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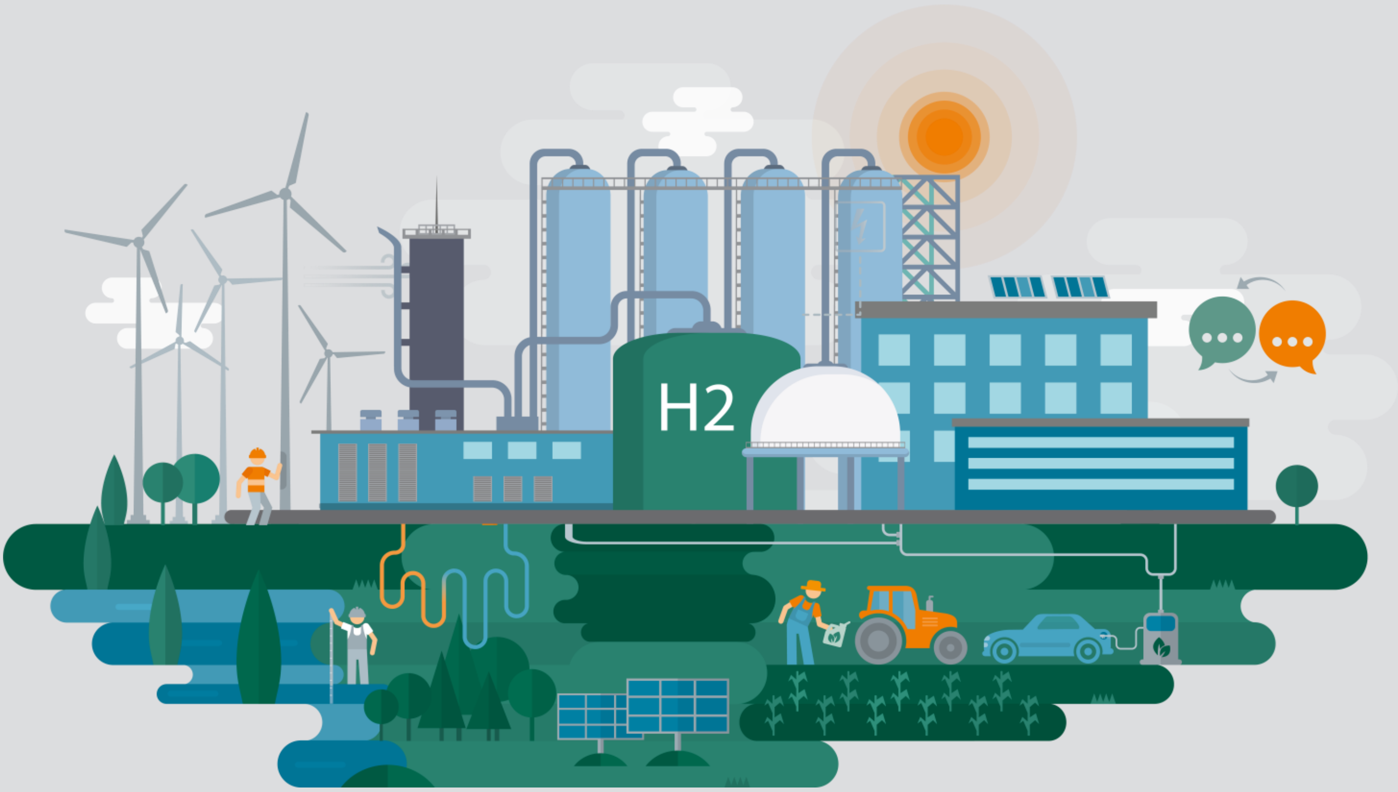
Certification of green hydrogen: Recent efforts and developments in the European Union

Sino-German Energy Partnership



Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Imprint

The report "Certification of green hydrogen: Recent efforts and developments in the European Union" is published in the framework of the Sino-German Energy Partnership between the German Federal Ministry for Economic Affairs and Climate Action (BMWK), the National Development and Reform Commission (NDRC) and the National Energy Administration of the People's Republic of China (NEA). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH implements the project under commission of BMWK. The Sino-German Energy Partnership provides a platform for the regulatory, economic and technical exchange on the energy transition between both countries.

As a German federal enterprise, GIZ supports the German government in the achievement of its goals in international cooperation for sustainable development.

Published by

Sino-German Energy Partnership
commissioned by the German Federal Ministry for Economic Affairs and Climate Action (BMWK)

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100600 Beijing, P. R. China

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Image

Self-Illustration /Cover

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Contents

List of abbreviations

bcm	Billion cubic metres
CHN Energy	China Energy Investment Group
CCS	Carbon Capture and Storage
DAC	Direct Air Capture
DNSH	„Do no significant harm“
EJ	Exajoule
EU	European Union
GJ	Gigajoule
GHG	Greenhouse gas
GoO	Guarantee of Origin
MMt	Million metric tons
MWh	MegaWatt-hour
PPA	Power Purchase Agreement
PV	Photovoltaics
PtX	Power-to-X fuels
RED II	Renewable energy directive (EU) 2018/2001, recast of the Directive 2009/28/EC (RED I)
RED III	Planned EU Directive amending the Renewable Energy Directive RED II (currently in proposal stage)
RES-E	Electricity generated from renewable energy sources
RFNBOs	Renewable fuels of non-biological origin
R&D	Research and Development
TWh	TeraWatt-hour
T/CAB 0078-2020	Industry standard and assessment of low-carbon hydrogen, clean hydrogen and renewable hydrogen, proposed by the China Hydrogen Energy Alliance

1. Background

1.1 Objectives of the study

Hydrogen has been used in the chemical and petrochemical industry for a long time, but today it forms the base for a major strategy to decarbonise the economy in long-term scenarios on climate neutrality. Transforming hydrogen production, transport, and storage processes to low greenhouse gas (GHG) emissions and expanding it to many new uses will help to reduce carbon dioxide emissions. Particularly 'green' hydrogen, produced from electricity that was generated from renewable energies, and other renewable fuels of non-biologic origin (RFNBOs) derived from green hydrogen are of great importance for sectors that are expected to rely on gaseous and liquid fuels in the long-term, such as maritime and aviation, but also the energy and industry sectors.

Today, however, hydrogen is almost entirely supplied from natural gas and coal. And even if produced by electrolysis with green electricity, system boundaries of a respective balancing need to be based on a well-to-tank approach and include all steps of the life cycle of hydrogen and various other factors. Assuming that in many countries, domestic production of 'green' hydrogen and other derivates will not be able to cover the demand, leading to large imports and international trading, we need to also carefully consider the environmental and social impacts on exporting countries, particularly on water supply under advancing climate change.

Currently, different definitions and certification schemes exist to assess the sustainability of hydrogen and derived power-to-X (PtX) fuels, with more or fewer stages of the hydrogen production and supply chain being included. For an international trading of 'green' hydrogen that is now starting to develop, it will be beneficial if major potential importing and exporting countries can agree on a joint certification system of low-carbon hydrogen that also meets other sustainability criteria. A continued exchange on this matter could help to develop a harmonized system of certification standards as a viable assessment instrument.

Against this background, the study aims to give an overview of:

- General sustainability aspects relevant for the certification for extended 'green' hydrogen
- More particularly, the status and current development at the European Union (EU) level regarding the definition of green hydrogen and PtX for certification purposes, including the consequences for market development and sustainability of hydrogen, for which the delegated acts were published on May 23rd, and the consultation process closed on June 17th 2022.
- Potentially more comprehensive certification standards
- Additional aspects to be considered for synthetic fuels based on hydrogen.

Based on the findings, a number of recommendations are suggested. The results of this study may serve as a basis for following workshops.

1.2 Hydrogen production in China

As a brief background, a few facts on the situation and plans in China regarding hydrogen are provided here. With 33 million tons of hydrogen produced per year, China is currently the largest producer of hydrogen in the world (GIZ 2022). Most of the hydrogen is produced from fossil energy (60% coal, 25% natural gas) and other sources, or as industrial by-product (14%). Water electrolysis is the least used production means under the current economic circumstances (only 1%). Currently, the country depends on imports of many key materials. Domestically produced components need to be further developed. The China Hydrogen Energy Alliance expects the hydrogen demand in China to reach 35 million MMt per year by 2030 and 60 MMt in 2050 (Earley 2021). In March 2022, the National Development and Reform Commission (NDRC) published the first comprehensive hydrogen strategy, the "Medium and Long-term Plan for Hydrogen Energy Industry Development (2021-2035)". Hydrogen is considered to play a key role in the development of the energy sector and for reaching carbon peaking and neutrality goals for 2030 and 2060. China plans to develop a hydrogen economy and establish an integrated hydrogen supply chain also covering transportation, and application in energy storage and industry, supported by respective innovation, hydrogen energy infrastructure, demonstration projects and improved policies and standards. Renewable hydrogen production shall reach 100.000 to 200.000 tons per year until 2025 (3.3-6.7 TWh, which equals to 1.3 GW of electrolysis capacity) (GIZ 2022).

An official standard or policy for identifying green or low-carbon hydrogen currently does not exist. But in December 2020, the major state-owned energy company CHN Energy and hydrogen-related associations and companies published a voluntary industry standard T/CAB 0078—2020 that is not related to national policy. The "Standard and evaluation of low-carbon hydrogen, clean hydrogen and renewable hydrogen" denoted GHG emissions per kg of hydrogen according to three categories and recognizes that the whole lifecycle needs to be considered. Major criteria are the GHG intensity limit and whether the energy is sourced from a renewable source (Earley 2021) (see Table 1).

Hydrogen from natural gas without CCS would be able to achieve the GHG intensity limit for low-carbon hydrogen, while blue hydrogen from natural gas with CCS would qualify as clean hydrogen.

Table 1: Classification criteria for low-carbon, clean, and renewable hydrogen in T/CAB 0078-2020, Standard and evaluation of low-carbon hydrogen, clean hydrogen and renewable hydrogen. Issued 29 December 2020 (based on Earley 2021)

	Hydrogen classification		
	Low-Carbon	Clean	Renewable
GHG intensity limit ($kgCO_{2eq}/kgH_2$) ≤	14.51	4.9	4.9
GHG intensity limit converted to kg CO_{2eq}/GJ	ca. 120	ca. 40	ca. 40
Energy source is from a renewable source	No	No	Yes

2. General sustainability aspects of certification for 'green' hydrogen

General aspects of sustainable hydrogen are presented in the following that are being discussed in literature and could be considered for a national or international certification scheme that aims to ensure green and equitable fuel production. They refer both to national and international levels and will lay the foundation for the next chapters.

As a market for hydrogen is developing with speed, support programs for industry transformation in building a hydrogen economy and extensive intergovernmental hydrogen co-operations are launched, and gigantic production capacities for hydrogen are being planned all around the world, it is crucial that this new energy path will truly ensure a sustainable development.

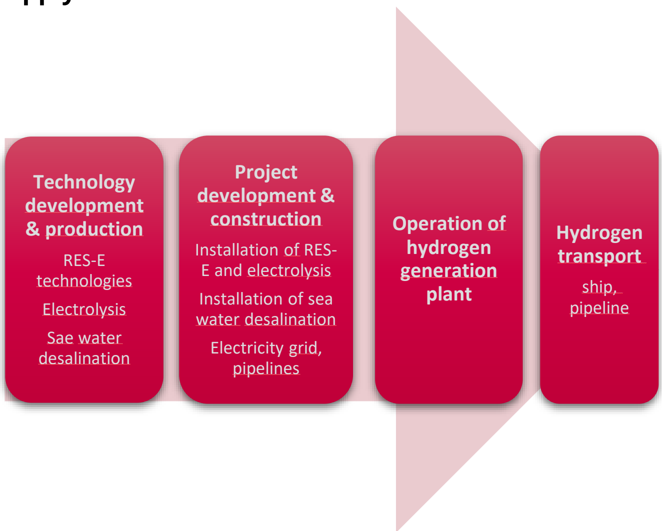
We focus on green hydrogen in this study, but the principle of life-cycle assessment and the further aspects of sustainability are important for all other forms of low-carbon hydrogen, especially blue hydrogen from fossil fuels with carbon capture and storage. The additionality of low-carbon power production would also apply to hydrogen that may be produced from nuclear power.

2.1 GHG – Whole supply chain assessment: development, construction, operation and transport

In order to ensure a positive impact on greenhouse gas reduction, it is important for certification to look at emissions of the whole value chain of hydrogen production and supply. Typically, four basic steps are being considered (Heinemann and Mendelevitch, 2021, Jensterle et al 2019/GJETC 2020): (1) The development and production of the technology, including the renewable energy production plants, electrolysis, seawater desalination plants and other technologies in case derivatives from hydrogen are being produced, (2) the construction and interconnection of the different components forming a hydrogen production plant (engineering and construction work), (3) the operation of the hydrogen plant (and refining of derivatives if these are to be exported), and (4) the transport of hydrogen or derived products to the point of application and storage. Facing different options of transport methods (pipelines, shipping, road), but also greatly differing distances between exporting and importing countries, especially the last element of the supply chain can be responsible for very high shares of the GHG emissions of the hydrogen supplied to use.

Unless all of these four steps use zero-carbon energy sources, the hydrogen cannot be zero-carbon, but only low-carbon. Therefore, setting a GHG intensity limit for low-carbon hydrogen is required.

Figure 1: Value chain of hydrogen production and supply



Own graphic based on Heinemann and Mendelevitch (2021)

2.2 Electricity demand covered by additional renewable power

Electricity is the major input to zero-emission or low-carbon hydrogen generation. It is not only needed for the electrolysis, but also for seawater desalination, for producing derivates from hydrogen, and for other steps along the value chain. If hydrogen shall contribute to reduce the GHG intensity, the electricity being used at all these steps needs to be produced without GHG emissions.

Therefore, it has to be ensured that the electricity for the *entire* hydrogen production process is generated from *additional* renewable energy capacities or from renewable electricity generation exceeding the total system demand without electrolysis. Otherwise, renewable hydrogen could deplete existing renewable capacity that is needed for other purposes.

When sourcing electricity from the electricity grid, the physically exact way to avoid additional GHG emissions is to only run the hydrogen production in time periods when the total power generation from renewable energy sources (or other low-carbon power plants) in the system exceeds the total load without electrolysis. Otherwise, the *marginal* power demand for the electrolysis will be generated from gas or coal power plants, leading to high additional GHG emissions for the hydrogen produced.

For certification, it therefore has to be decided how to *define the additionality* of renewables. The most rigorous approach would be to only accept amounts of renewable electricity generation as additional, which exceed the demand without electrolysis in a *systemwide* 100%+ renewable power situation. It may also be justified to include renewable electricity that is exceeding 100% of *regional* demand and cannot be transported to distant centers of demand.

However, such phases of excess renewable power generation will only arise after at least 50 to 60% of renewable power generation has been reached, and may initially only cover few hours of the year, which would drastically reduce the cost-effectiveness of green hydrogen production.

Therefore, the criteria could also allow for an *economic or political* definition of additionality, e.g., for renewable power capacity *purpose-built* for electrolysis in a system distant from 100% renewable power share at any time. A political link could be established in a renewable power support system with auctions for a maximum amount of capacity defined by the government. If the capacity defined and auctioned is increased by a certain amount for the purpose of providing electricity for electrolysis, this may be seen as additional to the baseline policy. An economic link would be established by hydrogen producers securing additional renewable power capacity for the electrolyser, e.g., through a purchasing power agreement outside of the general support system for renewable electricity.

2.3 Water, land, biodiversity, socio-economic impact and raw materials

Even the production and supply of green hydrogen may have negative impacts on sustainability in other areas, making it crucial that these aspects should also be addressed by criteria in a certification system for green or clean and sustainable hydrogen. Heinemann and Mendelevitch (2021) underline the following fields.

Water usage and supply: Water is needed as a feedstock for the electrolysis. IRENA (2021) has estimated the future global hydrogen demand to grow up to 74 EJ (today 8.4 EJ), deriving the respective water consumption to rise up to 25 bcm per year. In most cases, water from seawater desalination plants will be used. While stoichiometrically, 9 kg of water are needed to produce 1 kg of hydrogen (IEA 2019), electrolysers need high-quality water which requires water treatment and much more raw water. The input here has been estimated to 18 to 30 kg for 1 kg hydrogen (Blanco 2021). Parts of it may be recirculated. However, also in other steps of the value chain, especially electricity production, e.g. cleaning or cooling PV panels, water is required. Blanco calculated up to additional 19 kgH_2O/kgH_2 for PV and up to 2.1 kgH_2O/kgH_2 for wind. Even though it is argued that the resulting amounts of water demand globally would still be relatively little compared to other water uses, e.g. by agriculture (2770 bcm per year), industry (768 bcm) and municipalities (464 bcm), it has to be considered that for potential exporting countries (or regions) that provide good conditions to generate renewable electricity, water stress may typically be a serious issue. Additional water demand for hydrogen production in these regions could lead to competition for scarce water resources, resulting in rising prices (especially in the coastlines where agricultural use and population density are usually higher). The dramatically advancing climate crisis in the coming decades with more extreme weathers, especially droughts and heat waves, could lead to rising water demands and diminishing water supplies, exacerbating the water scarcity in further regions.

Jones et al (2019) see the actual key barrier to desalination expansion in the brine production and the energy consumption of desalination facilities. They point to the fact that the brine production is at 141.5 million m^3/day and already exceeded past estimates by 50%. The hydrosaline concentrate requires disposal that is costly and causes negative environmental impacts. The authors call for improved brine management strategies and disposal options.

Land and soil: Land use for generation facilities of renewable electricity and hydrogen production, but also for desalination and transport and harbour infrastructure, and – if necessary – for direct air capture (DAC) in case of further processing into other products requiring CO_2, may lead to land use conflicts and impact on local land rights.

Additionally, in the context of international trade, the question arises how the use of the best renewable power production sites intended for exports may affect the domestic decarbonisation efforts in developing countries.

Biodiversity: Generation facilities, transport and harbour infrastructure, but also the ecological impact of desalination facilities on maritime biospheres due to the salination of surrounding areas is high and can conflict with nature and wildlife.

Socio-economic impact, human rights, safety: Establishing a hydrogen export value chain may support, but also challenge local society and economy. Economic participation of the local population related to jobs or capacity-building could be restricted, if the implementation processes are not developed in cooperation with local municipalities. Work processes and land use changes may harm their interests. Hydrogen or derivates may cause accidents that harm workers or the environment.

Raw materials: Building electrolysers and renewable power plants requires raw materials that are rare and may be mined under working conditions that harm the health of workers and local population.

Table 2 summarizes the sustainability dimensions and aspects in hydrogen production and supply discussed in this chapter.

Table 2: Sustainability dimensions in hydrogen production and supply to be addressed by certification

Electricity supply	Water supply	Land use and biodiversity	Socio-economic impacts, human rights, safety	Raw materials
• CO_2-emissions from electricity generation • Indirect effects on electricity grid due to new large scale demand • Competition for low-cost RES-E potentials • Need for additional RES-E production • Socio-economic and ecological impacts	• Scarcity of water • Brine disposal with low ecological impact (sea water desalination) • Electricity input for sea water desalination	• Land use competition • Ecological significance of land • Socio-cultural significance of land	• Human rights • Potential for added value in exporting country • Potential local effects on labor • Safety issues, handling of hazardous goods, health of workers and local population	• Raw material for building electrolysers and Renewable powerplants are rare • Labour standards in mines

Source: Own table based on Heinemann and Mendelevitch (2021)

3. Regulatory framework and efforts for hydrogen certification in the EU

How are sustainability aspects regarding hydrogen and its certification addressed and covered in EU legislation? The central regulatory basis in Europe for the certification of hydrogen and its derivates is the Renewable Energy Directive (recast) of 2018 (RED II). This directive requires EU Member States to oblige fuel suppliers to increase the renewable energy share in transport fuels and defines a framework for the recognition of so-called renewable fuels of non-biological origin (RFNBOs) for the transport sector. In May 2022, the European Commission published drafts for the respective delegated acts and launched a 4-week-consultation on the drafts clarifying how "green" hydrogen produced from renewable energy can be legally counted as additional and verified as such, and also detailing the emission accounting methodology for assessing greenhouse gas emissions reductions (termed 'savings' in the documents) from RFNBOs.

In addition, the EU Taxonomy Regulation, which defines requirements for sustainable investments, sets out criteria for several activities related to hydrogen production, storage, transport, and use.

For the implementation of the Paris Climate Agreement, many European countries have identified the use of green or low-carbon hydrogen as a key means of achieving their climate targets: Green hydrogen produced from water electrolysis and renewable electricity is considered an important substitute for fossil energy in the transport and industry sectors, where direct or battery-electric use of renewable electricity is not possible. It is also a solution for mid- to long-term storage in the energy sector.

The future quantities of hydrogen demand are large. The EU expects a total demand for green hydrogen and hydrogen-based fuels of up to 60 million tons or 2,000 TWh by 2050 (World Energy Council 2021). Facing limited renewable energy potential in the EU Member States, millions of tons of decarbonized hydrogen and corresponding derivatives will have to be imported every year. Therefore, the need to define criteria and processes for certification of green hydrogen in the EU is urgent.

There are two relevant sets of provisions related to the certification of hydrogen in the RED II: (1) The Guarantee of Origin for consumer disclosure (Article 19) showing that a given share of energy does in fact come from renewable sources and (2) the certification of hydrogen as "100% renewable" for use as an RFNBO in transport. So far, the RED II includes this requirement for a definition of hydrogen as "100% renewable" only for transport fuels, in view of the obligation on fuel suppliers to increase the share of renewable energies in transport fuels (Articles 25-30). The RED requires that the European Commission establishes rules to ensure that power installations providing electricity for green hydrogen are „additional" to other uses of electricity. This is, therefore, not a requirement for a systemwide or regional excess of renewable electricity, but a form of economic/political link to define "additionality" of the renewable electricity. It is to prevent a wrong allocation of green electricity and avoid that electrolysers producing hydrogen could use renewable electricity that is needed for direct uses in traditional end uses and in the increasingly electrified heat, transport and industry sector. This would unintendedly support longer operating times of fossil or nuclear power plants, and would lead to additional GHG emissions.

On May 23rd 2022, draft delegated acts have been published for establishing a Union methodology setting out detailed rules for the production of RFNBOs and (by) establishing a minimum threshold for GHG emissions savings of recycled carbon fuels and (by) specifying a methodology for assessing greenhouse gas emissions savings from RFNBOs and from recycled carbon fuels (European Commission, 2022a, b, c)[1]. They were open for public feedback in the usual consultation process until June 17th 2022.

Based on the increased climate ambition of the EU (Green Deal), the European Commission recently introduced a legal proposal to amend RED II towards what would be a RED III. The aim is to extend the hydrogen certification beyond transport fuels to all sectors, and also set the

[1] https://ec.europa.eu/info/news/commission-launches-consultation-regulatory-framework-renewable-hydrogen-2022-may-20_en

standard for "green hydrogen", e.g., in the industry or the heating sector.

3.1 Guarantee of Origin (GoO)

A Guarantee of origin (GoO) is an energy certificate. For example concerning electricity, it guarantees that a given amount of power is produced at a certain power plant. Showing whether the energy being supplied is produced from renewable energy ('green') sources, it gives customers the choice to select green energy. At the same time, the document ensures that this quality can only be sold once and thus helps producers using renewable energy sources. While Article 15 of the RED II defines GoO for electricity, Article 19 specifies that there could also be GoOs for hydrogen that demonstrate its quality as a renewable energy. However, to date there is no GoO system in place except for electricity (GIZ 2021: 10/11). The existing system of GoOs could, if necessary, be adapted to further verification requirements. They could refer, e.g., to additionality or temporal and geographical correlation, as part of the current RED II reform. Due to this status, we do not expand on this type of certification here any further.

3.2 Sustainability criteria for RFNBOs

In articles 25 and 27, the RED II defines general **sustainability criteria** for renewable fuels of non-biological origin for certifying the respective fuels **as 100% renewable**. They cover the definition of renewable electricity for electricity and supply-chain aspects that have been discussed in the previous chapter. Other sustainability criteria, such as those discussed in chapter 2 or included in the EU Taxonomy Regulation, are not addressed or required by the RED-II for RFNBOs.

Sustainability criteria for RFNBOs:

1. Additionality of the renewable power plants in general
2. Temporal correlation of electricity and hydrogen generation for grid-connected renewable power plants
3. Geographic correlation of electricity and hydrogen generation for grid-connected renewable power plants
4. Greenhouse gas emissions balance / reduction of at least 70%

The RED-II also calls for a **methodology for assessing GHG emissions reductions from RFNBOs** in Article 28 (5).

For these criteria – being ambiguous in their general form –, the recently published draft delegated acts with detailed definitions clarifying the EU rules and criteria on renewable hydrogen under the 2018 directive have been expected with great tension, intensive discussions, and the demands of hydrogen associations to set a design that is not too strict, in order to avoid putting a brake on the ramp-up of hydrogen. Chapter 3.3 presents the criteria for defining additionality or renewable power for green hydrogen from both the RED II itself and the proposed delegated acts.

3.3 Definition of additionality for green hydrogen in RED II: Article 27 (3)

Due to the target set on transport fuel suppliers for the share of renewable energy in their fuels, this paragraph concerns the definition of a fuel as renewable. As a principle, RFNBOs are considered renewable when the hydrogen component is produced in an electrolyser that uses renewable electricity (RED-II Art 27 (3)). This renewable electricity may be supplied by an installation that is *directly connected* to the installation that produces RFNBOs, or may *come from the grid*. The increase in the production of renewable electricity corresponding to its use in electrolysis has to be ensured by including strict criteria for additionality in this methodology. RED II distinguishes the following 3 cases of green hydrogen production. The delegated acts define details for cases 1 and 3, particularly for temporal and geographical correlation. Table 3 presents the main characteristics of the 3 cases (for a detailed description, see Appendix).

Table 3: Possible cases of green hydrogen production following the RED II and the Delegated Act

Case 1: Direct connection	**Direct connection between renewable production facility and hydrogen production facility:** ▪ No grid connection/no consumption of grid electricity. ▪ New renewable energy power plant installation. ▪ Plants that are directly connected to the RFNBO production plant need to come into operation not earlier than 36 months before the installation producing the RFNBOs.	„100% green hydrogen“
Case 2: Average share	**Grid connection, Member State´s electricity mix**[2] ▪ Fully green hydrogen option: if electrolyser is located in a bidding zone[3], where the average proportion of renewable electricity exceeded 90% in the previous calendar year, and the production of RFNBOs does not exceed a maximum number of hours/year[4]. ▪ Not fully renewable hydrogen option: Average share of renewable energy in the electricity mix of a member state (2 years before) determines the share of renewable energy being used in the production of green hydrogen.	"100% green hydrogen“ or „Partly green hydrogen"
Case 3: Grid delivery	**Grid connection, additionality criteria to be fulfilled** ▪ Additionality of the renewable power generation: Power Purchasing Agreement(s) (PPA) with the renewable power generators are required, and the electricity produced must be the same amount as that used in the electrolyser, except in case of redispatch; ▪ Temporal correlation: The proposed match is 1 hour - hydrogen must be produced in the same hour as the renewable electricity is generated; electricity from local storage, which has been charged in line with the 1 hour matching rule, and power purchase from the grid at less than €20/MWh or less than 0,36 times the price of an allowance to emit one tonne of CO_{2eq} are also allowed[5] ▪ Geographic correlation: The renewable energy production unit is located in the same or neighbouring bidding zone as the electrolyser. It may also be in an offshore bidding zone adjacent the RFNBOs installation zone.	"100% green hydrogen"

[2] For example, as the share of RES-E in Germany has been 44,1 % in 2020, 44,1 % of the hydrogen being produced in 2022 with electricity from the German grid will be counted as 'renewable'.

[3] A bidding zone is the largest geographical area in which market players can trade electricity without any restriction due to internal bottlenecks. https://www2.deloitte.com/content/dam/Deloitte/fr/Documents/financial-advisory/economicadvisory/deloitte_delimitation-zones-marches-electriques-Europe-et-consideration-des-congestions-internes.pdf

[4] Art. 4 (1) of the draft delegated act states: "This maximum number of hours shall be derived by multiplying the total number of hours in each calendar year by the share of renewable electricity reported for the bidding zone where the renewable hydrogen is produced." The total number of hours in each calendar year will be 8,760 or 8,784.

[5] There is no explanation given in the draft delegated act, why this exception for hours with low electricity prices has been included. Presumably, the rationale is that during such hours, there will be excess electricity supply available, which may be generated from variable renewable power plants, i.e. solar PV and wind energy. However, this does not mean that all power produced will be from RES-E. Therefore, this suggestion can be seen as economically motivated for using cheap electricity to increase the operation times of electrolysers and thereby improving their cost-effectiveness and reducing the price of RFNBOs, but its environmental integrity may be in doubt.

3.4 RFNBO GHG emission reduction threshold and accounting methodology: Articles 25 (2) and 28 (5)

This chapter concerns the accounting methodology for the – potential – greenhouse gas emission reduction of RFNBOs. This is, therefore, a subject different from the previously discussed Article 27 (3) on the share of renewable energies.

Fossil comparator and reduction target of 70%

Article 25 (2) RED II stipulates that the GHG emissions reductions from the use of RFNBOs shall be at least 70% compared to fossil fuel. Article 25 (2) RED II required that the European Commission shall adopt a delegated act, which specifies the necessary methodology on how to calculate the GHG emissions reduction requirement. This draft delegated act was also published recently. The GHG Emissions Rules from the delegated act propose to set the fossil fuel comparator for RFNBOs at 94 gCO_{2eq}/MJ (equivalent to 11,3 $kgCO_{2eq}/kgH_2$), in line with the value set out for biofuels and bioliquids in Directive (EU) 2018/2001. This value approximately equals the GHG intensities / total emissions of heavy fuel oil (94.2 gCO_{2eq}/MJ), diesel (95.1 gCO_{2eq}/MJ), gasoline (93.3 gCO_{2eq}/MJ) and also methanol (97.1 gCO_{2eq}/MJ) (see draft delegated Act 28, (5)). In light of the 70% reduction requirement, this translates to a threshold of 28.2 gCO_{2eq}/MJ (3,4 $kgCO_{2eq}/kgH_2$) that the fuel has to meet in order to be considered renewable. Further details on GHG intensity and savings are determined in accordance with the methodology set out in Annex I of the delegated act.

Whole supply chain approach

The delegated act calls for an accounting methodology that takes into account the full life-cycle emissions from producing RFNBO and recycled carbon fuels, including emissions from the supply of inputs, the processing, transport and distribution, combusting the fuel in its end-use and also emission savings from carbon capture and geological storage. All elements of the supply chain need to be audited for their GHG emissions related to hydrogen (RFNBO), and the contributions of all of them need to be combined to result in the total GHG balance.

Emissions from the manufacture of machinery and equipment and emissions from compressing and distribution of hydrogen for its direct use in vehicles are not taken into account. Details on the relevant segments of inputs for such life-cycle analysis are set out in the Annex of the GHG Emissions Rules.

Additional renewable electricity

Electricity qualified as fully renewable in accordance with Article 27 RED II (cf chapter 3.3) shall be attributed zero GHG emissions (a carbon intensity of zero should be applied to this electricity).

Where electricity used to produce RFNBOs is taken from the grid and is not considered as fully renewable, the average carbon intensity of electricity consumed in the Member State where the fuel is produced shall be applied (the Annex of the delegated act contains standard values for greenhouse gas emission intensities of[6] electricity, and the emission intensity of generated electricity in the various European Union Member States 2018 which are needed to calculate the respective share of green hydrogen).

Alternatively, electricity taken from the grid that does not qualify as fully renewable, may be attributed GHG emissions values depending on the number of full load hours the installation producing RFNBOs and recycled carbon fuels is operating. Where the number of full load hours the electrolyser is producing is equal to or lower than the number of hours, in which the marginal price of electricity was set by installations producing renewable electricity or nuclear power plants in the preceding calendar year for which reliable data are available, grid electricity used in the production process of RFNBO and recycled carbon fuels shall be attributed a GHG emissions value of zero gCO_{2eq}/MJ. Where this number of full load hours is exceeded, grid electricity used in the production process of RFNBO and recycled carbon fuels shall be attributed a greenhouse gas emissions value of 183 gCO_{2eq}/MJ.

Electricity used for the hydrogen production process	GHG emissions intensity	Example
Qualified fully renewable according to Article 27 RED II	0 gCO_{2eq}/MJ	Case 1; Case 2, Electrolyser in bidding zone with more than 90% renewables; Case 3 meeting criteria, cf. Table 3
Taken from the grid and not qualified fully renewable	Average carbon intensity of electricity consumed in EU MS	Case 2 in Table 3
▪ Alternative for electricity taken from the grid and not qualified fully renewable ▪ Subcase 1: Number of full load hours the electrolyser is producing is *equal or less* the number of hours, in which the marginal price of electricity was set by installation producing renewable or nuclear power plants in the preceding calendar year	0 gCO_{2eq}/MJ	Case 2 in Table 3
▪ Alternative for electricity taken from the grid and not fully renewable ▪ Subcase 2: Number of full load hours the electrolyser is producing *exceeds* the number of hours, in which the marginal price of electricity was set by installation producing renewable or nuclear power plants in the preceding calendar year	183 gCO_{2eq}/MJ	Case 2 in Table 3

Based on Delegated act Article 28 (5)

The carbon intensity of the electricity mix is expected to gradually decrease due to higher proportions of renewable and low-carbon electricity, and it is suggested to consider this by applying an improvement factor that is derived from energy statistics.

Carbon capture technologies

In addition to green hydrogen, the use of blue hydrogen is also approved in the RED-II in principle. The GHG Emissions Rules recognise specific segments of carbon capture technologies, but also point out that the capturing of emissions from non-sustainable sources should only be considered as avoiding emissions until 2035.

3.5 Scope of application

The rules set out in this Regulation apply regardless of whether the RFNBOs are produced inside or outside the territory of the Union (draft delegated act 27 (3), Article 6 "Certification of compliance").

For international certification mechanisms to work, international monitoring must be introduced and recognized by the EU. Certification of RFNBOs has not been carried out yet (GIZ Chile 2021: 44). Voluntary schemes aiming at certifying RFNBOs need to incorporate the requirements and criteria defined in the delegated acts before being able to certify RFNBOs according to RED II. Currently, hydrogen for any use can be voluntarily certified as a product via the CertifHy or TÜV Süd testing organizations. For further description, see GIZ (2021).

3.6 Hydrogen in the EU taxonomy

The EU Taxonomy Regulation defines requirements for sustainable investments and sets out the criteria for determining whether an economic activity qualifies as environmentally sustainable. It is designed to contribute to the European Green Deal by promoting private investment in green and sustainable projects. Above all, it enables a uniform and transparent understanding of which economic activities are considered environmentally sustainable. The EU Taxonomy refers to six EU environmental objectives: (1) Climate change mitigation, (2) Climate change adaptation, (3) Sustainable use and protection of water and marine resources, (4) Transition to a circular economy, (5) pollution and prevention control and (6) protection and restoration of biodiversity and ecosystem.

Currently, the taxonomy covers 70 activities from eight economic sectors that are responsible for 93,5% of the GHG emissions of the EU. EU taxonomy-compliant economic activities are those that make a significant contribution to one of the six EU environmental objectives, avoid significant harm to the other environmental objectives, meet minimum social standards, and meet the technical assessment criteria for the activity. Technical screening criteria are detailed for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives. In the EU taxonomy, hydrogen is mentioned in the manufacturing sector and in the energy sector (sections 3 and 4), and included in the following activities[7]:

- Manufacture of equipment for the production and use of hydrogen (p. 41)
- Manufacture of hydrogen (p. 53)
- Manufacture of anhydrous ammonia (p. 59)
- Storage of electricity (p. 75)
- Storage of hydrogen (p. 77)

Partly there are specifications of the technical screening criteria for contribution to climate change mitigation, but also regarding the DNSH (do no significant harm) criteria regarding the other Environmental targets. The manufacture of hydrogen and hydrogen-based synthetic fuels is the central activity, which the other activities mostly refer to.

GHG emissions reduction, including CCS

The taxonomy underlines the **substantial contribution of hydrogen** regarding the goal of climate change mitigation. It is stated that the activity of manufacturing hydrogen complies with the life-cycle GHG emissions savings requirement of 73,4% for hydrogen [resulting in life-cycle GHG emissions lower than 3.0 tCO_{2eq}/tH_2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO_{2eq}/MJ in analogy to the approach set out in Article 25(2) of and Annex V to the RED-II Directive (EU Taxonomy, p.53). Interestingly, therefore, the threshold for renewable hydrogen is defined slightly more ambitious as 73,4% or 3,0 kg/kgH_2, not 3,4 as in the RED II. Life-cycle GHG emissions savings are calculated using the methodology referred to in Article 28(5) of Directive (EU) 2018/2001 or, alternatively, using ISO 14067:2018 or ISO 14064-1:2018. Quantified life-cycle GHG emission savings are verified in line with Article 30 of Directive (EU)

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2139&from=EN

2018/2001 where applicable, or by an independent third party.

Where the CO_2 that would otherwise be emitted from the manufacturing process is captured for the purpose of underground storage, the CO_2 needs to be transported and stored underground in accordance with the respective technical screening criteria set out for transport of CO_2 and underground permanent geological storage of CO_2.

Environmental targets of climate change adaptation, water and marine resources, biodiversity and ecosystems

Following the EU taxonomy, significant harm to the other environmental objectives needs to be avoided. For (2) climate change adaptation, (3) sustainable use and protection of water and marine resources, (5) pollution prevention, and (6) protection and restoration of biodiversity and ecosystem, the taxonomy defines that hydrogen manufacturing needs to be compliant with the criteria set out in the respective appendices. The appendices relating to the most relevant sustainability targets described in the previous chapter are summarized in the following.

Regarding **climate change adaptation**, there are water-related hazards like, e.g., sea level rise, water stress and droughts, but also saline intrusion that appear to be relevant to hydrogen production. The generic criteria for DNSH states that risks need to have been identified by performing a robust climate risk and vulnerability assessment, proportionate to the scale of the activity and its expected lifespan. The projections and assessment of impacts need to be based on best practice and available guidance, and take into account the state-of-the art science and related methodologies. The economic operator needs to implement physical and non-physical adaptation solutions, over a period of up to five years that reduce the most important identified physical climate risks that are material to that activity. They shall not adversely affect the adaptation efforts or the level of resilience to physical climate risks of other people, nature, cultural heritage, assets and other economic activities. They need to be consistent with local, sectoral, regional or national adaptation strategies and plans, and consider the use of nature-based solutions or rely on blue or green infrastructure to the best extent possible.

Regarding the **sustainable use and protection of water and marine resources**, environmental degradation risks relate to preserving water quality and avoiding water stress. They need to be identified and addressed with the aim of achieving good water status and good ecological potential, as well as a water use and protection management plan, developed thereunder for the potentially affected water body or bodies, in consultation with relevant stakeholders.

Regarding **protection and restoration of biodiversity and ecosystems**, an environmental impact assessment or screening needs to be completed in accordance with Directive 2011/92/EU. The required mitigation and compensation measures for protecting the environment need to be implemented. For sites/operations located in or near biodiversity-sensitive areas (including the Natura 2000 network of protected areas, UNESCO World Heritage sites and Key Biodiversity Areas, as well as other protected areas), an appropriate assessment, where applicable, has to be conducted, and based on its conclusions, the necessary mitigation measures are to be implemented.

4. Potentially more comprehensive certification standards

For ensuring so-called green and clean hydrogen, the EU certification currently focuses on GHG emissions and mainly demands the additionality of renewable electricity to secure respective emission reductions. In the EU taxonomy, hydrogen will qualify as sustainable, if it complies with the life-cycle GHG emissions savings requirement of 73,4%. Other environmental targets are mentioned there, but not being made mandatory (The "Do no significant harm" criterion will suffice for the others, see chapter 3.6). Against the background of the tremendous impacts on ecological and social systems that hydrogen production can have in its life-cycle supply chain and due to the expected quantities, this chapter discusses whether the EU criteria for GHG emissions reductions and additionality of renewable electricity are appropriate and sufficient, and which other sustainability criteria would be advisable for a national or international certification scheme for green/clean and sustainable hydrogen. It also takes into account the economic challenges and possible compromises in a transitional phase that could help to achieve both goals; immediate GHG emissions reductions and developing infrastructure; and the supply and use of technologies already in the short-term.

4.1 Greenhouse gas emissions: need for ambitious reduction targets and pathways

Technically achievable emission limits

The intense discussions on the expected delegated acts reflect the enormous challenge of the new pathway: realizing large scale CO_2 reduction, shifting hydrogen production from fossil to green production methods, while green hydrogen is still not available and affordable in the way it would be needed. Accordingly, the EU refers as a baseline of the emission reduction targets to the GHG emissions caused by conventional hydrogen, setting the criteria as an overall reduction share of 70%. Given the urgency of mitigating climate change and urban pollution, such targets would be best defined by what is **technically achievable and economically feasible in GHG emissions limits**. The EU taxonomy´s thresholds of 3 $kgCO_{2eq}/kgH_2$ or 25 g per MJ seem to be best current practice here. If CCS technologies can be advanced to improve safety, reduce costs, and receive public support, the GJETC (Shibata et al., 2020: 51 f.) has concluded that blue hydrogen production could also achieve strong reductions in GHG emissions to as low as around 20 g CO_{2eq}/MJ_{H2}. Including such blue hydrogen could secure much bigger amounts of hydrogen, if the stable use or storage of the captured carbon could be achieved.

Including thresholds for hydrogen transport

Beyond production, also the *emissions from hydrogen transport* to the border gate of the importing countries need to be included and quantified (Shibata et al 2020). These strongly depend on the distance (e.g., Norway, Morocco, Middle East, Australia or Chile) as well as on the means of transport – pipeline or vessel, and even the form of gas or liquid carried, e.g., liquified hydrogen or methylcyclohexane. In order to stimulate innovation and efforts for reducing transport distances and emissions, extra GHG emissions allowed for transport to the border gate may be defined, but should not exceed 10 g CO_{2eq}/MJ_{H2}. Taken together with the 20 g CO_{2eq}/MJ_{H2} found possible for blue hydrogen production, this would yield a potential total maximum universal absolute threshold level of specific GHG emissions for imported hydrogen until the border gate of 30 g CO_{2eq}/MJ_{H2} (equivalent to ca. 3.6 $kgCO_{2eq}/kgH_2$). This would be around half of the border-gate GHG emissions of natural gas, the fossil fuel with the lowest GHG emissions, thus enabling significant GHG emissions reductions of at least 50 % from the start. It would be defined to include both production and transport, to allow flexibility between both.

For certification purposes, the RED-II and the delegated act set a threshold of 3.4 $kgCO_{2eq}/kgH_2$, or 28.2 g CO_{2eq}/MJ_{H2}. This is very close to what the previous paragraph has discussed as feasible for both green and blue hydrogen, and could, therefore, be seen as appropriate for the next few years, for both domestic and imported, green and blue hydrogen.

As soon as technology developments allow, these *thresholds should be reduced further,* eventually to zero by 2050 or earlier. Therefore, it would be good to define pathways with declining emissions thresholds reaching zero by 2050 or earlier. The system should also provide incentives to go below the maximum universal absolute threshold level sooner than its revisions in order to prevent lock-in effects. For example, a second 'clean premium' level of GHG emissions 30 or 50% less than the maximum universal absolute threshold level could be set in the EU taxonomy and in an international certification scheme.

4.2 Additionality of generated electricity: Using electrolysis as flexible load, particularly when renewable power generation exceeds total demand

Only additionally generated renewable electricity should be used as an input to green hydrogen production. For Case 1 and 2 in the RED, 'Direct connection between renewable production facility and hydrogen production facility' and 'Grid connection resulting in partly green hydrogen', the criterion appears clear and appropriate. For Case 3, 'Grid connection, but additionality criteria to be fulfilled', however, it seems that more situations could occur that need to be regulated. It is laudable that the RED II and the draft Delegated Acts try to improve the link between the additional renewable power plant and the hydrogen production through the temporal and spatial correlation regulations, and a shorter time interval for the temporal correlation. However, this is taking a view from an electricity system *either* with relatively low shares of renewable energy, particularly PV and wind power, and hence without periods of time, in which the total renewable power generation exceeds the total load; *or* with almost 100% (as per the draft EU delegated acts, at least 90%) of renewable power in the system.

In the case of relatively low shares of renewable energy, it may make sense to ensure a close temporal correlation of the renewable power generation and the hydrogen production, because the combined new renewable and hydrogen plants would thus not cause additional flexibility needs. However, the shorter time frame for the temporal correlation will increase the costs, because the hours of operation of the electrolyser will be lower. For example, an annual accounting period will allow the size of the electrolyser to be reduced and the annual operating hours to be increased compared to shorter time frames for the temporal correlation. According to estimates, the cost may increase by up to 1.2 € / kg of hydrogen comparing an annual accounting period with a quarter-hourly period (frontier economics, 2021).

Further subcases with electrolysis as a source of flexibility

In neither case, however, is there a possibility to use the electrolyser itself as a source of flexibility. And this will be needed especially in systems, in which there are time periods, in which the total renewable power generation exceeds the total load. This will happen at a share above ca. 50 to 60 % of renewable electricity in the system and increase with higher shares. Germany and Denmark are countries, in which this situation is close or already existing. We would, therefore, recommend to allow two further cases or sub-cases of additionality for the RED II and its Delegated Acts (see table 4). Both would be relevant for electricity systems with shares of renewable energies between 50 and 90 %; above 90%, the respective subcase of case 2 (average share) would apply (cf. table 3 in chapter 3.3) .

In case 3 "*Additional grid-connected renewable power plant",* we suggest to define a subcase 3(b) with the condition that the electrolyser can be used by the system operators as a flexible load. This condition would differ from case 3 included in the RED II (see Table 3 in chapter 3.3). However, it contradicts a strict temporal correlation of one hour, since the condition means that the electrolyser will not be operating during some times, in which its PPA power plant is producing electricity, or vice versa. In order to solve this problem and to reward this flexibility service, a longer time frame should be allowed for temporal correlation. Further analysis will be needed to determine if one month would be enough, or if several months or up to a year would be appropriate.

Furthermore, we would add a new case 4 where the grid-connected electrolyser is only operating in time periods, in which the total renewable power generation exceeds the total load (or the total load minus some must-run fossil power plants, e.g., in combined heat and power). No PPA linkage to renewable power generation will be needed in this case, because this condition ensures the additionality of the renewable electricity.

The same criteria and monitoring processes should also be used for GoO outside RFNBOs, which will be needed in case their use is expanded to all sectors as foreseen in the proposed revision of the RED II towards a RED III.

Table 4: Additional cases suggested for recognition of green hydrogen

Case 3: Grid delivery with the electrolysis as a flexible resource	**Grid connection, additionality criteria to be fulfilled** **Case 3(a): defined by RED-II and suggested Delegated Act** ▪ see Table 2 **NEW: Case 3(b) – electrolysers as flexible load** ▪ the electrolyser can be used by the system operators as a flexible load (not only for redispatch) ▪ Additionality of the renewable power generation: PPA, and the electricity produced must be the same amount as that used in the electrolyser, except in case of redispatch or use as a flexible load ▪ Temporal correlation: Allowing between 1 month and 1 year (definition of suitable time frame needs further analysis) ▪ Geographic correlation: same or neighbouring bidding zone	"100% green Hydrogen"
NEW: Case 4: Grid delivery, electrolysis only for use and storage of excess renewable electricity	**Grid connection, electrolysers as storage of excess renewable electricity** ▪ Electrolyser is only operating, when the total renewable power generation exceeds the total load in the system ▪ This condition ensures the additionality of the renewable electricity. Therefore, no PPA and no temporal or geographic correlation is needed.	"100% green Hydrogen"

Source: Own table

4.3 Striving for 'green and sustainable' hydrogen

The EU Taxonomy addresses some but not all of the discussed sustainability aspects of hydrogen. Analysing where the specifications by the EU taxonomy could be further improved would go beyond the scope of this study. But Heinemann & Mendelevitch (2021) have developed possible criteria for sustainable green hydrogen and tried to operationalise them. They suggest to differentiate between criteria for a minimum standard ("do no harm") and for additional support of sustainable development ("do good") to consider differing claims on hydrogen projects. If and where possible, existing criteria sets should be used to keep the hurdle for complying with sustainability criteria in hydrogen production low.

Electricity

In addition to the current regulation, the authors suggest to exclude biomass and nuclear energy as a source for low-carbon hydrogen.[8] Regarding electricity production from

[8] The devastating environmental disasters that the use of nuclear energy can cause, and the large amounts of hazardous high-level radioactive waste, while no country currently has managed to create a safe final repository, pose a great risk and question the sustainability of this energy source. Bioenergy in general encompasses a wide variety of feedstocks, technology pathways and application areas (electricity, heat and fuel production). In some cases, it has a better greenhouse gas balance than fossil energy, but it is also being controversially discussed. Especially crop or other biomass especially cultivated for energy supply has been associated with a variety of negative effects on humans and the environment, particularly in exporting countries. It may lead to competitive uses (e.g., "plate or tank") causing price fluctuation, indirect land use change and ecological costs, including indirect GHG emissions, e.g., by the destruction of natural land. This can undermine global GHG emissions reductions and result in low public acceptance. It should thus not be in the focus regarding the energy production, as the amount of sustainable biomass (e.g., wood residues or unavoidable food waste) will remain limited (UBA 2022; Heinemann & Mendelevitch 2021).

other renewable energy sources, competition for renewable energy sites between exports and local decarbonisation should be addressed. Stepping forward, additional renewable energy capacity to decarbonise local energy systems could be required and provisions for additional infrastructure development adopted.

Sustainable use of water

It is suggested that sourcing water from groundwater and surface water should be excluded in areas with water stress and limited to areas with high water availability. When using water from seawater desalination plants, these plants should be additional to the existing ones, and fulfill minimum efficiency and ecological standards, and should be powered by renewable energy. Local water prices should be monitored, and countermeasures should be taken if prices increase due to hydrogen production.

Investment in improved local water infrastructure to reduce losses and evaporation, and additional water production through seawater desalination could support local sustainable development. Additional disclosure of information on water use should be included in GoO. Criteria for brine management and disposal need to be developed.

Land use and Socioeconomics

It is suggested that land-use change for hydrogen production and especially renewable electricity production should not take place in ecologically protected areas. Local stakeholder consultations should make sure that local and informal land rights are not violated. Economic participation of the local population and enabling co-benefits (such as shading local agricultural areas by agri-photovoltaic systems) could be options to further support local sustainable development. Additional disclosure of information on (sustainable) land use should be included in GoO.

Socio-economic risks need to be mitigated by following the due diligence procedures, including publication and contact points. It is suggested to define sector-specific risks and report adequate measures to mitigate those risks. Human rights violations and corruption need to be prevented, while the socio-economic participation of the local population should be supported, following initiatives that define standards for economic participation and make the flow of money transparent. In addition, it is suggested to specify that compliance with due diligence and international labour safety standards is mandated for the whole value chain.

Socio-economic participation of the local population could be supported by guaranteeing a certain share of local workforce, establishing a local supply chain for technology, direct investments in R&D and local capacity building initiatives. Criteria for involvement of local actors, additional investment, and reduction of poverty, however, still need to be defined.

4.4 To be analysed further: Hydrogen leakage, water vapour, and its potential impacts on the atmosphere

Hydrogen produced by water electrolysis and renewable electricity offers an important alternative for energy supply that helps reducing fossil fuel emissions. However, the use of hydrogen may also lead to changes in the atmospheric composition. Researchers (Warwick et al 2022; Cooper et al 2022; Ocko & Hamburg 2022; Derwent et al 2020; Stevenson 2006) have raised the question of unintended side effects when leaked hydrogen, e.g., sequesters hydroxyl radicals that normally serve as chemical sinks for greenhouse gases like methane, prolonging their lifetime in the atmosphere and thus indirectly strengthening the greenhouse gas effect. Greenhouse gas potential of water vapor also increases if emitted to the stratosphere by hydrogen airplanes, where it has a much higher life span than near ground level.

While leaks and water vapor may currently only account for a small share, their relevance may increase if hydrogen use grows to higher dimensions in the coming decades. This could offset some of the gains obtained in a switch to hydrogen. The complexity and uncertainties that exist regarding these effects, including an assessment for hydrogen leakage, need to be addressed by further research.

5. Outlook: additional aspects for synthetic fuels based on hydrogen

Synthetic fuels based on hydrogen can substitute mineral oil or natural gas as a fuel or feedstock, which avoids investment in novel use technologies such as fuel cells, but needs further steps of refinery and carbon dioxide or nitrogen as common input material. But also with synfuels, the environmental footprint varies greatly depending on which process is employed, what feedstock and pollution controls are applied, and what the transportation distance and methods are for feedstock procurement and end-product distribution. In this chapter, we look at some additional sustainability aspects that should be considered specifically regarding hydrocarbons, assuming that green and sustainable hydrogen is being used. Existing and recommended options will be identified.

5.1 Sustainable CO_2 for hydrocarbons

Sources of CO_2 and measuring emission reductions

Carbon dioxide is needed as an input to produce derivatives from hydrogen and can originate from different sources. If fossil CO_2 is used that results from burning fossil fuels, the decarbonisation of the economy might be delayed, as an incentive to replace fossil fuels would be missing. Bracker (2017) and Jensterle (2019) therefore suggest that the required CO_2 should stem from biomass, biogas, or the atmosphere. Also Heinemann and Mendelevitch (2021) call to limit CO_2 sources for producing derivates of hydrogen to those sources that create a closed and short-term carbon-cycle with the atmosphere, and suggest only use CO_2 from Direct Air Capture or from waste streams from industrial processes based on sustainable biomass. However, GIZ/ILF/LBST (2021) acknowledge that DAC would be more flexible and could be located on non-arable land near geologic storage sites, but point to the big ecological footprint of DAC referring to the land surface needed.

According to the RED II, credits should not be granted for capturing CO_2, which has already been taken into account under other provisions of law. To this end, this kind of captured CO_2 should not be considered as being avoided when determining the emissions from the input's existing use or fate.

The electricity used for DAC must be fully renewable, and the emissions for the transport of biomass and of CO_2 between carbon capture location to the synfuel plant have to be considered, including infrastructure, transport modes and distances. They may reduce the emission reductions achieved.

5.2 Further feedstock supply

The reconversion to hydrogen into other energy carriers, such as ammonia, methanol or synthetic fuels, requiring other feedstock supply, notably nitrogen from air separation units, is also a relevant value chain element. The production of these feedstocks using green electricity and obeying other sustainability criteria should also be guaranteed and certified. Furthermore, leakages of hazardous substances are a risk to the biodiversity, soil, water, health and safety of the local population. In the case of ammonia, nitrogen pollution can lead to nitrogen accumulation which impacts plant species diversity (GIZ/ILF/LBST 2021). Regarding transport and delivery, safety precautionary measures to avoid such environmental damages have to be installed, just like for hydrogen. GIZ/ILF/LBST (2021) suggest to follow restrictions related to hazardous activities as stated, e.g., by ISCC.

5.3 The EU Taxonomy and hydrogen-based fuels

The EU taxonomy states under 3.10 Manufacture of hydrogen and hydrogen-based synthetic fuels, that the activity complies with the life-cycle GHG emissions savings requirement of "70% for hydrogen-based synthetic fuels" relative to a fossil fuel comparator of 94 gCO_{2e}/MJ in analogy to the approach set out in Article 25(2) of and Annex V to Directive (EU)2018/2001. No criteria for the origin of the CO_2 are defined. For the other environmental criteria, the same as for hydrogen production applies (see chapter 3.6).

6. Recommendations

In the EU, drafts of the delegated acts defining green hydrogen were published on May 23rd 2022, with consultation until June 17th. The strong discussions beforehand reflect that the regulatory processes are evolving in a fierce field of tension where a careful balance must be found to achieve a rapid, effective reduction in greenhouse gas emissions by a market ramp-up of green or low-carbon hydrogen, while securing sufficient amounts of renewable electricity, available at reasonable conditions and prices. This could pose an economic risk and end up in not being accepted by the industry or having to be heavily subsidised by the public sector.

However, the currently discussed EU regulation will have a significant effect on the definition and verification of green hydrogen not only in the transport sector, but in all sectors. This should be secured in the EU by expanding the certification to all sectors, which has been proposed for the amendment of the EU Directive to its next version, RED III.

Based on the analysis of general criteria and the EU certification system that is under development, we therefore suggest further development of hydrogen certification standards for realizing hydrogen production and use as well as its enabling regulatory framework in China and for international trade of these fuels. We particularly advocate a stronger expansion of certification criteria, especially in the areas of whole value chain assessment, additionality of renewable electricity and further sustainability aspects to be included.

Whole supply chain GHG emissions reduction

GHG emissions reductions need to be achieved for the full supply chain as the basis for the 'mitigation of climate change' indicator in the certification. The GHG emissions limit should be at least 50% lower than the next best fossil fuel, i.e. natural gas. The values suggested by the EU's RED-II of 3.4 $kgCO_{2eq}/kgH_2$ (equivalent to ca. 28 gCO_{2eq}/MJ_{H2}) or by Shibata et al. (2020) of 30 gCO_{2eq}/MJ_{H2} (equivalent to ca. 3.6 $kgCO_{2eq}/kgH_2$) would achieve this, and enable to still use both, green and blue hydrogen. However, it would be good to define pathways with declining emissions thresholds reaching zero by 2050 or earlier. And the system should also provide incentives to go below the maximum universal absolute threshold level sooner than its revisions in order to prevent lock-in effects.

Additionality of renewable electricity

The EU legislation aiming to ensure the additionality seems to be reasonable. However, we recommend to address in total 4 cases, adding two further (sub-)cases. Cases 1 and 2 seem fine as suggested: the direct connection between renewable energy production facility and hydrogen production facility in case 1 proves 100% green hydrogen if the electrolyser is directly connected to electricity generation from renewable energy and the corresponding power plant was explicitly built for the electrolysers. The grid connection of the hydrogen production facility in case 2 leads to shares of green hydrogen according to the renewable energy share in a Member States's electricity mix, provided that the renewable energy share is high.

For Case 3, the grid-connected hydrogen production facility needs to fulfill additionality criteria to be considered based on fully renewable electricity and hence producing 'green' hydrogen. Here, an economic link through a renewable power purchasing agreement (<36month old, 1h temporal correlation, renewable energy facility located in the same or neighbouring geographical bidding zones) proves that the installation of the renewable power generator is additional to baseline developments, and through measuring the load curves of both the generator and the hydrogen production plant, to demonstrate that the hydrogen production did not use more electricity than produced by the contracted generator. However, in more and more Member States the renewable energy shares are increasing towards 100%, requiring additional flexibility resources. Therefore, we suggest adding a subcase for hydrogen plant operators allowing the electricity system operator to use the electrolyser itself as a source of flexibility. We suggest to then allow longer periods of time for temporal correlation, up to 1 year, in return for this flexibility service.

Finally, an additional Case 4 is needed, allowing full additionality and 100% hydrogen when the grid-connected electrolyser is only working in time periods, in which the total renewable energy power generation exceeds the total load.

Incorporating sustainability criteria into certification systems

Facing the large scale of future hydrogen demand, it has been pointed out that hydrogen production may not only be a chance, but also imply risks of negative impacts on environmental, social or economic developments. This holds true especially for required imports from production sites outside the own country or union in connection with the ongoing climate crisis, with increasing heat waves and water stress. Negative effects on other environmental and social conditions aside from climate change mitigation have to be avoided. The green hydrogen economy therefore must be sustainable and equitable from the start and should be based on ambitious and clearly defined sustainability criteria, being integrated into a certification scheme that specifies, standardizes, and advances the implementation also of the following criteria: Certification, Priority of Local Supply, Water Supply, Conservation and Land tenure, Development, Free Prior and Informed Consent, Participation, and Good Governance (Heinrich Böll Foundation et al 2022). This will provide investment security for companies and a basis for a long-term recognition of imported hydrogen as a climate protection instrument. However, there is further need for research to define pragmatic ways of assessment.

Heinemann and Mendelevich (2021) see several options to use sustainability criteria for hydrogen imports, such as trade regulations, financing guidelines, technology support and standards, state procurement of hydrogen or voluntary labels. As next steps, they suggest to work towards a set of sustainability criteria at an international level, foster the uptake of certification systems for sustainable hydrogen and resolve open questions, set sustainability standards for seawater desalination, establish initiatives that set standards and monitor socio-economic effects, and close co-operations with possible exporting countries.

Table 4: Potential criteria for sustainable green hydrogen

	Electricity	Water	Land use	Socio-economics
Minimum standard	▪ Exclude Biomass and nuclear power plants ▪ If sourcing from direct connection to dedicated RES-E capacity: RES-E should be additional ▪ If sourcing from electricity grid: RES-E should be additional, temporal correlation to RES-E, Geographical correlation to RES-E	▪ Exclude surface and ground water in areas with regional water stress ▪ If sourcing from Sea Water Desalination (SWD): SWDs should be powered by RES-E, SWDs water supply need to be additional, Compliance with yet to be developed international environmental stanrads for brine disposal, monitoring	▪ Exclude protected areas ▪ Respect local (informal) land rights	▪ Comply with due diligence ▪ Secure human rights ▪ Prevent corruption and enable monitoring local economic participation (transparency initative)

		and securing existing water prices		
Support of sustainable development	▪ Additional RES-E capacity to decarbonise local energy system ▪ Provisions for additional (funds for) infrastructure: flexibility, grid	▪ Additional water production exceeding the needs for hydrogen production ▪ Improve existing water infrastructure	▪ Enable co-benefits for exapmple: Shading from “Agrivoltaics”, Local economic participation	▪ Capacity Building (R&D) ▪ Establishing and operating a local supply chain for technology ▪ Secure a share of local work force

Source: Own table based on Heinemann and Mendelevitch (2021)

Appendix

Detail on the definition of additionality for green hydrogen in RED II: Article 27 (3)

As a principle, RFNBOs are considered renewable when the hydrogen component is produced in an electrolyser that uses additional renewable electricity (RED-II Art 27 (3)). This renewable electricity may be supplied by an installation that is *directly connected* to the installation that produces RFNBOs, or may *come from the grid*. The increase in the production of renewable electricity corresponding to its use in electrolysis has to be ensured by including strict criteria for additionality in this methodology. RED II distinguishes the 3 cases of green hydrogen production presented in Table 2. The delegated acts define details for cases 1 and 3, particularly for temporal and geographical correlation.

Case 1: Rules for counting electricity sourced from directly connected installations as fully renewable

Hydrogen will be classified "100% green Hydrogen", if the electrolyser is directly connected to the electricity generation from renewable energy and the corresponding powerplant plant was explicitly built for the electrolysers. The delegated act details and concretizes to count electricity obtained from direct connection to an installation generating renewable electricity as fully renewable, if evidence is provided that

- the installations generating renewable electricity are connected to the installation producing RFNBOS via a direct line, or the RE electricity production and production of RFNBOs take place within the same installation
- the installation generating renewable electricity came into operation not earlier than 36 months before the installation producing RFNBOs. Where additional production capacity is added to an existing installation producing RFNBOs, the added capacity shall be considered to be part of the existing installation, provided that the capacity is added at the same site and the addition takes place no later than 24 months after the initial installation came into operation.
- the installation producing electricity is not connected to the grid, or the installation producing electricity is connected to the grid but a smart metering system that measures all electricity flows from the grid shows that no electricity has been taken from the grid to produce RFNBOs (Draft delegated Act, p.6).

Case 2: Rules for counting electricity taken from the grid as partially or fully renewable – Case based on average share of renewables

If the electricity used to produce RFNBOs is taken from the electricity grid and is not considered as fully renewable, the average carbon intensity of electricity consumed in the Member State where the fuel is produced should be applied, given that this best describes the GHG intensity of the whole process.

Fuel producers may count electricity taken from the grid as fully renewable if the installation producing the RFNBOs is located in a bidding zone, where the average proportion of renewable electricity exceeded 90% in the previous calendar year and the production of RFNBOs does not exceed a maximum number of hours set in relation to the proportion of renewable electricity in the bidding zone. This maximum number of hours shall be derived by multiplying the total number of hours in each calendar year by the share of renewable electricity reported for the bidding zone where the renewable hydrogen is produced.

Case 3: Rules for counting electricity taken from the grid as fully renewable – Case based on additionality criteria

In an environment where electricity generation still relies to a significant degree on fossil fuels and where the production of RFNBOs is likely to be subject of public support, the requirements for additionality and temporal and geographic correlation are particularly important. There must be an economic link to prove that the installation of the renewable power generator is additional to baseline developments. Electricity taken from the grid here can be counted fully renewable if fuel producers have concluded one or more renewables power purchase agreements (PPA) with economic operators producing renewable electricity in one or more installations generating RES-E for an amount that is at least equivalent to the amount of electricity that is claimed as fully renewable, and the electricity claimed is effectively produced in this or these installations, provided that the **following criteria** are met:

a) Additionality of the renewable power plant

According to the RED, a renewable energy power plant must come „into operation after, or at the same time as the installation producing the renewable liquid and gaseous transport fuels of non-biological origin“ (Art 27(3)) to ensure its additionality.

The installation generating renewable electricity came into operation not earlier than 36 months before the installation producing the RFNBOs.

Where an installation generating renewable electricity complied with the requirements set out in the first subparagraph under a renewable PPA with a fuel producer that has ended, it shall be considered to have come into operation at the same time as the installation producing the RFNBOs under a new renewable PPA.

Where additional production capacity is added to an existing installation producing RFNBOs, the added capacity shall be considered to have come into operation at the same time as the initial installation, provided that the capacity is added at the same site and the addition takes place no later than 36 months after the initial installation came into operation.

It is hoped that electrolysers will contribute to relief of the power grid, as they use electricity that otherwise might not have been used.

b) Temporal correlation: Matching of hydrogen production with power generation from PPA facilities

In order to ensure that the renewable hydrogen is produced from renewable electricity and can be certified as 100% green, the hydrogen must be verified to have been produced in the same calendar hour as the renewable electricity has been generated under the renewable PPA, or that renewable electricity that has been locally stored and charged during such time periods is used.

A third possibility is that hydrogen was produced during a one-hour period where the clearing price of electricity resulting from single day-ahead market coupling in the bidding zone, as defined in Art 39(2), is lower or equal to 20 EUR per MWh or lower than 0,36 times the price of an allowance to emit one tonne of CO_{2eq} during a specified period for the purpose of meeting the requirements of Directive 2003/87/EC (Draft delegated act, p.7).

These requirements will be valid from 2027 on. Before this year, the respective calendar day will be the attribution period.

c) Geographical correlation: RES-E facilities in the same or neighbouring bidding zones

For being certified as 100% green hydrogen, it must be verified that the renewable energy facilities were used in the same or neighbouring bidding zone. In detail it is required that the installation generating renewable electricity under the renewable power purchase agreement is located, or was located at the time when it came into operation, (i) in the same bidding zone as the electrolyser, or (ii) in a neighbouring bidding zone, and electricity prices in the relevant time period on the day-ahead market are equal or higher than in the bidding zone where the RFNBOs is produced. For geographical correlation, the installation generating renewable electricity under the renewable Power purchase agreement may also be located in an offshore bidding zone adjacent to the bidding zone where the electrolyser is located.

This requirement shall avoid the creation or aggravation of grid congestions in the electricity grid.

d) Curtailment: Consumption during an imbalance settlement during which power generating facilities using renewable energy were downward redispatched

As an exception, electricity taken from the grid that is used to produce RFNBOs may also be counted as fully renewable if the fuel producer demonstrates that the electricity used to produce RFNBOs is consumed during an imbalance settlement, during which it can be demonstrated that power-generating facilities using renewable energy sources were downward redispatched (as per Article 13 of Regulation (EU) 2019/943) and the electricity consumed for the production of RFNBOs is reducing the need for redispatching by a corresponding amount.

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