do not contribute in a significant manner to the comparison. In the underlying analysis, thus, emissions occur from inputs and the production of hydrogen.

The emission accounting according to LCA methodology and DA methodology differs in three aspects. One difference is that in the DA, emissions from plant construction, for example, stack production, are not included. Second, renewable electricity, defined according to the RED II, is accounted for with an emission factor of 0. This is in line with the previous specification, as emissions from solar, wind and water energy are connected to the power plant. When grid electricity is used, the DA methodology provides for its accounting the following options. A country-specific emission factor for grid electricity can be used, which is provided for EU countries in the DA. Furthermore, a marginal power plant approach depending on the full load hours of the electrolyzer can be applied. When the number of full load hours of the production plant is lower than the number of hours when the marginal power plant was a renewable or nuclear power plant, no emissions are attributed to the electricity mix from the grid.

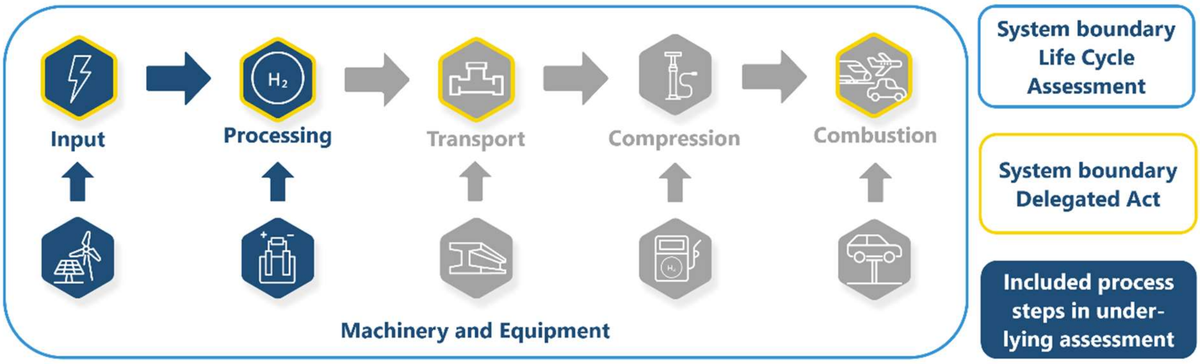

Figure 1: System boundaries for entire LCA and DA methodology with process steps included in this assessment (blue).

Another difference is that the DA divides inputs into elastic and rigid inputs with consequences for the emission accounting. Rigid inputs refer to inputs whose production cannot be scaled to adapt to an increase in demand. This is relevant for recycled carbon fuels, as by definition captured carbon is classified as a rigid input. Other rigid inputs are those inputs, which are produced in a fixed ratio and are of minor economic importance[2]. For rigid inputs, also emissions arising from the diversion from the previous or alternative use shall be accounted for. Hence, when rigid inputs are present, the emission accounting in the current draft of the DA becomes more challenging and complex. As the inputs in the underlying assessment are elastic inputs, rigid inputs are not relevant.

2.2 Description of Data Basis

To show the differences in the emission accounting methodologies for hydrogen, the carbon footprint of hydrogen produced via polymer electrolyte membrane (PEM) electrolysis is calculated. The carbon footprint determined in accordance with LCA and DA methodology is provided for hydrogen produced from the electricity mix as well as from solar and wind power. The model for this comparison is based on the project BEniVer [10].

In general, ecoinvent 3.8 serves as the underlying LCA database for the model [11]. The electricity emission factors for the LCA are based on the German Federal Environmental Agency (Umweltbundesamt, UBA) [12, 13]. The Annex of the DA draft provides emission factors for several inputs besides the electricity mix. Additionally, the DA explicitly names other appropriate data sources in case the required input is not listed in the Annex, e.g. reports from renowned organizations, governments or LCA databases such as ecoinvent.

For hydrogen from electrolysis, the emission factor of the electricity used is decisive [10]. The emission factor that the DA provides for Germany (446.4 g CO_2e/kWh) is applied in this comparison. For the LCA, the emission factor from the UBA is used which includes upstream emissions (538 g CO_2e/kWh) [13]. Also, the values applied for solar energy from photovoltaics (38.8 g CO_2e/kWh) and wind energy (5.2 g CO_2e/kWh) stem from the UBA [13]. The emission

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[2] The input represents less than 10% of the economic value of the overall output.

factor of solar electricity varies significantly depending on the data source. Therefore, also emission factors from photovoltaics from ecoinvent are used (102.2 g CO_2e/kWh).

3 Results and Discussion

3.1 Carbon Footprint of Hydrogen from Electrolysis

The results from the comparison are shown in Figure 2. The difference between the two emission accounting methods for hydrogen becomes evident. The carbon footprint calculated using the DA methodology is in general lower due to the exclusion of upstream emissions from plant and equpment, both of the electrolyzer and of the power plants.

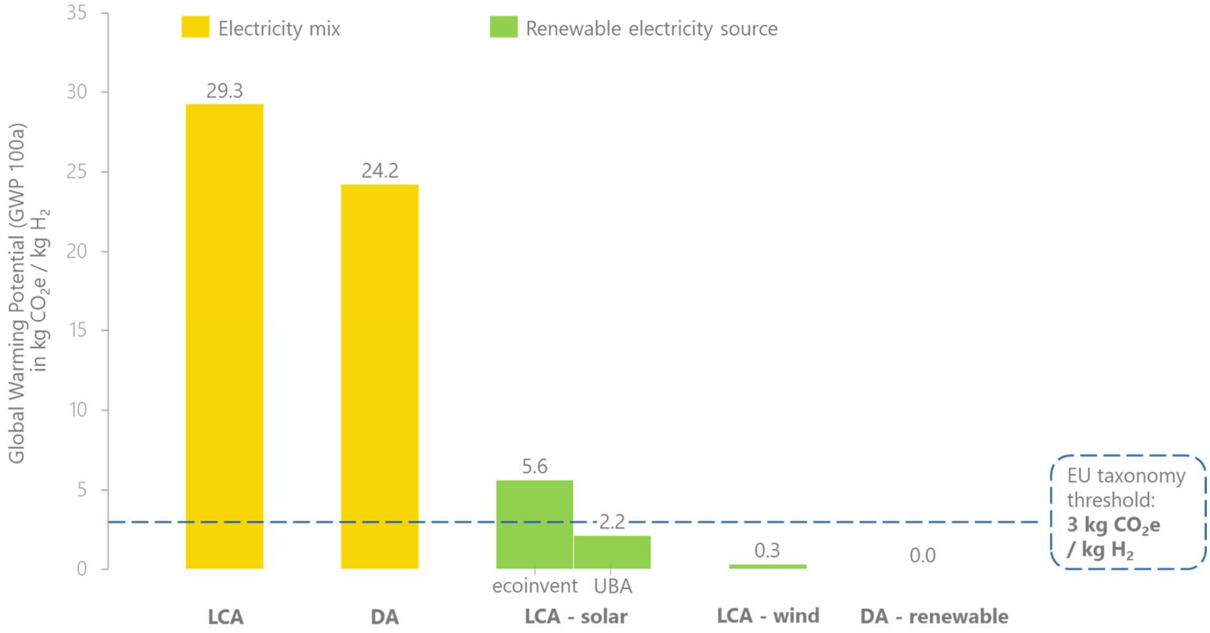

Figure 2: Carbon Footprint expressed as Global Warming Potential of hydrogen produced by PEM electrolysis with different electricity sources and accounting methods (LCA: Life Cycle Assessment; DA: Delegated Act) and using different data sources for upstream chain emissions of solar electricity (ecoinvent 3.8 [11]; UBA: Umweltbundesamt [13])

Regardless of the methodology, the emission factor of the electricity source strongly determines the carbon footprint. Hydrogen produced with electricity from the German grid has a significantly higher carbon footprint than that produced with renewables. The carbon footprint of hydrogen produced from the electricity mix exceeds the threshold due to the significant share of non-renewable power sources in the electricity mix.

For hydrogen produced from renewable electricity, the differences in the methodologies become relevant. The carbon footprint diminishes for the DA accounting methodology in this analysis because the emission factor for renewable electricity is set to zero. Hence, the type of energy source is irrelevant as long as it counts as renewable according to the RED II definition. The carbon footprint of hydrogen is small (0.004 kg CO_2e / kg H_2) when produced with renewable electricity. The remaining footprint stems from GHG emissions produced from the water used. In contrast, the LCA methodology takes the construction and end-of-life of the electrolyzer and the power plants into account. Therefore, the emission factor for electricity is higher which translates to a higher carbon footprint of hydrogen under LCA. Due to the differences in the emission factors, the carbon footprint of hydrogen produced from wind power is lower compared to solar electricity.

For the LCA of hydrogen from solar electricity, two different data sources are used to show the variability in the resulting carbon footprint. Using the emission factor provided by the UBA [8], the carbon footprint remains below the threshold set in the EU taxonomy. However, with data from the common LCA database ecoinvent, the climate impact amounts to 5.6 kg CO_2e per kg H_2 which significantly exceeds the threshold for green hydrogen, both for the EU taxonomy and the RED II. Reasons for the significant difference in the emission factors of photovoltaics is the actuality of data and assumptions regarding the production and use of the power plants.

3.2 Discussion

First, the calculated carbon footprints are put into context. It is important to highlight that the system boundary scrutinized in this paper differs from the system boundary outlined in the DA. Taking into account other life cycle emissions, like transportation and distribution, will lead to higher carbon footprints than the values presented. High leakage rates might also influence the carbon footprint, as recent studies discuss the global warming potential of hydrogen [14]. Hence, especially the carbon footprint of an LCA of hydrogen produced from solar power can exceed the threshold when further process steps are included. For the DA methodology, in contrast, emissions not considered in this assessment are unlikely to increase the carbon footprint significantly beyond the threshold of 3 kg CO_2e per kg H_2.

In the following, the relevance of the results is discussed in the context of the regulatory framework. Firstly, a clear definition of green hydrogen is necessary. Currently, the two EU regulatory frameworks concerned with green hydrogen are the DA and the EU taxonomy. However, they fail to provide a consistent framework for GHG emission accounting. First, the thresholds for the GHG emissions reduction for hydrogen differ. Second, the EU taxonomy does not specify one emission accounting method but allows for accounting in accordance with the DA complementing the RED II or the established carbon footprint method. The introduction of a new emission accounting methodology instead of the established LCA methodology can be favorable if it simplifies carbon footprint calculation for practitioners. Even though the exclusion of emissions from plants and machinery is a simplification, accounting for rigid inputs introduces complexity. In summary, the coexistence of several emission accounting methodologies for hydrogen in the regulatory framework of the EU compromises comparability.

The carbon footprint of hydrogen is in general lower when applying DA compared to LCA methodology, but the EU taxonomy foresees the same threshold. This raises the issue, that the same hydrogen produced from solar power can comply with the EU taxonomy under DA methodology, whereas it can also exceed the threshold when LCA methodology is applied. In principle, a threshold must be seen in the context of the underlying methodology and should always be adapted to it.

Additionally, the results of the assessment show that a common database is necessary to ensure the comparability of results. The DA already details some emission factors in its Annex.

However, reliable data sources for solar electricity still result in strongly varying carbon footprints for hydrogen.

One example of enhanced comparability of hydrogen's carbon footprints is the IRA. It specifies the emission accounting model (GREET) and database used for calculations [15]. However, also in the USA, the legislation has not been completed, as the IRA announces further instructions for determining the life cycle of GHG emissions to follow within one year.

4 Conclusion

This work is a discussion basis for the further development of the regulatory framework regarding the emission accounting of hydrogen. In general, a clear regulatory framework for defining the criteria for green hydrogen is highly relevant. However, current EU legislation lacks clarity. The carbon footprint thresholds for green hydrogen differ in the RED II and the EU taxonomy. Furthermore, the EU taxonomy allows for different emission accounting methods which result in different carbon footprints for the same production paths. Yet, only one threshold is provided. Additionally, the comparability of carbon footprint results is compromised because there is no common database. This work shows that both the chosen methodology and the database are relevant to comply with the green hydrogen threshold, especially in the case of solar power.

To ensure comparability, the emission savings threshold and emission accounting methodology should be standardized, at least among EU legislation. In practice, emission accounting according to the DA will prevail to demonstrate compliance with the regulatory thresholds, as it results in a lower carbon footprint. However, LCA is an established method standardized in ISO guidelines and might be seen as more reliable in other contexts. Hence, the need for calculating the carbon footprint of hydrogen according to two different methodologies might arise which means additional expenses for hydrogen producers.

In the EU, the legislative process regarding the emission accounting of hydrogen is not yet completed, as the final version of the DA is still pending. Anyhow, a reliable and binding regulatory framework should be adopted timely to ensure stable boundary conditions necessary for the ramp-up of a low-carbon hydrogen economy.

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Literature

[1] Sailer, Katharina: Global Harmonisation of Hydrogen Certification - Overview of global regulations and standards for renewable hydrogen. Berlin, DE: Deutsche Energie-Agentur (dena), 2022.

[2] Inflation Reduction Act (IRA). Ausgefertigt am 2022-8-16; United States of America: 117th Congress.

[3] Draft delegated regulation - Ares(2022)3836721 (DA RED II). Ausgefertigt am 2022-05-20; Brussels: European Commission, 2022.

[4] Delegierte Verordnung (EU) 2021/2139 der Kommission vom 04. Juni 2021 zur Ergänzung der Verordnung (EU) 2020/852 des Europäischen Parlaments und des Rates durch Festlegung der technischen Bewertungskriterien, anhand deren bestimmt wird, unter welchen Bedingungen davon auszugehen ist, dass eine Wirtschaftstätigkeit einen wesentlichen Beitrag zum Klimaschutz oder zur Anpassung an den Klimawandel leistet, und anhand deren bestimmt wird, ob diese Wirtschaftstätigkeit erhebliche Beeinträchtigungen eines der übrigen Umweltziele vermeidet. Ausgefertigt am 2021-06-04, Version vom 2021-06-04; Brüssel: Kommission, 2021.

[5] Richtlinie EU 2018/2001 des Europäischen Parlaments und des Rates vom 11. Dezember 2018 zur Förderung und Nutzung von Energie aus erneuerbaren Quellen (RED II). Ausgefertigt am 2018-12-11, Version vom 2018-12-21; Brüssel: Europäisches Parlament und Rat, 2018.

[6] DIN 14040 – Umweltmanagement – Ökobilanz – Grundsätze und Rahmenbedingungen (ISO 14040:2009) - Deutsche und Englische Fassung EN ISO 14040:2009. Berlin: DIN Deutsches Institut für Normung e. V., 2009.

[7] Umweltmanagement – Ökobilanz – Anforderungen und Anleitungen (ISO 14044:2006); Deutsche und Englische Fassung EN ISO 14044:2006. Berlin: DIN Deutsches Institut für Normung e.V., 2006.

[8] DIN EN ISO 14067:2018 Treibhausgase – Carbon Footprint von Produkten – Anforderungen an und Leitlinien für Quantifizierung (Umwelt). Ausgefertigt am 2018-09, Version vom 2019-02; Berlin: Beuth Verlag GmbH, 2019.

[9] Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[10] Pichlmaier, Simon et al.: Ökobilanzen synthetischer Kraftstoffe - Methodikleitfaden zum Projekt: Begleitforschung Energiewende im Verkehr (BEniVer). München: Forschungsstelle für Energiewirtschaft e.V., 2020.

[11] The ecoinvent Database, Version 3.8: https://ecoinvent.org/the-ecoinvent-database/data-releases/ecoinvent-3-8/; Switzerland: Ecoinvent, 2021.

[12] Icha, Petra: Entwicklung der spezifischen Treibhausgas-Emissionen des deutschen Strommix in den Jahren 1990 - 2021. Dessau-Roßlau: Umweltbundesamt, 2022.

[13] Hengstler, Jasmin et al.: Aktualisierung und Bewertung der Ökobilanzen von Windenergie- und Photovoltaikanlagen unter Berücksichtigung aktueller Technologieentwicklungen. Dessau-Roßlau: Umweltbundesamt, 2021.

[14] Warwick, Nicola: Atmospheric implications of increased Hydrogen use. London, UK: United Kingdom Department for Business, Energy & Industrial Strategy , 2022.

[15] More about GREET. In: https://greet.es.anl.gov/homepage2. (Abruf am 2018-10-15); (Archived by WebCite® at http://www.webcitation.org/78DSdORi0); Argonne: Argonne National Laboratory, 2018.