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EXPLAINING THE NEW EU CARBON BORDER ADJUSTMENT MECHANISM (CBAM)

Implications for PtX imports to the EU

IMPRINT

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Berlin, December 2023

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Summary

The European Union is committed to reducing their economy-wide net greenhouse gas emissions by at least 55 % compared to 1990 level by 2030. The EU Emissions Trading Scheme (EU ETS 1) delivers harmonised pricing of greenhouse gas emissions for energy-intensive sectors in EU Member States, Norway, Iceland, and Liechtenstein. The price signal has been weakened by the current measures to avoid carbon leakage, i.e. the relocation of production to third countries for reasons of costs related to EU climate policies. The carbon border adjustment mechanism (CBAM) seeks to replace those measures.

The CBAM shall ensure that imported goods into the EU and goods produced within the EU face the same cost of carbon. Producers of goods with lower specific emissions have an advantage over producers causing more emissions in the production process. Operators within the EU report yearly the emissions of their installations since the introduction of the EU ETS 1 in 2005. Starting now, importers must report the emissions related to the production of the imported goods (embedded emissions) upon importation. EU producers already now need to surrender EU allowances to offset their emissions; they can buy the allowances at auctions or from other market participants and receive some allowances for free. Importers will from 2026 onwards need to surrender CBAM allowances to offset embedded emissions in imported goods, too. As long as EU producers receive free allocation, only part of the embedded emissions need to be offset by importers, too. The surrendering obligation is reduced to reflect the carbon price effectively paid in the country of origin, if applicable.

The CBAM covers only goods from certain sectors. Hydrogen, ammonia, and green steel are PtX products covered by the CBAM regulation, e-fuels are not. Importers of CBAM products must report on the emissions associated to the production of those goods. The first reports are due by 31 January 2024 covering the last quarter of the year 2023. The importers rely on information provided by the producers of the good.

As the CBAM is a new instrument and requires monitoring and reporting data from operators not covered by the EU ETS 1 so far, it starts with a transitional phase up to the end of 2025. In this phase, simplified monitoring rules apply; external verification is suspended and no CBAM allowances must be surrendered. From 2026 onwards, the surrendering requirement will be introduced gradually while the free allocation to EU producers will be reduced at the same pace. This is to ensure that goods produced in the EU are in no case treated more favourable compared to goods imported into the EU.

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The EU ETS 1 reform under increased EU climate ambition

In 2020, the EU significantly increased its climate ambition, adopting a target to reduce its greenhouse gas (GHG) emissions by 55% (instead of previously 40%) by 2030. In order to reach this enhanced target, the European Commission proposed a systematic overhaul of the EU's climate and energy policies called the 'Fit for 55 package'. It consists of new legislation and of amendments sharpening existing EU legislation. [1] These include the strengthening of the EU emissions trading scheme (EU ETS 1) and the introduction of a carbon border adjustment mechanism (CBAM) for certain goods regulated under EU ETS 1. A new EU emissions trading system for building and road transport fuels (EU ETS 2) was introduced to drive emission reductions in these sectors. It is accompanied by the Social Climate Fund to provide support for citizens affected or in danger of facing energy or mobility poverty. Furthermore, several existing policies foresee a higher carbon emission reduction targets: the Effort Sharing Regulation on Member States' GHG emission targets, regulation on Land Use, Forestry and Agriculture (LULUCF), CO_2 emission standards for cars and vans, the energy efficiency directive and the Renewable Energy Directive. The alternative fuels infrastructure regulation (AFIR) was introduced jointly with policies for the uptake of alternative fuels in the maritime and aviation sector (Fuel EU Maritime Regulation and ReFuel EU Aviation Regulation). The proposed Energy Taxation Directive is still under negotiations.

The EU ETS 1 is a cornerstone of EU climate policy since its introduction in 2005.[2] It sets a limit for emissions, the cap, that is reduced annually. It covers over 10 000 installations generating electricity and manufacturing industrial goods as well as emissions from flights between participating countries. To make sure that emissions do not surpass the emissions limit, installation operators report their emissions every year and surrender corresponding emission allowances (certificates) to offset the reported emissions. By surrendering allowances, the participants compensate for their emissions. They buy these allowances at auctions organized by Member States. Operators of industrial installations also receive some allowances for free based on benchmarks. Operators can freely trade the allowances. The total amount of emissions is limited by the cap, and declines over time. This creates a carbon price and incentivizes emission reductions.

Over the years, the scheme has grown in coverage of sectors and gases: to date, it regulates electricity and heat generation, oil refineries, the production of iron and steel, aluminum, metals, cement, lime glass, ceramic, pulp, paper, cardboards acids and bulk organic chemicals. Moreover, it covers aviation emissions within and between participating countries and, from 2024 onwards, maritime transport emissions. The EU ETS regulates CO_2 emissions from all these activities, nitrous oxide emissions (N_2O) from the production of nitric, adipic and glyoxylic acids as well as glyoxal and perfluorocarbon emissions (PFCs) from the production of aluminum. In total, the EU ETS 1 covers about 40% of the EU's greenhouse gas emissions.[3]

[1] All but two of these regulations are adopted, the Renewable Energy Directive and ReFuel EU Aviation Regulation are provisionally agreed, the final vote is pending. Source: Fit for 55: Delivering on the proposals (europa.eu) accessed on 27th August 2023.
[2] Directive 2003/87/EC as amended by EU (2023c).
[3] EU Emissions Trading System (EU ETS) (europa.eu), accessed on 27th August 2023.

Development of the CO_2 price since 2013

Figure 1: Based on closing prices at primary auctions of EU allowances (EUAs) (EEX 2023)

In the past, the carbon prices have been rather low as there was a surplus of allowances in the market. Policy makers have reacted with several reforms which demonstrated the political will to make the policy instrument work and have first stabilized and then boosted price levels. Currently, one ton of CO_{2e} has a price of about 85 Euro.[4] The revision of the EU ETS 1 adopted in 2023 doubles the "linear reduction factor", i.e. the pace at which the emission cap is reduced every year, from 2.2% yearly to 4.3% yearly starting in 2024 and 4.4% yearly from 2028 onwards. All other things being equal, this will lead to an increase of emission prices in the EU ETS. This reform reinforced the concern that, in a world with different levels of climate ambition and carbon prices, EU policies may cause emission intensive production to shift to countries with or without lower carbon prices, leading to an increase of emissions abroad (carbon leakage), and to a loss of economic activities in the EU. In the long-term, this would jeopardise the political acceptance for climate action in the EU.

The goal of the CBAM is to mitigate carbon leakage by ensuring that emission intensive goods sold in the EU market face the same carbon price regardless whether they have been produced in the EU or elsewhere. To achieve this, the CBAM imposes a carbon price to certain imported goods. In the past, the industry sectors deemed at risk of carbon leakage have received a certain amount of EU ETS allowances for free. To ensure a level playing field, the CBAM will be gradually introduced, replacing the free allocation to sectors producing those goods in the EU.

[4] The average price in 2023 of EU emissions allowance auctions at the EEX was 86.46 Euro (includes values up to the 11th of December) (EEX 2023), accessed on 12 December 2023.

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The Carbon Border Adjustment Mechanism

The CBAM aims to strengthen climate action by including imported goods into carbon pricing and thus give goods with a lower carbon footprint an advantage over goods associated with high emissions. The CBAM shall ensure that the same carbon price is paid for goods within the EU irrespective whether they are produced in the EU and thus covered by the EU ETS 1 or abroad.[5] Importers report on the emissions occurring when the good is produced (embedded emissions) and surrender CBAM certificates sold at the average price of EU allowances. If producers pay a carbon price in third countries, the surrendering obligation is reduced to reflect the price effectively paid. The obligation to surrender allowances starts in 2026 and increases over time, from 2034 onwards the embedded emissions have to be covered entirely.

Overview of actors in the CBAM

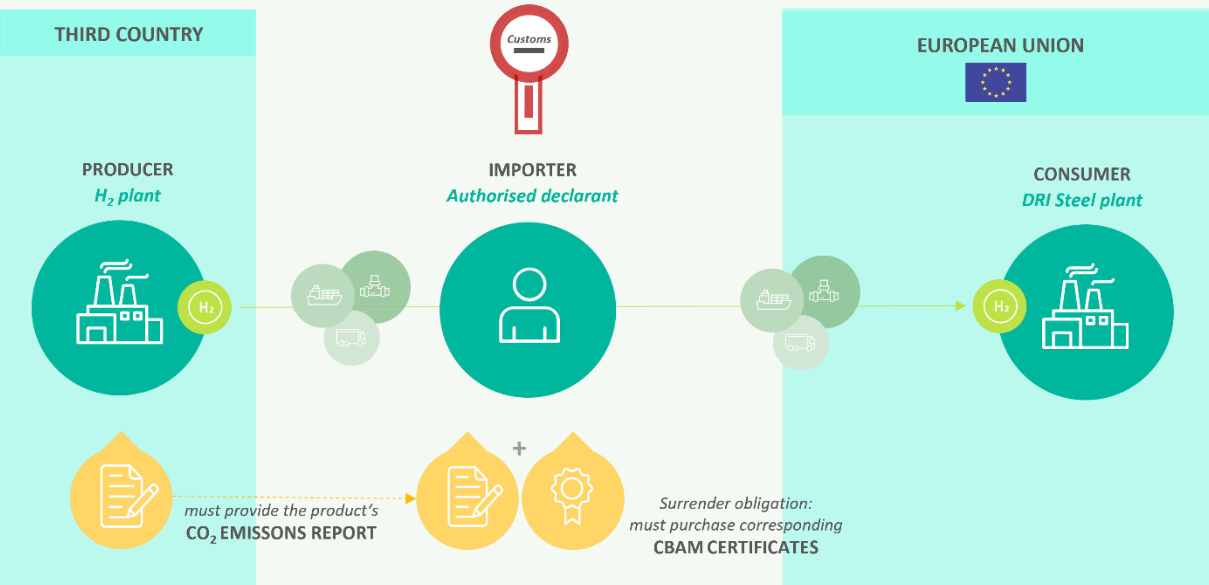

Figure 2: Illustration by Öko-Institut

Coverage

Starting in October 2023, the CBAM applies to selected basic materials and basic material products in the following sectors namely **cement, iron and steel, aluminium, fertilisers, hydrogen and electricity**.[6] PtX products covered by CBAM include hydrogen, ammonia – belonging to fertilisers - and DRI steel produced with hydrogen.[7] Other PtX products as well as their fossil counterparts such as kerosene/e-kerosene or methane are not covered by the CBAM regulation to date, but might be included in the future.

[5] Three non-EU countries (Iceland, Liechtenstein and Norway) participate in the EU ETS. Therefore, the CBAM provisions do not apply to them. The same is valid for Switzerland, which has struck an agreement with the EU fully linking its ETS to the EU ETS 1. Refer to Annex III CBAM regulation (2023).

[6] Throughout the paper we refer to the basic materials and basic material products as goods. For a concise summary of the CBAM regulation compare UBA - Umweltbundesamt (2023)

[7] The following codes in the statistical system “Combined nomenclature” are covered by the CBAM: CN code 2804 10 00 Hydrogen and CN code 2814 – Ammonia, anhydrous or in aqueous solution. Refer to the Annex I of the regulation CBAM regulation (2023).

Currently the CBAM covers only certain sectors regulated by the EU ETS. Organic chemicals and refinery products are not included due to technical limitations: as they are mostly produced in integrated processes with different chemicals/fuels as output, the allocation of embedded emissions on individual goods could not be set unambiguously at the time of passing the legislation.[8] The Commission shall conduct a review in 2026 based on the data collected during the first years of implementation. The Commission shall assess the possibility to extend the scope to include goods from further sectors and to broaden the coverage of embedded emissions of goods already covered to indirect emissions from electricity generation for all goods, embedded emissions from the transport of goods and further input materials (called precursors in the CBAM terminology) (Art. 30 CBAM regulation 2023).

The CBAM regulates emissions directly related to the production process (direct embedded emissions) for all goods covered. To treat integrated production sites and installations specialising on a certain production step equally, embedded emissions for certain input materials (precursors) are covered, too.[9]

Indirect emissions included in electricity used to produce the goods are currently only covered for goods from the cement and fertiliser sectors.[10] To treat imported goods equally to products produced within the EU indirect emissions are not taken into account initially for goods from the other sectors. EU Member States may currently compensate producers of goods from those sectors for the indirect carbon cost incurred by the EU ETS 1 included in electricity consumption.[11] The CBAM regulation stipulates that the "inclusion of indirect emissions would further enhance the environmental effectiveness of the CBAM and its ambition to contribute to fighting climate change" and that data should be collected to further specify the methodology for the calculation of indirect emissions.[12] Indirect emissions related to hydrogen production are to be reported during the transitional period additional and not during the definitive period unless the regulation is changed.[13]

Goods stemming from countries participating in the EU ETS 1 or linked to it are excluded from the application of the CBAM. The regulation includes an option to exclude further countries based on agreements and if the carbon price paid in those countries is effectively charged and comparable to the EU ETS 1.

Roles and responsibilities

Importers or their representatives have to register as 'authorised declarants' to be allowed to import CBAM goods. They submit a CBAM report every three months. The report includes (Art. 35 (2) CBAM regulation 2023):

- the amount of CBAM goods imported (expressed in tonnes for goods and megawatt hours for electricity);
- the total embedded emissions per ton/MWh;
- evidence on the carbon price paid abroad (if applicable);
- the number of CBAM certificates to be surrendered;
- copies of verification reports on the emissions reported issued by accredited verifiers.

The producers of the goods set up a monitoring plan and report on the embedded emissions of their products following the corresponding reporting rules. The producers´ information feeds into the report by the importer. The reports are verified by accredited verifiers.

The importers are required to purchase CBAM certificates and surrender them via the CBAM registry. CBAM certificates will be sold at the average price of an

[8] Recitals 33 to 35 CBAM regulation (2023).
[9] The implementing regulation CBAM implementing regulation (2023) specifies the relevant precursors. These are for example cement clinker and calcined clay for the production of cement. Separately produced hydrogen is a precursor when used in the production of ammonia, pig iron or directly reduced iron. Ammonia is considered a precursor as input to the production of nitric acid, urea and fertilisers.
[10] The CBAM regulation defines indirect emissions as "emissions from the production of electricity which is consumed during the production processes of goods, irrespective of the location of the production of the consumed electricity." (Article 3(34), CBAM regulation (2023))
[11] Refer to the Annex 1 of the guidelines on certain State aid measures in the context of the system for greenhouse gas emission allowance trading, EC 2020
[12] Refer to recital 19, CBAM regulation (2023).
[13] See guidance document on CBAM implementation: (European Commission 2023), Footnote 33, page 37.

EU ETS allowance in the preceding week via a common central platform managed by the EU Commission.

Transitional period (2023-2025)

The introduction of the CBAM starts with a learning phase. In the transitional period running until the end of 2025, monitoring and reporting rules are simplified, no verification is required, and importers do not have to surrender CBAM certificates. The first report due by the end of January 2024 has to cover the period from October to December 2023.

Based on the experience in the transitional phase, rules are improved and refined and the inclusion of further goods and/or indirect emissions are considered.

Definite period

Starting in 2026, importers have to purchase CBAM certificates to offset embedded emissions in imported goods. The surrendering obligation is calculated based upon:

- the relevant embedded emissions;
- the carbon price paid abroad;
- adjustment to reflect free allocation within the EU.

At the beginning the surrendering obligation is rather small, its share increases until 2034 when the full surrendering obligation applies. For imports in the year 2026, CBAM certificates corresponding to 2.5% of embedded emissions have to be surrendered. The figure below shows the increasing surrendering requirement reflecting the declining free allocation.

Share of CBAM surrendering obligation (2023-2034)

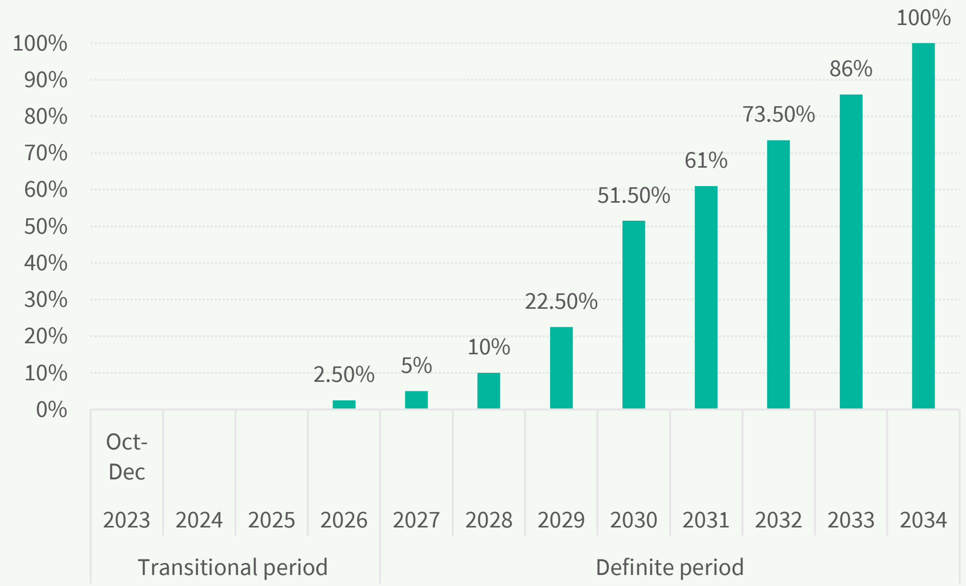

Figure 3: Based on Art. 10a (3) of the EU ETS directive EU 2023c

The figure below illustrates the situation for producers both in third countries and in the European Union. If we imagine a producer of ammonia situated in the EU, she/he reports the emissions caused by the production of ammonia. The emissions will vary based on the technology and the efficiency of the installation. The EU producer will receive some allowances for free (free allocation), but typically not enough to offset all emissions. The producer will purchase additional allowances at auctions or from other market participants. The number of allowances the producer needs to purchase increases over time as the free allocation decreases. In 2025 the EU producer receives a free allocation of 1,570 t CO_2e per ton of ammonia based on the corresponding benchmark (EC 2021). The benchmark is based on the most efficient EU installations, less efficient installations will have to buy additional EU allowances on top of free allocation.

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In 2026 the EU producer will receive 97.5% of the ammonia benchmark for free and even installations producing as efficiently as the benchmark will have to buy allowances to offset the missing 2.5% of their emissions. By 2030, EU producers will have to buy allowances to offset 51.5% of their emissions. In the year 2034, the EU producer finally has to offset his production emissions entirely.

A producer of ammonia situated in a third country outside of the EU selling the ammonia to EU costumers reports the emissions related to the production of ammonia (embedded emissions) upon importation.

From 2026 onwards, the importer has to buy CBAM certificates to offset a share of embedded emissions. At the beginning only a small share of embedded emissions needs to be offset: 2.5% in 2026. The number of CBAM certificates to be surrendered increases over time at the same pace as free allocation for EU producers is decreasing: 51.5% in 2030 and 100% from 2034 onwards. If a carbon price applies in the third country, the importer has to buy less CBAM certificates – in the example of our graph we assume that the carbon price in the third country is lower than the EU ETS price and thus reduces the offsetting obligation partially.

Overview of the share of emissions to be offset by CBAM certificates by importers compared to EU producers in different years

Figure 4: Illustration by Öko-Institut

Calculation of embedded emissions for PtX products

The CBAM regulation empowers the EU Commission to adopt an implementing regulation specifying the rules to calculate embedded emissions. The implementing regulation for the transitional period was published on 17 August 2023, accompanied by guidance documents and summarized in this chapter.[14] The European Commission provides up-to date information, guidance materials and presentations on a dedicated website: Carbon Border Adjustment Mechanism (europa.eu). The rules are expected to be improved and refined for the definite period starting from 2026.

The producer may choose to report **direct emissions** either based on a "calculation approach" using fuels and material inputs and corresponding calculation factors such as emission factors, or the "measurement-based approach" measuring the concentration of greenhouse gases and the flow of fuel gas. In the EU ETS, producers report predominantly based on the calculation approach, measurement approaches are found in large installations and for non-CO_2 gases.[15] For the period up to 31 December 2024, producers may apply other methods for emission monitoring if they lead to a similar emission coverage and accuracy. This might be based on a carbon pricing scheme or a compulsory emission monitoring scheme where the installation is located or an emission monitoring scheme which can include verification by an accredited verifier. Furthermore, up to 31 July 2024 also default emission values per good can be used.

Indirect emissions occurring during the generation of electricity consumed in the production process are calculated based on the electricity consumed and the relevant emission factor. The emission factor depends on whether the electricity comes from the grid, is generated within the installation itself or by a specific installation under a power purchase agreement (PPA).

If **relevant precursor materials** are used during production their embedded emissions are reported as well, in order to treat installations specialising on a certain production step equally to integrated installations. If hydrogen is produced in one installation and then transferred to a second installation producing steel by direct reduction or producing ammonia, the hydrogen is considered a precursor and its embedded emissions have to be included in the emission report.

Table 1: Overview of obligations for importers of PtX products from CBAM

	Transitional period (2023-2025)			Definite period (2026-…)		
	Direct emissions	**Indirect emission**	**Precursor emissions**	**Direct emissions**	**Indirect emissions**	**Precursor emissions**
Hydrogen	MR	MR		MRV CBAM certificates	*	
Ammonia	MR	MR	MR	MRV CBAM certificates	MRV CBAM certificates	MRV CBAM certificates
Steel	MR	MR	MR	MRV CBAM certificates	MRV CBAM certificates	MRV CBAM certificates

Notes: MR – monitoring and reporting, MRV – monitoring, reporting and verification; CBAM certificates – obligation to purchase CBAM certificates to offset emissions
* The CBAM regulation in its current form does not include indirect emissions from the production of hydrogen from 2026 onwards, but this may change with the review of the regulation.
Source: Table by Öko-Institut based on CBAM regulation

[14] https://taxation-customs.ec.europa.eu/news/commission-adopts-detailed-reporting-rules-carbon-border-adjustment-mechanisms-transitional-phase-2023-08-17_en, accessed August 27, 2003.
[15] Refer to chapter 6.1.3. CEMS in DG CLIMA (2023).

The calculation of embedded emissions for hydrogen

The implementing regulation specifies that only pure hydrogen or mixtures of hydrogen with nitrogen usable in ammonia production are covered (Annex II, 3.6.1).[16] The CBAM currently covers solely direct CO_2 emissions for hydrogen. In the transitional period, additionally, indirect emissions related to the consumption of electricity are to be reported separately.

The CBAM reports include the amount of hydrogen imported and specify the producing installation as well as the production route. The importer gathers the information on embedded emissions from the producer. For each production route the monitoring rules are specified. These include:

- the system boundaries (what is covered),
- the relevant input factors such as fuels or precursors and,
- emission factors for combustion and process emissions.

In the case of hydrogen, the following production routes are distinguished (CBAM implementing regulation 2023, Annex II, 3.6.2):

- Steam reforming
- Partial oxidation
- Electrolysis of water
- Chlor-Alkali electrolysis and production of chlorate

To calculate **direct emissions**, all processes occurring in the installation directly or indirectly linked to hydrogen production and all fuels used in the production of hydrogen irrespective of their energetic or non-energetic use are covered. Fuels include typically natural gas for the steam reforming production route and heavy feedstocks, for example residual heavy oils or coal, in the partial oxidation route. Also, the process materials used for fuel gas cleaning are to be included in the calculation of direct emissions. If the emissions are captured and sequestrated, the embedded direct emissions will reflect this (stored CO_2 is deducted from the emissions if the storage site follow CBAM monitoring rules). Please note that in the transitional period other methods can be used, too.[17]

Indirect emissions are most relevant if hydrogen is produced through electrolysis, but also in the other production routes electricity consumption may occur and shall be included in the reporting in the transitional period. Indirect emissions are equivalent to the emissions caused by the production of the consumed electricity. The amount of electricity consumed is multiplied with the applicable emission factor for electricity.

Generally, for indirect emissions default national emission factors for electricity provided by the European Commission are to be used. These factors are based on IEA data and includes fossil generation. Unless the national electricity factor is zero, producers of green hydrogen from renewable energy might want to report specific electricity emissions factors instead. Under the following conditions specific emissions from a power plant or renewable electricity source can be reported:

- if there is a direct technical link (electricity cable) between the electricity generation source and the installations producing hydrogen; or
- if the producer has a power purchase agreement with an electricity generator.

If the produced hydrogen is certified to comply with Commission Delegated Regulations (EU) 2023/1184 (EU 2023a), an emission factor of zero for the electricity may be used. The certification is necessary if producers wish to export the hydrogen as "renewable hydrogen" to the EU.[18]

[16] "Not covered are the production of synthesis gas or of hydrogen within refineries or organic chemical installations, where hydrogen is exclusively used within those plants and not used for the production of goods listed in Annex I to Regulation (EU) 2023/956." CBAM implementing regulation (2023), Annex II, 3.6.1.

[17] See information in the preceding section and in Section 6.9 in the Guidance document: European Commission 2023

[18] A detailed explanation of EU requirements for renewable hydrogen can be found in (PtX-Hub 2023).

When electricity from power plants or CHP plants using fossil fuels is consumed, the emission of the electricity is determined based on the CBAM monitoring rules.[19] **If hydrogen is produced simultaneously to other products**, e.g., oxygen from the electrolysis of water is collected or chlorine and sodium hydroxide are produced along with hydrogen using the chlor-alkali electrolysis the embedded emissions are attributed to the various products based on molar proportion of the various products.[20]

The calculation of embedded emissions for ammonia

The calculation of embedded emissions for ammonia follows the same principles. Ammonia is synthesized from nitrogen and hydrogen via the Haber-Bosch-Process. All fuels directly or indirectly linked to ammonia production and materials used for fuel gas cleaning as well as indirect emissions attributed to the consumption of electricity shall be monitored. Indirect emissions are calculated as described above.

If separately produced hydrogen is used in the ammonia production process it is treated as a **precursor**. This means that embedded emissions of the used hydrogen are to be added to the emission calculation. Ammonia in turn is a precursor to the production of nitric acid, urea and mixed fertilisers.

[19] Refer to the CBAM implementing regulation, Annex III, Section C on heat flows, D on electricity and Annex IX on efficiency reference values for separate production of electricity and heat in CBAM implementing regulation (2023) Furthermore the guidance document presents the rules for electrical energy and its emissions in chapter 6.7.3. as well as the rules for combined heat and power in chapter 6.7.4., (European Commission 2023).
[20] Implementing regulation CBAM implementing regulation (2023), Annex II, Section 3.6. This allocation approach differs to the one in the Delegated Regulation 2023/1185; in the latter the allocation is based on the economic value of the by-products (refer to Annex, A. 15 (f) EU (2023b))

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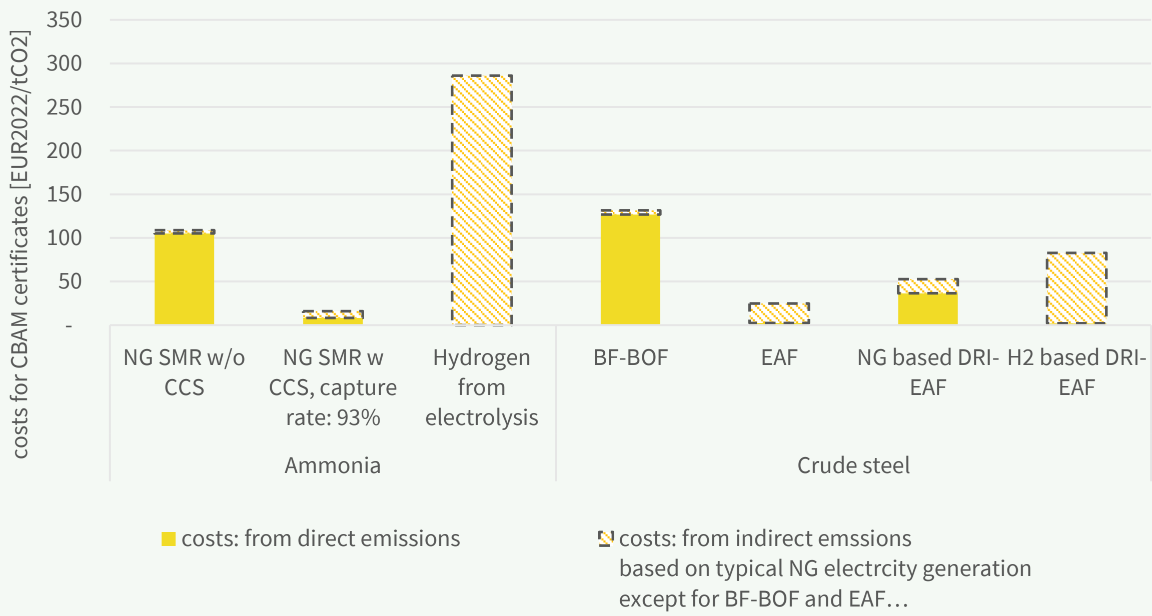
Exemplary calculation of mark-up on imported ammonia and crude steel induced by CBAM

In the starting years of the CBAM, emissions related to certain PtX products are reported but no CBAM certificates have to be purchased. However, this changes in 2026, when the obligation to purchase CBAM certificates to offset part of the embedded emissions is phased in. The cost for CBAM offsets depends on the following:

- the emission intensity of the production;
- the share of embedded emissions to be offset; and
- the price for CBAM certificates.

For ammonia and crude steel, we exemplify the mark-up induced by the CBAM for different production routes (see figure below). The emission intensity and thus the related costs differ substantially. Costs are calculated assuming an EU ETS certificate price of 120EUR$_{2022}$/tCO_2 in 2030 and considering the corresponding share of CBAM surrendering obligation (51.5%) as detailed in Figure 3. This yields an effective CBAM certificate price of around 62EUR$_{2022}$/tCO_2.

Exemplary calculation of mark-up in 2030 on imported ammonia and crude steel induced by CBAM for different production routes



Note: details on the underlying parameters of the calculation are documented in the annex.
NG SMR w/o CCS: natural gas-based steam methane reforming without carbon capture, transport and storage
NG SMR w/ CCS: natural gas-based steam methane reforming with carbon capture, transport and storage
BF-BOF: blast furnace-Blast oxygen furnace route
EAF: electric arc furnace route
NG based DRI-EAF: natural gas-based direct iron reduction and electric arc furnace route
H_2 based DRI-EAF: hydrogen-based direct iron reduction and electric arc furnace route

Figure 5: Illustration by Öko-Institut based on IEA (2023b), ArcelorMittal (2017) and JRC (2022)

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For **ammonia** three production routes are examined:

i) Natural gas-based ammonia production using steam methane reforming (SMR) technology.
ii) Natural gas-based ammonia production using steam methane reforming (SMR) technology with 93% share of CO_2 captured and stored (CCS).
iii) Electrolysis-based ammonia production

i) Natural gas-based ammonia production using steam methane reforming (SMR) technology without carbon capture transport and storage (CCS) is the technology most commonly applied in current ammonia production accounting for 70% of production in 2021, most of the rest is produced via coal gasification (IEA 2023a). It is characterized by high direct emissions (around 1.7 tCO2/tNH_3) and low indirect emissions from electricity consumption.[21] Applying the effective CBAM certificate price, importers will encounter additional costs of 109 EUR_{2022}/tNH_3. IEA (2023) reports current production costs to be in the range of 300-1100 USD/tNH_3. Hence, CBAM would add around 24% to the production costs for this production route with natural gas as the single-most important input and with unabated CO_2 emissions.

ii) Combining the natural gas-based ammonia production using steam methane reforming (SMR) technology with CCS reduces direct emissions substantially. The high share of CO_2 captured and stored (93%) can only be achieved with substantial additional energy input and additional investment into the CCS facilities. Direct emissions for this production route are around 0.1 tCO2/tNH_3, with the remain 93% of emissions captured and stored. Additional electricity demand for capturing the CO_2 accounts about 0.15 MWh/tNH_3.[22] Applying the effective CBAM certificate price, importers will encounter additional costs of 16 EUR_{2022}/tNH_3. Hence, CBAM would add around 4% to the production costs for this natural gas-based production route with a very high share of CO_2 capture.

iii) Electrolysis-based ammonia production produces the hydrogen required as input for the ammonia production via electrolysis in an integrated in-site process. This production route is not associated with significant direct emissions. Electricity demand for hydrogen production is around 10 MWh/tNH_3. Additional electricity is required for air separation to get N_2 as a feedstock 0.7 MWh/tNH_3. Assuming all electricity is supplied from a typical natural gas-based power plant this corresponds to around 4.6tCO_2/tNH_3. However, if the importer can prove that the electricity is supplied from renewable sources (see above for different possibilities to do so) the emission factor is zero. Whereas renewable hydrogen will face no CBAM cost, depending on the emissions intensity of the electricity the CBAM cost for electrolysis-based ammonia can be very significant, e.g., 286 EUR_{2022}/tNH_3 for natural gas-based electricity.

The assessment illustrates that ammonia production based on natural gas without CCS will face substantial CBAM costs when being imported to the EU. The CBAM cost is substantially lower if CCS is applied. Green ammonia will face no CBAM costs as long as the producer can prove that the electricity stems from renewable sources. The CBAM thus makes less emission intensive production routes more competitive.

For **steelmaking** four production routes are examined:

i) Blast furnace and blast oxygen furnace (BF-BOF);
ii) Electric arc furnace (EAF);
iii) Natural gas based direct iron reduction and EAF (NG DRI-EAF); and
iv) Hydrogen-based direct iron reduction and EAF (H_2 DRI-EAF).

i) BF-BOF-based production route[23]: This technology is most commonly applied in current crude steelmaking accounting for 72% of production in 2022 (Worldsteeel Association 2023). It is a primary production route that converts iron ore into crude steel using coal as both heat source and reduction agent. Direct emissions for this production route are around 2.1 tCO_2/t of crude steel. Indirect emissions add about 0.1 tCO_2/t of crude steel. Applying the effective CBAM certificate price, importers will encounter additional costs of 132 EUR_{2022}/tNH_3. IEA (2023) reports current production costs to be in the range of 350-650 USD/t crude steel. Hence, CBAM would add around 30% to the production

[21] Electricity demand for the air separation unit is around 0.13 MWhel/tNH3. Assuming electricity is supplied from a typical natural gas-based power plant this would correspond to around 0.1 tCO2/tNH3.
[22] Assuming electricity is supplied from a typical natural gas-based power plant this would correspond to around 0.1tCO2/tNH3.
[23] For the blast furnace and blast oxygen furnace (BF-BOF) and the electric arc furnace (EAF) production routes emissions calculations are based on data from JRC (2022). Here, emission factors represent the median factors of major crude steel exporters to the EU.

costs for this production route with coal as the single-most important input and with unabated CO_2 emissions.

ii) EAF-based production route: This technology makes up for the bulk of the remaining current crude steelmaking, accounting for 28% of production in 2022 (Worldsteeel Association 2023). It is a secondary production route where scrap steel is recovered into crude steel using very high temperature generated via electricity. Direct emissions on this route originate coal or natural gas used for pre-heating the scrap steel and from the electrodes of the electric arc furnace. The median direct emissions on this production route are around 0.04 tCO_2/t of crude steel. Indirect emissions add about 0.4 tCO_2/t of crude steel. Applying the effective CBAM certificate price, importers will encounter additional costs of 25 EUR_{2022}/t of crude steel. Hence, CBAM would add around 7% to the production costs for this production route if production is based on the national grid emission factor. If the importer can prove that renewable energy was used for the production, then there are zero additional costs.

iii) Natural gas-based direct iron reduction and EAF (NG DRI-EAF) route: This technology is most commonly applied in current DRI making, accounting for 70%[24] of production in 2022 (Midrex Technologies, Inc. 2023). It is a primary production route that convers iron ore DRI and later into crude steel using natural-based syngas[25] as reduction agent and for electricity generating high temperatures. Direct emissions for this production route are around 0.6 tCO_2/t of crude steel. Electricity demand for the EAF accounts for around 0.6 MWh/t crude steel. Assuming electricity is supplied from a typical natural gas-based power plant this would correspond to around 0.3 tCO_2/t crude steel. Applying the effective CBAM certificate price, importers will encounter additional costs of 53 EUR_{2022}/t crude steel. Hence, CBAM would add around 12% to the production costs for this natural gas-based production route. If the importer can prove that electricity is taken from renewable sources, then importers will only encounter additional costs of 36 EUR_{2022}/t crude steel.

iv) Hydrogen-based direct iron reduction and EAF (H_2 DRI-EAF) route: This technology is envisioned to be compatible with a zero-emissions energy system, if hydrogen is produced from renewable sources. It is the same as the previous production route but here hydrogen from electrolysis is directly used as reduction agent and electricity for generating high temperatures. Direct emissions for this production route are around 0.04 tCO2/t of crude steel, or below. Electricity demand for hydrogen production and the EAF accounts for around 2.9 MWh/t crude steel. Assuming electricity is supplied from a typical natural gas-based power plant this would correspond to around 1.3 tCO_2/t crude steel. Applying the effective CBAM certificate price, importers will encounter additional costs of 83 EUR_{2022}/t crude steel. Hence, CBAM would add around 19% to the production costs for this natural gas-based production route. If the importer can prove that electricity is taken from renewable sources, then importers will only encounter zero additional.

In a nutshell, CBAM can add significant costs to the basic products depending on the emission intensity of the respective production route. However, in parallel to increasing obligations under CBAM, EU producers will reciprocally receive less free allocation and hence will be exposed to the EU ETS in the same way. This creates a strong incentive to decarbonize production and to focus on low-emissions production routes. With a certificate price of 150€/t CO_2 in the EU-ETS in 2030, electrolysis-based ammonia production can have a competitive advantage of 100-110EUR_{2022}/tNH_3 compared to conventional and unabated production, if electricity supply comes from renewable energy sources. Similarly, H_2-based crude steel could have a competitive advantage of around 130EUR_{2022}/t crude steel compared to coal-based steel from the BF-BOF route, if electricity comes from renewable sources.

[24] Note that the DRI needs to be further processed in an EAF or BOF to be converted to crude steel. Therefore the 127 Mt of DRI produced in 2022 are not a separate category of steelmaking but are input into the crude steel finally reported as supplied on the BOF-BOF or EAF route.
[25] A mixture of hydrogen, CO and CO2.

Comparison of CBAM reporting rules to other regimes, and outlook

The CBAM reporting rules mirror as closely as possible the rules of the EU ETS 1 monitoring rules in order to ensure a level playing field between importers and domestic producers. They are different to other carbon footprint methods such as the GHG Protocol or ISO 14067.[26] Whereas carbon footprint methods are often based on a life cycle perspective, EU ETS 1 and CBAM rules focus on the production process; neither downstream emissions from product use, nor transport and distribution emissions or processes further upstream are included.[27] The embedded emissions reported under the CBAM are thus lower than those calculated based on carbon footprint methods.

EU requirements for renewable hydrogen and its derivates are aligned e.g. concerning the requirements to account for 100% renewable electricity[28] the CBAM rules refer to CDR 2023/1184 (EU 2023a). They differ, though, in respect to the coverage of transport and distribution emissions. The emission factor for electricity consumed from the grid may differ, too. Furthermore, the attribution of emissions when various products are produced jointly differs.

The monitoring and reporting rules in the CBAM are expected to be developed further for the definite CBAM period starting in 2026. This is an opportunity to streamline the reporting requirements concerning electricity consumption. The methodological difference concerning the scope of emissions covered will most likely remain unless the coverage of the EU ETS 1 is changed.

The CBAM cost producers face will vary substantially depending on the emission intensity of the production. PtX products are characterized by low specific emissions as long as the electricity used in the production process can be demonstrated to be renewable. Thus, the CBAM and the ETS can help reducing the cost difference between green products and conventional production.

Whether indirect emissions from electricity will be covered for more products in the definite period is of particular interest to producers of renewable hydrogen. To date, indirect emissions will be covered for ammonia but not for hydrogen and steel. If indirect emissions are not covered, renewable hydrogen and hydrogen produced using electricity generated by fossil fuels would both benefit from zero CBAM costs, albeit the latter hydrogen does cause substantial indirect emissions.

Lastly, the CBAM is a new instrument and will face challenges in the first years. This includes practical challenges for producers to report emissions, for importers to collect the necessary information and submit corresponding reports, for implementing authorities in Member States to review and correct those reports where necessary and ensure compliance, for the EU Commission to develop further the rules and to set up the CBAM registry or establish auctioning platforms for CBAM certificates – to cite some. The experience with the EU ETS 1 showed that in the first years the evaluation of the functioning of the policy is of outmost relevance to ensure that all operators are treated equally. Furthermore, the CBAM may be challenged at the WTO despite the effort to design it in a way that producers in third countries are treated equally to EU producers. The further development of the CBAM and the EU ETS will thus be interesting both for scholars and practitioners.

[26] For further information see https://ghgprotocol.org/ and (ISO 2013).

[27] (European Commission 2023), chapter 6.2.

[28] For a concise resume refer to (PtX-Hub 2023).

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Annex

General parameters for the exemplary calculation of mark-up on imported ammonia and crude steel
H_2-efficiency of an ammonia plant: 82% (Fasihi et al. 2021)
Energy content of ammonia: 5.2 kWh NH_3/kg NH_3
Energy content of hydrogen: 33.3 kWh H_2/kg H_2
Emission factor of NG-based electricity: 56.1 tCO_2/TJ NG (IPCC 2019) with assumed electrical efficiency of 44.5%; 0.45 $kgCO_2$/kWhel
Energy demand for air compression unit: 0.13 MWhel/tNH_3 (Xinyu Liu et al. 2020).
EU-ETS price in 2030: $120EUR_{2022}/tCO_2$
Share of emissions to be covered via CBAM certificates in 2030: 51.5%

Ammonia
Ammonia NG SMR w/o CCS:
Natural gas demand for hydrogen production: 44.5 kWh/kg H_2 (International Energy Agency (IEA) 2023, S. 41).

Ammonia NG SMR w/ CCS (capture rate 93%):
Natural gas demand for hydrogen production: 49 kWh/kg H_2 (International Energy Agency (IEA) 2023, S. 41).
Electricity demand due to CO_2 capture: 0.8 kWhel/kg H_2 (International Energy Agency (IEA) 2023, S. 41).

Ammonia w/ electrolysis-based H_2:
Electricity demand for electrolysis: 50 kWhel/kg H_2 (International Energy Agency (IEA) 2023, S. 41).
Energy demand for air separation unit: 0.142 kWhel/kWh NH_3 (Fasihi et al. 2021)

Crude steel
BF-BOF:
Direct emissions: 2.05 tCO2/t; median major exporting countries to EU27 , not weighted by export volume (own calculation based on (own calculation based on JRC 2022: Table A4: Scope 1).
indirect emissions: 0.08 tCO2/t; median major exporting countries to EU27 , not weighted by export volume (own calculation based on (own calculation based on JRC 2022: Table A4: Scope 2). Country-specific emission factors where apply in the study taken from IEA (2019).

Scrap-based EAF:
Direct emissions: 0.04 tCO2/t; median major exporting countries to EU27 , not weighted by export volume (own calculation based on JRC 2022: Table A4: Scope 1).
indirect emissions: 0.36 tCO2/t; median major exporting countries to EU27 , not weighted by export volume (own calculation based on JRC 2022: Table A4: Scope 2). Country-specific emission factors where apply in the study from IEA (2019).

NG-based DRI-EAF:
Direct emissions: 0.59 tCO2/t (own calculation based on JRC 2022: Table A1: NG-based DRI-EAF).
indirect emissions: 0.26 tCO2/t; assuming NG-based electricity supply (own calculation based on JRC 2022: Table A1: NG-based DRI-EAF)

H2-based DRI-EAF:
Direct emissions: 0.03 tCO2/t (own calculation based on JRC 2022: Table A1: EAF; average of coal and gas for pre-heating) (own calculation based on JRC, 2022: Table A1: EAF; average of coal and gas for pre-heating).
indirect emissions: 1.05 tCO2/t; assuming NG-based electricity supply with 1.9 MWh H_2 /t crude steel; DRI-share in EAF of 85% and 70% efficiency for the electrolysis (own calculation based on ArcelorMittal (2017).

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