International Hydrogen Ramp-up Program – H2Uppp

Determining Embedded emissions under CBAM for three different hydrogen production pathways during the transitional period

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1 Introduction

1.1 What is the purpose of the document?

The aim of this document is to provide an overview of how emissions can be determined under the European Union's Carbon Border Adjustment Mechanism (CBAM) transitional phase for three different hydrogen production pathways by applying the CBAM methodology for emissions accounting. This document should serve as a learning exercise in preparation of the definitive period where a new methodology will be adopted. The new methodology is expected to be largely based on the methodology used during the transition phase. The CBAM Regulation provides for a series of implementing and delegated acts to be adopted which will clarify and harmonise key technical aspects of the CBAM, such as the calculation of embedded emissions (Article 7), adjustments of the CBAM obligation taking into account the carbon price effectively paid in the country of origin of the product (Article 9) and reflecting the EU ETS free allocation between 2026 and 2034 (Article 31). At the time of drafting this document, the European Commission was conducting several public consultations on these and other important aspects for a review of the CBAM.

1.2 What are CBAM objectives?

The European Union Carbon Border Adjustment Mechanism (CBAM) aims to support the goal of achieving climate neutrality by 2050 and will work alongside other measures in the "Fit for 55" package.[1] CBAM main goals include carbon leakage prevention, to complement, and reinforce the EU emissions trading system (EU-ETS), and to contribute to global decarbonization. The EU-CBAM also seeks to apply an equivalent carbon price on emissions of specific goods under CBAM scope produced in the EU and imported into the EU.

Carbon leakage occurs when carbon-intensive industries in the EU relocate their production to third countries with less stringent climate policies, thus undermining global decarbonization efforts. Existing measures to prevent carbon leakage, particularly the allocation of free emission allowances under the EU Emissions Trading System already exists. CBAM aims to gradually phase-out the EU-ETS free allowances, among others, to ensure that there is no double protection for EU producers.

CBAM will start addressing a specific number of products within six main sectors whose production is carbon intense and which are more prone to carbon leakage. These sectors are aluminium, iron and steel, cement, fertilisers, electricity, and hydrogen.

1.3 Implementation of CBAM

The implementation of the CBAM will unfold along two main phases, which have different characteristics and requirements as explained below:

Transitional phase (October 2023 – December 2025): This phase is deemed as a learning phase for all parties involved. During this phase CBAM will focus on monitoring and reporting, meaning that no certificate purchase will be required. CBAM quarterly reports outlining the quantities of goods imported under CBAM scope, the embedded emissions associated with these goods imported, as well as any carbon pricing due should be reported under the CBAM transitional registry.

From 1 January 2025 onwards, a new portal section of the CBAM transitional Registry will allow installation operators outside the EU to upload and share their installations and emissions data with reporting declarants. The registration for installation operators is open from 1 January 2025[2]. From the same date onwards, CBAM declarants will be able to apply for the "authorized CBAM declarant" status, via the CBAM Registry. In this case, the application will be processed by the National

[1] European Commission - Delivering the European Green Deal (Link)

[2] European Union External Action - CBAM Registry access is open for non-EU installation operators (Link)

Competent authority of the EU Member State where they are established. It is important to mention, that from 1 January 2026 (definitive regime) this status will become mandatory for the import of CBAM goods in the EU customs territory.[3]

During 2025 the European Commission will develop an extensive review of some of CBAM's main design elements, which might include an emission and a product scope extension.

The European Commission presented on 26 of February a new package of proposals to simplify EU rules. One of the measures includes simplifications of the carbon border adjustment mechanism (CBAM). Based on the experience gained during the transitional period, and continuous engagement and consultations with key partner countries in bilateral and multilateral settings, the European Commission proposed a set of measures to simplify key aspects of the CBAM Regulation that will benefit all stakeholders in third countries and the EU.[4]

Post transitional phase (2026 to 2034): from 1st January 2026, only authorized declarants will be able to import CBAM goods into the EU. They will have to buy and surrender CBAM certificates, corresponding to the embedded emissions in the imported goods. The price of the CBAM certificates will be based on the average weekly price of the ETS auctions.

2 Considerations for hydrogen

The CBAM mechanism includes specific considerations for the hydrogen sector. Some of these are explained in the following section in the form of and Q&A:

-Is hydrogen a complex[5] or a simple good?
Hydrogen is considered as a **simple good,** as there are no relevant precursors to be taken into account in the production process. Relevant precursors refer to those raw materials used in the production of complex CBAM goods that are CBAM goods themselves[6].

-What are the GHG emissions under scope?
The only greenhouse gas considered is **carbon dioxide.**

-What is hydrogen CN code[7]?
The code under this scope is 2804 10 000

-What is the emission scope during the transitional period?
During the transitional period, the emissions scope includes **direct[8] and indirect[9]** emissions.

-What is the emission scope during the definitive period?
During the definitive period, the scope will only include **direct emissions**. This will be subject to review at the end of the transitional period.

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[3] European Commission – Carbon Border Adjustment Mechanism (Link)

[4] European Commission 2025 - Staff Working Document Accompanying the document COM(2025) 87(link)

[5] Complex goods means that input material/raw materials/precursors to produce the complex good, are themselves under the scope of CBAM. Q62 - European Commission – Questions & Answers (Link)

[6] Example of a complex good is Portland Cement, since it uses cement clinker as a precursor, which is under the scope of CBAM itself. Q62 - European Commission – Questions & Answers (Link)

[7] CN states for Combined Nomenclature and is a **tool for classifying goods**, set up to meet the requirements both Common Customs Tariff and of the EU's **external trade statistics**. - European Commission -What is the Common Customs Tariff? (Link)

[8] Direct emissions cover the emissions generated during the production processes of CBAM goods, including from the production of heating and cooling, irrespective of the location of the production of the heating and cooling. This means that when the production of heating and cooling takes place outside the installations, the resulting emissions are counted as direct emissions. Q63 - European Commission – Questions & Answers (Link)

[9] Indirect emissions cover the production of electricity that is consumed during the production of CBAM goods. Q63 - European Commission – Questions & Answers (Link)

-What are the main elements that will define the monetary value of the CBAM financial adjustments during the definitive phase?

- quantity of imported hydrogen in tons,
- direct emissions of hydrogen production[10]
- Carbon price effectively paid.[11]
- Specific emissions covered by EU ETS free allocation.[12]
- % of CBAM phase in as CBAM will be progressively introduced.

-Who will be responsible for reporting?
The responsibility for reporting lies with the reporting declarant. The reporting declarant can be either:
The importer: who can act on its own or use a direct representative (if the importer is located in the EU). Or; the indirect customs representative if the importer is based outside the EU.

-Who will be responsible for the monitoring?
Although the reporting declarant will be responsible for reporting obligations under CBAM, they will rely in some cases on the monitoring of emissions carried out at the installation level. Operators may monitor emissions according to the CBAM methodology to facilitate the compliance obligations of the importer.

-How will reliability of data provided be ensured?
The European Commission, and EU member states will continuously monitor reported emissions and other information provided. During the definitive period, a verification system will be put in place and an accredited verifier will prepare a verification report. In case of non-compliance penalties could be imposed.

-Should emissions always be reported based on the application of the CBAM method during the definitive period?
Art. 7(7)(a) empowers the Commission to adopt implementing acts on the methodology to "specify the conditions under which it is deemed that actual emissions cannot be adequately
determined". In other words, default values could be used for reporting purposes just under certain conditions stablished by the European Commission. However, the proposed amendments to the CBAM Regulation as part of the Omnibus simplification package, propose that declarants would be allowed to freely choose between actual embedded emissions and default values with a mark-up.

-What is the CBAM Transitional Registry?
The CBAM Transitional Registry is a standardized and secured electronic database containing common data elements for reporting in the transitional period, and to provide for access, case handling and confidentiality.[13]

Table 1. Hydrogen key information under CBAM during the transitional phase.

	Type of good	**CN Code**	**Greenhouse gas**	**Emissions**
Hydrogen	Simple good	2804 10 000	Carbon dioxide	Direct & indirect

3 How to determine Direct and Indirect emissions

[10] During the definitive period will be only direct emissions, subject to review. Q39 - European Commission – Questions & Answers (Link)

[11] Carbon price effectively paid stands for the monetary amount paid in a third country, under a carbon emissions reduction scheme, in the form of a tax, levy or fee or in the form of allowance under a greenhouse gas emissions trading system (…) Q134 - European Commission – Questions & Answers (Link)

12 The CBAM obligation to be paid by importers will be reduced by the corresponding free allocation that an EU producer would receive for the production of the same goods. This will ensure that products produced in the EU and in third countries are treated equally. This adjustment for free allocation will include a definition of CBAM benchmarks, which in turn will be based on a combination of the EU ETS benchmarks.

[13] Q49 - European Commission – Questions & Answers (Link)

3.1 Monitoring approaches for direct emissions at the installation level during the transitional phase

For the performance of the monitoring in accordance with the CBAM methodology it is necessary to monitor direct emissions at the installation level. Direct emissions cover the emissions generated during the production processes of CBAM goods, including from the production of heating and cooling, irrespective of the location of the production of the heating and cooling. This means that when the production of heating and cooling takes place outside the installations, the resulting emissions are counted as direct emissions. [14]

There are different methods available for calculating direct emissions. One of them, which is used in the examples provided in section 3, is the calculation-based methodology. This method primarily relies on estimates and models and often uses emission factors to compute results. Another available method is the measurement-based methodology, which involves using data collected through sensors or monitoring devices to determine emissions. More detailed information about each methodology is provided in Table 2.

Table 2. Methods for the calculation of direct emissions

Calculation-based methodology		Measurement-based methodology
Standard method	Mass balance	Continuous emissions monitoring systems
-requires the quantity of all the fuels and input material -requires calculation factors such as net calorific value (NCV) and emission factor (EF)	determine carbon quantities of all fuels and input materials determine carbon quantities of output materials. Usually relevant when carbon remains on the product	continuous measurement of GHG concentration directly in the stack

3.1.1 Attribution of direct emissions

The CBAM Regulation builds on the principle of applying a top-down approach to calculating embedded emissions, starting from the installation level, and splitting those emissions such that they are attributed to different production processes (for which the system boundaries shall be defined), and thereafter to products, with further embedded emissions added for precursor materials. Below an explanation of the formula to be used for the calculation of direct emissions and a glossary explaining each of the terms that are part of the formula. Further information about the attribution of Direct emissions at installation level can be found on Section B, Annex III, of the Implementing Regulation[15] and for the standard method on section B.3.1.

$$AttrEm_{dir} = DirEm^{*} + Em_{H,import} - Em_{H,export} + WG_{corr,import} - WG_{corr,export} - Em_{el,prod}$$

Table 3. Glossary of terms for attribution of direct emissions

$AttrEm_{dir}$	attributed direct emission of the production process over the whole reporting period (tCO_2e)
$DirEm^{*}$	are the directly attributable emissions from the production process determined for the reporting period
$Em_{H,imp}$	are the emissions equivalent to the quantity of measurable heat imported to the production process

[14] Q63 - European Commission – Questions & Answers (Link)

[15] Section B, Annex III - European Commission – Implementing Regulation 2023/1773 (Link)

$Em_{H,exp}$	are the emissions equivalent to the quantity of measurable heat exported from the production process
$WG_{corr,imp}$	are the attributed direct emissions of a production process consuming waste gases imported from other production processes, corrected
$WG_{corr,exp}$	are the emissions equivalent to the quantity of waste gases exported from the production process, determined for the reporting period using the rules provided in Section B of Annex III to the Implementing Regulation.
$Em_{el,prod}$	are the emissions equivalent to the quantity of electricity produced within the boundaries of the production process, determined for the reporting period using the rules provided in Section D of Annex III to the Implementing Regulation.

Source: Guidance document on CBAM implementation for installation operators outside the EU– Link

Combustion emissions:[16]

The combustion emissions shall be calculated using the standard method as follows:

$$Em_i = AD_i x\ EF_i x\ OF_i$$

$$AD_i = FQ_i x\ NCV_i$$

$$OF = 1 - \frac{C_{ash}}{C_{total}}$$

The conservative assumption that OF = 1 may always be used to reduce monitoring efforts.

Table 4. Glossary of terms for combustion emissions standard method

Em_i	are the emissions [t CO_2] caused by fuel *i*
EF_i	is the emission factor [t CO_2/TJ] of fuel *i*
AD_i	is the activity data [TJ] of fuel *i*
FQ_i	is the fuel quantity consumed [t or m^3] of fuel *i*
NCV_i	is the net calorific value (lower heating value) [TJ/t or TJ/m^3] of fuel *i*
OF	is the oxidation factor (dimensionless) of fuel *i*
C_{ash}	is the carbon contained in ash and flue gas cleaning dust
C_{total}	is the total carbon contained in the fuel combusted.

Source: Implementing Regulation 2023/1773 – Link

3.2 Attribution of indirect emissions

Indirect emissions cover the production of electricity that is consumed during the production of CBAM goods, and it is calculated as the amount of electricity consumed multiplied with the applicable emission factor for electricity, as shown in the following formula:

$$AttrEm_{indir} = E_{el,cons} \times EF_{el}$$

Table 5. Glossary of terms for attribution of indirect emissions

$AttrEm_{indir}$	attributed indirect emission of the production process over the whole reporting period (tCO_2e)

[16] Section B.3.1.1, Annex II – European Commission – Implementing Regulation 2023/1773 (Link)

$E_{el,cons}$	electricity consumed expressed in MWh or TJ
EF_{el}	emissions factor for the electricity applied, expressed in tCO_2/MWh or tCO_2/TJ

Source: Implementing Regulation 2023/1773 – Link

For determining the emission factor of electricity (EF_{el}), the following possibilities exist[17]:

1) General case: the general rule for the determination of the emission factor is to use the default values:

- For the transitional period, the default emission factors for electricity are based in data from the International Energy Agency (IEA) covering a 5-year average. They are provided per country by the European Commission in the CBAM Transitional Registry.
- Other emission factors based on publicly available data (emission factor for electricity or the CO2 emission factor may be used).
  -

2) **Use of actual emission factors, in the case of:**

- direct technical link between the installation in which the imported good is produced and the electricity generation source, Or;
- the operator of the installation has concluded a power purchase agreement with a producer of electricity located in a third country for an amount of electricity that is equivalent to the amount for which the use of a specific [emission factor] value is claimed.

* Market-based specific emission factors, determined for example by Guarantees of Origin or Green Certificates cannot be used to justify the use of actual emission factors.

3.3 Specific embedded emissions

The specific embedded emissions indicate the amount of CO_2 emitted per unit of hydrogen produced (unit: tCO_2/unit). These are the emissions that should be reported by the reporting declarant. It should be kept in mind that during the transitional period both direct and indirect emissions should be calculated and reported. The specific embedded emissions results from the division of the total CO_2 emissions from hydrogen production by the total hydrogen production (normally in tones of hydrogen produced).

$$SEE_{g,dir} = \frac{AttrEm_{g,dir}}{AL_g}$$

$$SEE_{g,indir} = \frac{AttrEm_{g,indir}}{AL_g}$$

Table 6. Glossary of terms for specific embedded emissions for simple goods

$SEE_{g,dir}$	Specific embedded direct emissions
$SEE_{g,indir}$	Specific embedded indirect emissions
$AttrEm_{g,dir}$	attributed direct emission of the production process over the whole reporting period (tCO_2e)
$AttrEm_{g,indir}$	attributed indirect emission of the production process over the whole reporting period (tCO_2e)
AL_g	amount of goods produced

Source: Implementing Regulation 2023/1773 – Link

4 Renewable hydrogen (RFNBO)

[17] Q69 - European Commission – Questions & Answers (Link)

4.1 System boundaries of the production process

Renewable hydrogen is defined as hydrogen produced using renewable electricity through the process of electrolysis, which if compliant with the EU Renewable Energy Directive and Delegated Acts would fall under the categorization of RFNBO (Renewable Fuel of Non-Biological Origin).[18]

For this analysis, the elements considered within the system boundaries, and therefore included in the emissions calculation, are shown in Figure 1.

- **Inputs of the process are:** water and renewable electrical energy generated from solar panels,
- **Outputs of the process are:** hydrogen and oxygen, being the latter released to the atmosphere.

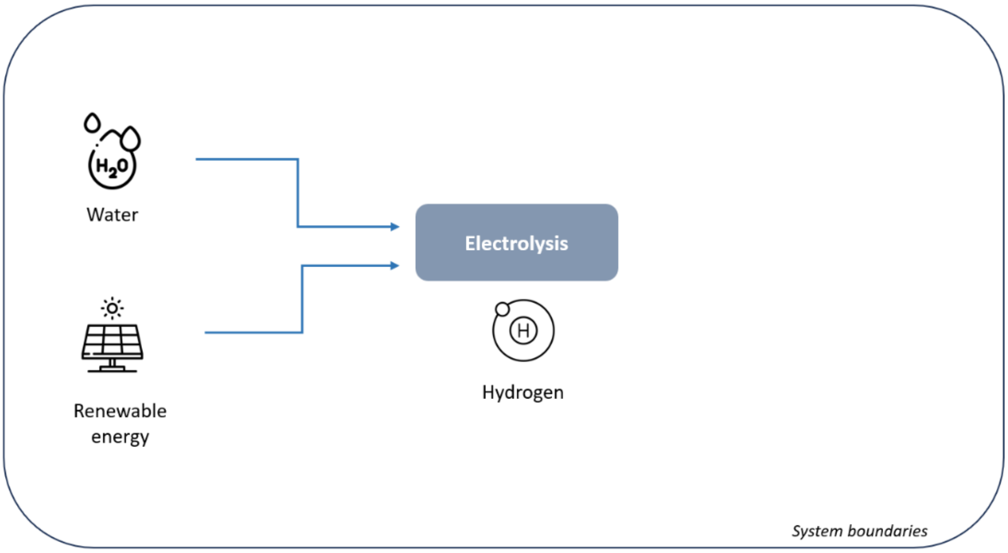

Figure 1. System boundaries of renewable hydrogen production. Source: own elaboration

4.2 Monitoring in general

For this specific example, we will consider the production of 50,000 tons of hydrogen (H_2) over the course of one year through electrolysis of renewable electricity as defined in the Renewable Energy Directive (~~RFNBO~~ RED). Given that the reporting period is quarterly, the production over each three-month period will amount to 12,500 tons of H_2. The electrical energy will come from solar energy. The oxygen produced in the process is released to the atmosphere[19]. The heat produced during the process will also be released to the atmosphere. For calculating the emissions, in this example we will use the **standard method**[20].

4.3 Direct emissions

[18] RFNBO renewable liquid and gaseous transport[4] fuels of non-biological origin means liquid or gaseous fuels which are used in the transport sector other than biofuels or biogas, the energy content of which is derived from renewable sources other than biomass RED II - European Commission – Directive 2018/2001 (Link)

[19] In case the oxygen is used in other production processes or is sold, then molar proportions are used to attribute emission. Section 3.6, Annex II – European Commission – Implementing Regulation 2023/1773 (Link) and Page 217 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link)

[20] Formula and parameters for the calculation standard method can be found under Section B.3.1, Annex II – European Commission – Implementing Regulation 2023/1773 (Link)

In the production of hydrogen through electrolysis, there are no waste gases other than the oxygen produced, which in this example is released to the atmosphere. Since the source of energy used is only electricity, there are no direct emissions involved or other streams to monitor. For reviewing formulas and variables, please refer to Section 1.4.1 of this document.

$$AttrEm_{dir} = DirEm^{*} + Em_{H,import} - Em_{H,export} + WG_{corr,import} - WG_{corr,export} - Em_{el,prod}$$

$$AttrEm_{dir} = 0$$

4.4 Indirect emissions

As mentioned before, the indirect emissions will only be relevant during the transitional period and reporting will not be required during the definitive period (this will still be subject to review at the end of the transitional period). Considering the electricity used comes from renewable sources in accordance with the Renewable Hydrogen Delegated Acts, and that the hydrogen is certified as RFNBO.[21], the emission factor EF_{el}, associated will be cero[22], and therefore, the indirect emissions will have a value of 0. For reviewing formulas and variables, please refer to Section 1.4.2 of this document.

$$AttrEm_{indir} = E_{el,cons} \times EF_{el}$$

$$AttrEm_{indir} = E_{el,cons} \times 0$$

$$AttrEm_{indir} = 0$$

4.5 Embedded emissions

Since there are no direct or indirect emissions in our example, then the embedded emissions will be also 0. This implies that in a hypothetical calculation of the CBAM certificates price, this will be also 0. For reviewing formulas and variables please refer to Section 1.4.3 of this document.

$$SEE_{g,dir} = \frac{AttrEm_{g,dir}}{AL_g} = \frac{0}{12{,}500} = 0$$

$$SEE_{g,indir} = \frac{AttrEm_{g,indir}}{AL_g} = \frac{0}{12{,}500} = 0$$

5 Hydrogen produced with natural gas through steam methane reforming with Carbon Capture and Storage

5.1 System boundaries

For this analysis, the elements considered within the system boundaries, and therefore included in the emissions calculation, are shown in Figure 2.

- **Inputs of the process are:** natural gas and electricity from the grid, are considered as inputs in the process.

[21] RED II - European Commission – Directive 2018/2001 (Link)

[22] Page 44 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link)

- **Outputs of the process are:** hydrogen and heat released to the atmosphere (meaning there is no export of heat to a different installation)

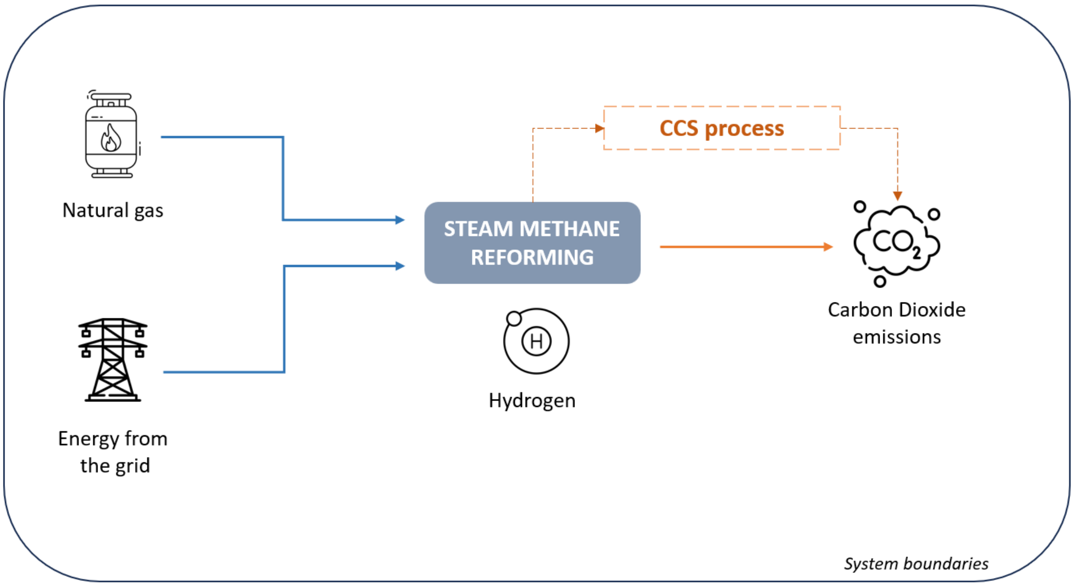

Figure 2. System boundaries of blue hydrogen production. Source: own elaboration

5.2 Monitoring in general

For this specific example, we will consider a hydrogen production plant using Steam Methane Reforming that produces 21,600 ton of hydrogen in three months. For this purpose, 65,664 tons of natural gas are needed[23]. Electricity consumption is 23,760[24] MWh, coming from grid electricity of a country with an emission factor of around: 0.278 tCO_2/MWh.[25] From the emissions derived from the production process, 60% is captured and will be transported for long term geological storage. Heat is released to the atmosphere, meaning, is not exported or used. For calculating the emissions, the **standard method will be used.**

In summary:
Time period: 3 months
Hydrogen production (SMR): 21,600 t
Natural gas consumption: 65,664 t
Electricity consumption: 23,760 MWh
CCS: 60% capture rate

The following inputs and outputs are the parameters used in the calculations:

Inputs of the process are:

Natural Gas

Natural Gas	
Net calorific value NCV (GJ/t)	**Emission factor (tCO_2/TJ)**

[23] The value used was 3.04 kg of natural gas for every 1 kg H_2 produced. – Table 5 - Budsberg et al. (2015) Ethanologens vs. acetogens: Environmental impacts of two ethanol fermentation pathways (Link)

[24] For this it was use the value of 1.1 kWh of electricity required to produced 1 kg of H_2 -Mehmeti et al. (2018) - LCA and Water Footprint of Hydrogen Production Methods from Conventional to Emerging Technologies – (Link)

25 The emission factor for electricity should be determined according to section 2.2. of this document. The value provided in this example has been chosen for explanatory purposes and does not represent a valid standard value.

48	56.1

Source: Annex VIII. Fuel emission factors related to net calorific values (NVC). EU 2023/1773

The Implementing Regulation EU 2023/1773 also provides information on how to determine the calculation factors, which can be found in further detail in Section B.5, Annex III[26]. To determine the calculation factors for the calculation-based methodology, one of the following methods may be chosen:

1. use of standard values.[27]
2. use of proxy data based on empirical correlations between the relevant calculation factor and other properties better accessible to measurement.[28]
3. use of values based on laboratory analysis.[29]

For the case of this example, we used 1) standard values

For the case of our example, we use standard values Type I, a) standard factors provided on Annex VIII Implementing Regulation 2023/1773

Electrical energy

Electrical Energy
Emission factor (tCO_2/MWh)
0.278

Source: Average emission factor from EU member states.

Outputs of the process are:

CO_2 captured

For this example, the SMR process has a capture of the carbon emissions with an efficiency rate of 60%. In order for the Carbon captured to be accepted for the deduction of the emissions, the following criteria should be met, based on the Section B.8.2 of Annex III in the Implementing Regulation.[30]

- The originating and receiving installations must both either be CBAM participants or in an 'eligible MRV system'[31]
- Receiving installations are for the purpose of CO_2 capture:
    - For storage or transport for long-term geological storage; or
    - To use CO_2 to produce products where the CO_2 used is permanently chemically bound. Which products are eligible will be defined in an implementing act under the EU ETS Directive (Article 12(3b)) which will also apply for the purpose of the CBAM.[32]

[26] Section B.5, Annex III – European Commission – Implementing Regulation 2023/1773 (Link)

[27] For further detail on standard values, check Section B.5.2, Annex III – European Commission – Implementing Regulation 2023/1773 (Link)

[28] For further detail on establishing correlations for determining proxy data, check Section B.5.3, Annex III – European Commission – Implementing Regulation 2023/1773 (Link)

[29] For further detail on requirements for laboratory analyses , check Section B.5.4, Annex III – European Commission – Implementing Regulation 2023/1773 (Link)

[30] Section 6.5.6.2 , Page 134 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link) or Section B.8.2, Annex III – European Commission – Implementing Regulation 2023/1773 (Link)

[31] Eligible MRV system: Eligible monitoring, reporting and verification system' means the monitoring, reporting and verification systems where the installation is established for the purpose of a carbon pricing scheme, or compulsory emission monitoring schemes, or an emission monitoring scheme at the installation which can include verification by an accredited verifier, in accordance with Article 4(2) of this Regulation. Section 6.5.3, Page 130 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link)

[32] CO_2 being chemically permanently bound, applies also to situation where the CO_2 is used for this purpose within the same installation. Currently no production process covered by the CBAM has been identified in the relevant legislation to allow considering CO2 to be considered chemically permanently bound. Section 6.5.6.2, Page 134 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link)

5.3 Direct emissions

For monitoring the direct emissions at installation level in this example we will again use the standard method. For this, we first calculate the combustion emissions, coming from the use of natural gas in the production process. For reviewing formulas and variables, please refer to Section 1.4.1 of this document or section B of Annex III in the Implementing Regulation.

$$Em_i = AD_i \; x \; EF_i x \; OF_i$$

$$AD_i = \; FQ_i x \; NCV_i$$

$$AD_i = \; 65{,}664 \; t \; x \; 48 \; \frac{GJ}{t} = 3{,}151{,}872 \; GJ = \; 3{,}151.872 \; TJ$$

$$Em_i = 3{,}151.872 \; TJ \; x \; 56.1 \; \frac{tCO_2}{TJ} \; x \; 1 = 176{,}820.019 \; tCO_2$$

$$AttrEm_{dir} = DirEm^*$$

$$AttrEm_{dir} = 176{,}820.019 \; tCO_2$$

Since the production of hydrogen includes a carbon capture storage technology with a 60% efficiency on capturing carbon, therefore the emissions will be:

$$Emissions \; captured = 176{,}820.019 \; tCO_2 x \; 0.6 = 106{,}092.012 \; tCO_2$$

$$AttrEm_{dir} = 176{,}820.019 \; tCO_2 - \; 106{,}092.012 \; tCO_2 = 70{,}728.00 \; tCO_2$$

5.4 Indirect emissions

As mentioned before, the indirect emissions will only be relevant during the transitional period and will not require to be reported during the definitive period (however this will still be under revision). Considering the electricity use comes from the grid with an emission factor EF_{el} = 0.278 tCO_2/MWh, and therefore, the indirect emissions will be calculated as follow (for further detail on formulas and variables, please refer to Section 1.4.2 of this document):

$$AttrEm_{indir} = \; E_{el,cons} \times \; EF_{el}$$

$$AttrEm_{indir} = \; 23{,}760 \; MWh \times \; 0.278 \frac{tCO_2}{MWh}$$

$$AttrEm_{indir} = 6{,}605.28 \; tCO_2$$

5.5 Embedded emissions

For the calculation of the embedded emissions, we use the total indirect and direct tCO_2 emissions produced and divide it on the amount of hydrogen produced in the same reporting period. For reviewing formulas and variables please refer to Section 1.4.3 of this document.

$$SEE_{g,dir} = \frac{AttrEm_{g,dir}}{AL_g} = \frac{70{,}728.00 \; tCO_2}{21{,}600 \; tH_2} = 3.274 \; \frac{tCO_2}{tH_2}$$

$$SEE_{g,indir} = \frac{AttrEm_{g,indir}}{AL_g} = \frac{6{,}605.28\ tCO_2}{21{,}600\ tH_2} = 0.3058\ \frac{tCO_2}{tH_2}$$

6 Electrolytic hydrogen

6.1 System boundaries

In this section we will refer to Electrolytic hydrogen as the hydrogen produced through electrolysis, using electricity from the grid.

For this analysis, the elements considered within the system boundaries, and therefore included in the emissions calculation, are shown in Figure 3.

- **Inputs of the process are:** water and electricity from the grid.
- **Outputs of the process are:** hydrogen and oxygen; the latter being released to the atmosphere.

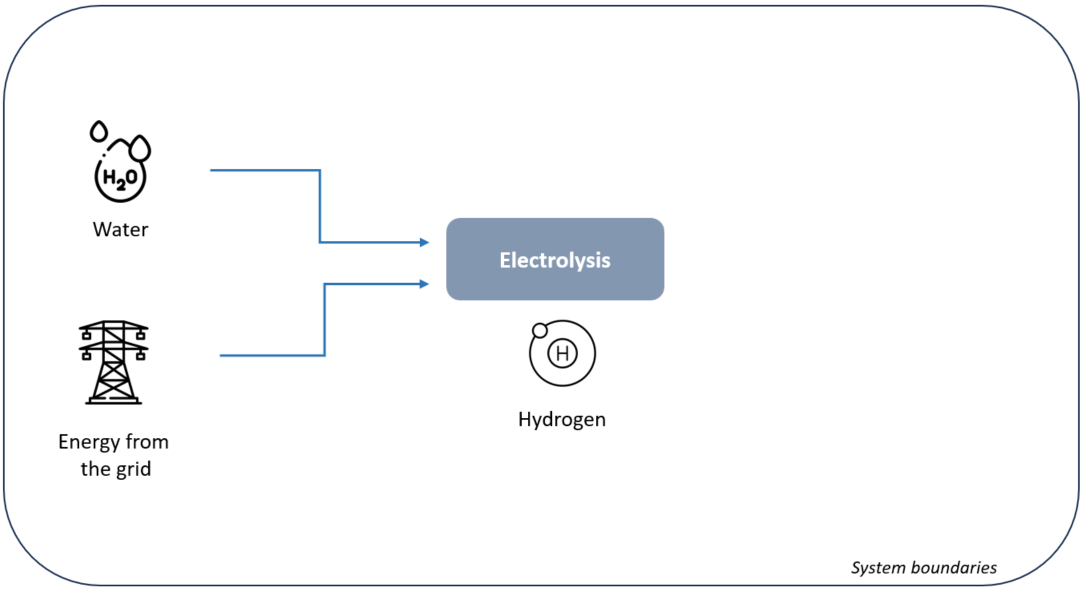

Figure 3. System boundaries of electrolytic hydrogen production. Source: own elaboration

6.2 Monitoring in general

For carrying out this example, we will consider the production of 50,000 tons of hydrogen (H_2) over the course of one year using electrolysis with a PEM electrolyser. Given that the reporting period is quarterly, the production over each three-month period will amount to 12,500 tons of H_2. The electricity consumed from the grid will be 682,500 MWh[33] f, with an emission factor of 0.278 tCO_2/MWh. The oxygen produced as part of the process is released to the atmosphere, meaning that is not exported to another installation.[34]. The heat released during the process will also be released to the atmosphere. For calculating the emissions, the **standard method** will be used.

[33] It was considered that a PEM requires 54.6 kWh to produce 1 kg of H_2 based on the paper. Table 1. Mehmeti et al. (2018) - LCA and Water Footprint of Hydrogen Production Methods from Conventional to Emerging Technologies – (Link)

[34] In case the oxygen is used in other production processes or is sold, then molar proportions are used to attribute emission. Section 3.6.2.2, Annex II – European Commission – Implementing Regulation 2023/1773 (Link) and Section 7.5.1.2, Page 217 - European Commission – Guidance document on CBAM Implementation for Installation Operators outside the EU (Link)

6.3 Direct emissions

To produce hydrogen through electrolysis, there are no waste gases produced other than oxygen, that is released to the atmosphere. Since the source of energy used is only electricity, there are no direct emissions to be monitored. For reviewing formulas and variables, please refer to Section 1.4.1 of this document.

$$AttrEm_{dir} = DirEm^{*} + Em_{H,import} - Em_{H,export} + WG_{corr,import} - WG_{corr,export} - Em_{el,prod}$$

$$AttrEm_{dir} = 0$$

6.4 Indirect emissions

As mentioned before, the indirect emissions will only be relevant during the transitional period (however this will still be under revision). Considering the electricity used comes from a grid with an emission factor EF_{el} = 0.278 tCO_2/MWh, the indirect emissions will be calculated as follow (for further detail on formulas and variables, please refer to Section 1.4.2 of this document):

Electrical energy

Electrical Energy
Emission factor (tCO_2/MWh)
0.278

Source: Average emission factor from EU member states.

$$AttrEm_{indir} = E_{el,cons} \times EF_{el}$$

$$AttrEm_{indir} = 682{,}500\ MWh \times 0.278\ \frac{tCO2}{MWh} = 189{,}735\ tCO2$$

6.5 Embedded emissions

For reviewing formulas and variables please refer to Section 1.4.3 of this document.

$$SEE_{g,dir} = \frac{AttrEm_{g,dir}}{AL_g} = \frac{0}{12{,}500} = 0$$

$$SEE_{g,indir} = \frac{AttrEm_{g,indir}}{AL_g} = \frac{189{,}735\ tCO2}{12{,}500\ tH_2} = 15.178\ \frac{tCO_2}{tH_2}$$

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