CLIMATE CHANGE
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Final report

Identification of possibilities to prove the origin of a product from a specific installation

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Disclaimer:

Please note that the recommendations presented here are based on good practices and established standards, as well as on the CBAM Regulation (EU) 2023/956 of 10 May 2023.

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Abstract: Identification of possibilities to prove the origin of a product from a specific installation

The report examines the challenges and methodologies for verifying the origin and emissions of imported goods under the EU's Carbon Border Adjustment Mechanism (CBAM). The study identifies suitable documentation, evaluates verification challenges for complex goods, and proposes possible solutions to (1) establish proof of origin for EU imports and (2) to address verification challenges for complex goods under CBAM.

Regarding the proof of origin for EU imports, the report identifies two possible categories of documents: trade and customs records (e.g. certificates of origin) and business records (e.g. production logs, delivery notes). These are assessed for coverage, accuracy, tamper-proof characteristics, and reliability. Since it seems that no single document can fully verify a product's origin, the study emphasizes a combination of different document types that may be further substantiated by system-based verification using ERP systems, cross-referencing, and virtual site visit techniques.

The report also reviews four complex goods from the CBAM sectors iron & steel, aluminium, cement and fertilizers regarding sector-specific verification challenges. Key observation highlights: Cement production requires precise allocation of emissions between clinker production and milling. Fertilizer production involves complexities from multiple precursors and shared resources. Iron and steel verification is complicated by integrated processes and cross-border supply chains, while aluminium production, amongst other things, faces challenges distinguishing between scrap types. The report suggests combining delivery notes, ERP extracts, and access to manufacturers' ERP system, supported by standardized templates, to enhance verification.

In conclusion, robust documentation, ERP system-based verification, and sector-specific approaches are essential for addressing challenges in the implementation of CBAM regulation.

Kurzbeschreibung: Identifizierung von Möglichkeiten zum Nachweis der Herkunft eines Produkts aus einer bestimmten Anlage

Dieser Bericht untersucht die Herausforderungen und Methoden zur Verifizierung der Herkunft und der Treibhausgasemissionen importierter Produkte im Rahmen des CO_2-Grenzausgleichmechanismus (Carbon Border Adjustment Mechanism (CBAM)) der EU. Der Bericht identifiziert geeignete Dokumentationen, bewertet die Verifizierungsherausforderungen für komplexe Produkte und schlägt mögliche Lösungen vor, um (1) den Nachweis der Herkunft von EU-Importen zu erbringen und (2) die Verifizierungsherausforderungen für komplexe Produkte im Rahmen des CBAM anzugehen.

Bezüglich der Herkunftsnachweise von EU-Importen identifiziert dieser Bericht zwei mögliche Kategorien von Dokumenten: Handels- und Zollunterlagen (z.B. Herkunftszertifikaten) sowie Geschäftsdokumente (z.B. Produktionsprotokolle und Lieferscheine). Diese sind hinsichtlich ihrer Abdeckung, Genauigkeit, Fälschungssicherheit und Zuverlässigkeit bewertet. Da es scheint, dass kein einzelnes Dokument die Herkunft eines Produkts vollständig nachweisen kann, betont der Bericht eine Kombination verschiedener Dokumenttypen. Diese können durch IT-System basierte Verifizierungen mithilfe von EPR-Systemen, Querverweisen und Ferntechniken weiter untermauert werden.

Der Bericht untersucht vier komplexe Produkte aus den CBAM Sektoren Eisen und Stahl, Aluminium, Zement und Düngemittel in Bezug auf sektorspezifische Verifizierungsherausforderungen. Wichtige Erkenntnisse umfassen: Der Produktionsprozess von Zement erfordert eine präzise Aufteilung der Treibhausgasemissionen zwischen Klinkerproduktion und Mahlen. Die Produktion von Düngemitteln ist aufgrund zahlreicher Vorstufen (precursors) und gemeinsam genutzten Ressourcen komplex. Die Verifizierung von Eisen und Stahl gestaltet sich komplex durch

integrierte Prozesse und grenzüberschreitende Lieferketten. Im Fall von Aluminium treten unter anderem Herausforderungen bei der Unterscheidung zwischen verschiedenen Schrottarten auf. Der Bericht schlägt eine Kombination aus Lieferscheinen, ERP-Auszügen und dem direkten Zugriff auf das ERP-System der Hersteller vor. Unterstützt wird der Abgleich durch standardisierte Vorlagen, um die Verifizierung zu verbessern.

Zusammenfassend sind eine solide Dokumentation, systembasierte Verifizierung, und sektorspezifische Ansätze entscheidend, um die Herausforderungen des CBAM zu bewältigen.

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List of abbreviations

Abbreviation	Explanation
ASI CoC Standard	Aluminium Stewardship Initiative’s Chain of Custody Standard
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism (CBAM)
CCR	Clinker to cement ratio
CEMS	Continuous Emissions Measurement System
CN	Combined Nomenclature
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CoC	Certificate of Conformity
COO	Certificate of Origin
CSI	Cement Sustainability Initiative
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
ERP	Enterprise Resource Planning
EU	European Union
EU ETS	EU Emissions Trading System
GHG	Greenhouse Gas
GJ	Gigajoule
GSP	Generalised Scheme of Preferences
IAI	International Aluminium Institute
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life-Cycle-Assessment
LOCODE	United Nations Code for Trade and Transport
LPG	Liquified Petroleum Gas
MRV	Monitoring, Reporting and Verification
N_2O	Nitrous oxide (laughing gas)
NPK	Nitrogen, Phosphorus, and Potassium

Abbreviation	Explanation
PEM	Pan-Euro-Mediterranean
RED	(Re-cast) Renewable Energy Directive
SAD	Single Administrative Document
SCS	Scientific Certification Systems
UBA	Umweltbundesamt

Summary

The research report focuses on identifying ways to trace the origin of a product in the context of emissions verification under the European Union's Carbon Border Adjustment Mechanism (CBAM). CBAM, introduced in October 2023, aims to equalize the carbon dioxide (CO_2) pricing of imported goods with those produced domestically under the EU Emissions Trading System (EU ETS). The study examines documents to prove the origin of the products and additional verification challenges for selected complex goods and explores solutions to address these challenges.

Objectives

The primary objectives of the study are:

- To identify suitable documents and methodologies for reliably verifying the origin of imported goods and their associated emissions.
- To analyse the specific challenges encountered in verifying emissions for complex products across different industrial sectors covered by CBAM.
- To propose possible solutions and recommendations to improve the verification process, ensuring compliance with CBAM regulations.

Content and methodology

The report is structured into two key sections:

1. Establishing proof of origin for EU import
   a. Two categories of documents are identified and evaluated: trade and customs documents (e.g., certificates of origin, import/export declarations) and business record documents (e.g., manufacturing process documentation, delivery notes).
   b. Documents are assessed based on criteria such as global coverage, accuracy, tamper-proof characteristics, and reliability. None of the documents alone can fully verify the origin of a product at the installation level, necessitating the use of multiple documents.
   c. Based on the assessment, the suitable documents and verification methods are identified to determine the origin of a CBAM product.
   d. Certificate of origin, delivery note, production documents and direct enterprise resource planning (ERP) system access for reconciliation of the information are suggested for required documents.
   e. System-based verification, enhanced reliability through supplier and importer data verification, review of production and storage documents, thorough verification processes for unautomated documentation cases, and submission of supporting documents along with the standardized communication template are suggested for addressing the challenges for the verification processes.
2. Other verification challenges for complex goods under the CBAM
   a. This part of the study examines specific challenges in verifying emissions for complex goods across four sectors: cement, fertilizers, iron and steel, and aluminium. Complex goods are produced in a production process requiring input materials (precursors) and fuels with specific embedded emissions.[1] Here the specific embedded emissions are

[1] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism. "Specific embedded emissions" means the embedded emissions of one tonne of goods, expressed as tonnes of CO_2e emissions per tonne of goods." (Annex IV).

released during the production of relevant precursor materials consumed in the production process.[2]

b. Key challenges include defining system boundaries, avoiding double counting of emissions, and attributing emissions accurately to specific production processes.
c. **Cement**: Challenges include splitting emissions between clinker production and cement milling, especially when shared equipment is used.
d. **Fertilizers**: The complexity arises from the use of multiple precursors, shared equipment, and the need to account for both direct and indirect emissions.
e. **Iron and Steel**: Verification is complicated by integrated production processes and cross-border supply chains.
f. **Aluminium**: Distinguishing between pre-consumer and post-consumer scrap aluminium adds layers of complexity to emissions reporting.

Overall observations and suggestions

To ensure accurate allocation of emissions for goods imported into the EU under the CBAM framework, a comprehensive approach to documentation and verification is required. Key documents include certificates of origin, delivery notes specifying plant and company details, and production records such as ERP extracts or alternative cross-referenced documents. Verifiers may also need direct access to manufacturers' ERP systems for virtual site visits to validate data integrity. A standardized submission protocol, aligned with EU Commission templates, ensures consistency and completeness in reporting.

Verification methodologies emphasize ERP system-based evaluations to mitigate the risk of document falsification. Cross-referencing supplier and importer data, customs declarations and production and inventory records enhance reliability. Challenges such as manual documentation in regions without ERP systems require rigorous evidence collection. Additionally, sector-specific guidelines, harmonized Life-Cycle-Assessment (LCA) standards, and precise production process boundaries are vital to avoid double counting and ensure reporting consistency.

Collaboration across facilities and centralized data management systems are recommended to improve data integration and traceability. Plausibility checks conducted by independent third parties (e.g., auditing firms), regular consistency reviews, and structured training programmes for verifiers all contribute to strengthening compliance and improving overall accuracy. For complex supply chains, international agreements and unique installation identifiers streamline verification, while sector-specific needs, such as distinguishing pre- and post-consumer scrap in metal recycling, ensure accurate emissions calculations.

Finally, digital verification tools, such as centralized platforms for emissions data uploads and automated checks, promote transparency and efficiency. In addition to ensuring the impartiality of the verifier, it must be ensured that the use of a standardised tool does not involve the provision of any advisory services. These measures collectively address the multifaceted challenges of CBAM compliance, ensuring transparency, consistency, and alignment with its objectives.

Conclusion

For successful implementation of CBAM, the verification challenges posed by complex global supply chains, diverse production processes and varying regulations must be addressed. Documents such as certificates of origin and delivery notes provide relevant information but often vary in detail and standardization. As a result, multiple documents are typically needed to ensure reliable traceability. In supply chains involving multiple sites and cross-border flows,

[2] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism

emissions attribution can be complex, which may require the use of measurement-based monitoring methods such as CEMS-though these are not universally implemented.

Robust verification methodologies, including ERP system-based checks, data cross-referencing and virtual site visits could be used to overcome these obstacles. Standardized templates and enhanced stakeholder collaboration could improve data reliability. Investing in monitoring technologies and refining regulatory frameworks would enable the EU to ensure that CBAM achieves its environmental integrity and equitable carbon pricing goals.

Zusammenfassung

Dieser Forschungsbericht konzentriert sich auf die Identifikation von Möglichkeiten, die Herkunft eines Produkts im Kontext der Emissionsverifizierung im Rahmen des Carbon Border Adjustment Mechanism (CBAM) der Europäischen Union (EU) nachzuvollziehen. Der CBAM, der im Oktober 2023 eingeführt wurde, hat das Ziel, die Kohlenstoffdioxid (CO_2)-Bepreisung von Importprodukten an die CO_2-Bepreisung des EU-ETS von in der EU produzierten Warenanzugleichen. Der Bericht untersucht die notwendigen Dokumente zum Herkunftsnachweis sowie weitere Verifizierungsherausforderungen für ausgewählte komplexe Produkte, und diskutiert potenzielle Lösungen, um diese Herausforderungen anzugehen.

Die Hauptziele des Berichts sind:

- Die Identifikation geeigneter Dokumente und Methoden zur zuverlässigen Verifizierung der Herkunft importierter Produkte und ihrer Emissionen.
- Die Analyse von spezifischen Herausforderungen bei der Verifizierung der Emissionen komplexer Produkte in verschiedenen Industriesektoren im Rahmen des CBAM.
- Das Vorschlagen von Lösungen und Empfehlungen zur Verbesserung des Verifizierungsprozesses, sowie zur Sicherstellung der Einhaltung der CBAM-Vorschriften.

Inhalt und Methodik

Der Bericht ist in zwei Hauptschnitte gegliedert:

1. Nachweis der Herkunft für EU-Importe
   a. Zwei Kategorien von Dokumenten werden identifiziert und bewertet: Handels- und Zolldokumente (z.B. Herkunftszertifikate, Import/Exportdeklarationen) sowie Geschäftsdokumente (z.B. Produktionsprozessdokumentation, Lieferscheine).
   b. Die Dokumente werden anhand von Kriterien wie globaler Abdeckung, Genauigkeit, Fälschungssicherheit und Zuverlässigkeit bewertet. Kein einzelnes Dokument kann die Herkunft eines Produkts auf der Installationsebene vollständig nachweisen, weshalb die Nutzung mehrerer Dokumente erforderlich ist.
   c. Basierend auf der Bewertung werden geeignete Dokumente und Verifizierungsmethoden identifiziert, um die Herkunft eines CBAM-Produkts zu bestimmen.
   d. Als erforderliche Dokumente werden Herkunftszertifikate, Lieferscheine, Produktionsdokumente und direkter ERP-Systemzugang bei den Herstellern zum Abgleich der Informationen vorgeschlagen.
   e. Zur Bewältigung der Herausforderungen im Verifizierungsprozess werden systembasierte Verifizierungen, erhöhte Zuverlässigkeit durch Datenverifizierung von Lieferanten und Importeuren, Überprüfung von Produktions- und Lagerdokumenten, gründliche Verifizierungsprozesse für nicht automatisierte Dokumentationsfälle sowie die Einreichung unterstützender Dokumente zusammen mit einer standardisierten Kommunikationsvorlage empfohlen.
2. Weitere Verifizierungsherausforderungen für komplexe Produkte unter dem CBAM
   a. Dieser Teil der Studie untersucht spezifische Herausforderungen bei der Verifizierung von Emissionen für komplexe Produkte in vier Sektoren: Zement, Düngemittel, Eisen und Stahl sowie Aluminium. Komplexe Produkte werden in einem Produktionsprozess hergestellt, der Inputmaterialien (Vorprodukte) und Brennstoffe mit spezifischen grauen

Emissionen[3] erfordert. Dabei werden die spezifischen grauen Emissionen während der Herstellung der relevanten Vorläufermaterialien freigesetzt, die anschließend im Produktionsprozess verbraucht werden.[4]

b. Zentrale Probleme umfassen die Definition von Systemgrenzen, die Vermeidung von Doppelzählungen von Emissionen und die präzise Zuordnung von Emissionen zu spezifischen Produktionsprozessen.
c. **Zement**: Herausforderungen bestehen in der Aufteilung der Emissionen zwischen der Klinkerproduktion und dem Mahlen von Zement, insbesondere bei der Nutzung gemeinsamer Ausrüstung.
d. **Düngemittel**: Die Komplexität ergibt sich aus der Verwendung mehrerer Vorstufen, gemeinsam genutzter Ausrüstung sowie der Notwendigkeit, sowohl direkte als auch indirekte Emissionen zu berücksichtigen.
e. **Eisen und Stahl**: Die Verifizierung wird durch integrierte Produktionsprozesse und grenzüberschreitende Lieferketten erschwert.
f. **Aluminium**: Die Unterscheidung zwischen Pre-Consumer- und Post-Consumer-Schrott-Aluminium fügt der Emissionsberichterstattung zusätzliche Komplexität hinzu.

Gesamtergebnisse und Vorschläge

Um eine genaue Zuordnung der Emissionen für in die EU importierte Waren im Rahmen des CBAM sicherzustellen, ist ein umfassender Ansatz für Dokumentation und Verifizierung erforderlich. Zu den zentralen Dokumenten gehören Herkunftszertifikate, Lieferscheine mit Angaben zu Werk und Unternehmen sowie Produktionsaufzeichnungen wie ERP-Auszüge oder alternative, querreferenzierte Dokumente. Verifizierer könnten außerdem direkten Zugang zu den IT-Systemen der Hersteller benötigen, um virtuelle Standortbegehungen durchzuführen und die Datenintegrität zu validieren. Ein standardisiertes Einreichungsprotokoll, das mit den Vorlagen der EU-Kommission abgestimmt ist, würde Konsistenz und Vollständigkeit bei der Berichterstattung gewährleisten.

Die Verifizierungsmethoden betonen ERP-System basierte Bewertungen, um das Risiko von Dokumentenfälschungen zu minimieren. Der Abgleich zwischen Lieferanten- und Importeurdaten, Zolldeklarationen und Produktions- und Lagerbestandsunterlagen erhöhen die Zuverlässigkeit. In Regionen ohne zentralisierte digitale ERP-Systeme erfolgt die Dokumentation von Nachweisen überwiegend manuell, was den Aufwand für eine verlässliche Sammlung und Prüfung erhöht. Darüber hinaus sind sektorspezifische Leitlinien, harmonisierte LCA-Standards und präzise Abgrenzungen der Produktionsprozesse entscheidend, um Doppelzählungen zu vermeiden und eine konsistente Berichterstattung sicherzustellen.

Eine Zusammenarbeit zwischen Anlagen und zentralisierte Datenverwaltungssysteme werden empfohlen, um die Datenintegration und Rückverfolgbarkeit zu verbessern. Plausibilisierungen durch unabhängige Parteien (z.B. Prüfungsunternehmen), regelmäßige Konsistenzprüfungen als auch Schulungsprogramme für Verifizierer erhöhen die Compliance und Genauigkeit. Für komplexe Lieferketten erleichtern internationale Abkommen und eindeutige Anlagenkennungen die Verifizierung, während sektorspezifische Anforderungen, wie die Unterscheidung zwischen Pre- und Post-Consumer-Schrott im Metallrecycling, eine präzise Berechnung der Emissionen sicherstellen.

[3] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism. „Spezifische graue Emissionen“ die grauen Emissionen einer Tonne Waren, ausgedrückt als Tonnen an CO_2e-Emissionen (CO_2-Äquivalent) pro Tonne Waren.” (Annex IV).
[4] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism

Digitale Verifizierungstools, wie zentralisierte Plattformen für den Upload von Emissionsdaten und automatisierte Prüfungen, fördern Transparenz und Effizienz. Neben der Sicherstellung der Unparteilichkeit des Verifizierers ist darauf zu achten, dass durch den Einsatz eines standardisierten Tools keine Beratungsleistungen erbracht werden. Diese Maßnahmen tragen insgesamt dazu bei, die vielfältigen Herausforderungen der CBAM-Compliance zu bewältigen und gewährleisten Transparenz, Konsistenz sowie eine Ausrichtung auf die Ziele des Mechanismus.

Schlussfolgerung

Für eine erfolgreiche Umsetzung des CBAM müssen die Verifizierungsherausforderungen, die durch komplexe globale Lieferketten, diverse Produktionsprozesse und unterschiedliche Vorschriften entstehen, bewältigt werden. Obwohl Dokumente wie Herkunftszertifikate und Lieferscheine grundsätzlich verlässliche Informationen enthalten, fehlen ihnen häufig spezifische Angaben, die für die Nachweisführung im Rahmen von CBAM erforderlich sind – etwa zur exakten Emissionshöhe oder zu einzelnen Produktionsschritten. Dies macht einen multidokumentarischen Ansatz notwendig, um die geforderte Genauigkeit und Nachvollziehbarkeit sicherzustellen. Lieferketten mit mehreren Standorten und grenzüberschreitenden Verbindungen erschweren die Zuordnung von Emissionen zusätzlich und machen auf direkte Emissionsmessung basierende Überwachungsmethode wie CEMS erforderlich, die jedoch nicht überall verfügbar sind.

Robuste Verifizierungsmethoden, einschließlich ERP-System basierter Prüfungen, Daten-Querverweise und Fernverifizierung, könnten genutzt werden, um diese Herausforderungen zu überwinden. Standardisierte Vorlagen und eine verstärkte Zusammenarbeit der Stakeholder könnten die Datenzuverlässigkeit verbessern. Investitionen in Überwachungstechnologien und die Verfeinerung regulatorischer Rahmenbedingungen würden es der EU ermöglichen, sicherzustellen, dass der CBAM seine Ziele der ökologischen Integrität und einer gerechten CO_2-Bepreisung erreicht.

1 Introduction

On 1 October 2023, the European Union (EU) introduced the Carbon Border Adjustment Mechanism (CBAM). The CBAM Regulation is a legal act of the EU with general validity and direct effect in the EU Member States. It establishes the European CBAM system and defines the scope of application to imported goods and greenhouse gases (GHGs).

After a transitional phase, the regular phase will begin on 1 January 2026, combining an annual reporting obligation (the so-called CBAM declaration) with an obligation to surrender CBAM certificates for each tonne of carbon dioxide equivalent (CO_2e). This should mean that emission-intensive products manufactured abroad will be subject to the same CO_2 price when imported into the EU as in the EU, where the manufacture of these products is subject to the EU ETS.

While GHG emissions are reported and certificates surrendered for energy and industrial installations in the EU ETS, the product is the subject of the reporting and surrender obligation in the CBAM. This leads to special requirements for monitoring, reporting and verification (MRV). In principle, the actual emissions generated during the manufacture of the product must be reported. Under certain conditions, product-specific default values can also be used.

When importing a product, it must be possible to reliably identify and verify the manufacturing facility to determine the emissions associated with the manufacture of the product (so-called grey emissions). If an installation manufactures different products, the emissions must be allocated to the different products. If several facilities are involved in the manufacturing processes of a CBAM product (so-called complex products), the facilities in the entire manufacturing chain must be reliably identified, the embedded emissions of the preliminary product determined, allocated to the respective product, verified from 1 January 2026 and passed on.

To determine the embedded emissions of a product, it is essential to reliably identify and verify the facilities involved in the manufacturing process and their emissions. When importing CBAM products, information on the product type (Combined Nomenclature (CN) code) and the country of origin is requested. Although detailed information must be provided in the CBAM declaration in accordance with Article 6 of the CBAM Regulation (or in the transitional phase for the CBAM report in accordance with Article 3 (2) of the CBAM Implementing Regulation), this is the importer's own information (which cannot be verified by the authorities). At present, competent authorities cannot, by default, independently verify the installation identity indicated by the declarant beyond the evidence submitted and available registry features. The scope of registry functions under Article 10a and any mandatory disclosure or verifier-report exchange remains subject to forthcoming acts and Guidance. Accordingly, claims on installation identity are qualified and tied to the submitted documentary evidence and verifier opinion.

The identification of possibilities to check and verify the origin of a product from a specific installation in the CBAM declaration is structured according to two guiding questions:

- Which documents are suitable for reliably proving the installation-related origin of a product imported into the EU (e.g. export documents, plausibility checks using extracts from the internal merchandise management system, possibly checked by an auditor, plausibility checks using invoices or similar)?

- What additional challenges for verification arise with complex products? To answer this question, a complex product is selected from each industrial sector in scope of CBAM; possible case constellations and challenges (e.g. workarounds) are described or identified, and potential solutions proposed.

The two ensuing sections discuss these questions in more detail.

The report focuses on the identification of suitable documentation to reliably evidence the installation-specific origin of CBAM goods and on the analysis of additional verification challenges for complex goods. Building on a structured literature review and stakeholder interviews, the analysis derives a documentation set and verifier procedures that can be applied under CBAM.

2 Establishing proof of origin for EU imports: Document types and verification standards

In a first step, based on desk research and selected interviews, two overarching categories of potentially suitable documents for determining the installation-specific origin of EU imported goods have been identified:

- **Category 1 – Trade and customs documents**: In the area of international commerce, various documents are commonly utilized to facilitate cross-border trade and custom procedures. Based on a stock-take of such documents, their applicability as proofs of origin for imported products into the EU within the CBAM framework has been assessed.
- **Category 2 – Business record documents**: This category involved scrutinizing internal corporate documents, which are based on production processes and internal inventory movements concerning warehouse and logistics management. Such documents may provide in-depth information on the production output, product characteristics and quantities produced in an installation, which can be a basis for product origin verification.

For the assessment of the relevant documents, several criteria have been established against which each document has been assessed:

- **Coverage**: The first criterion concerns the geographical applicability of the document, based on the goal to identify a universally accepted document that could standardize validation processes and ensure global comparability.
- **Accuracy of information**: The second criterion pertains to the precision of the information, whereby the document must provide detailed insights into the product's origin, specifically identifying the installation or manufacturing facility. Information at the country level is deemed insufficient for unequivocally determining product origin.
- **Tamper-proof:** The third criterion evaluates the document's protection to tampering. It is essential to ascertain the difficulty of falsifying the document, as a high risk of forgery would render it unsuitable for providing insights into the product origin in the CBAM context.
- **Reliability**: The fourth criterion is the document's reliability, emphasizing that only trustworthy information should be used to prove product origin, ensuring the correctness and verification of the provided information.

Table 1 provides an overview of the four criteria, and the evaluation scale applied to assess the documents for use under CBAM.

Table 1: Overview of document assessment criteria and evaluation scales

	Coverage	Accuracy of information	Tamper-proof	Reliability
Definition	Determination of whether the document is utilized in global trade or is limited to specific trade regions or agreements between countries/regions. Additionally, the criterion examines if the document is mandated for global use.	Assessment of whether the document contains detailed and granular information that allows precise identification of the product's origin at the installation or facility level.	Assessment of the document's susceptibility to forgery	Evaluation of the trustworthiness of the information contained in the document, attributed to its official nature and the verification processes involved.
Evaluation scale	**High**: Document exhibits global coverage and addresses CBAM goods. **Medium**: Document has regional coverage and addresses CBAM goods. **Low**: Document is limited to national coverage and addresses CBAM goods.	**High**: Information on product origin is at the facility or installation level. **Medium**: Information on product origin is at the manufacturer level. **Low**: Information on product origin is at the country level.	**High**: Document is highly tamper-proof, with forgery being highly unlikely. **Medium**: Document has moderate tamper-proof characteristics, with forgery being unlikely. **Low**: Document has unsatisfactory tamper-proof characteristics, with forgery being possible.	**High**: Information in the document is highly reliable and verified by a governmental institution. **Medium**: Information in the document is generally reliable and verified by a third party. **Low**: Information in the document is insufficiently reliable.

Source: Authors' scale, based on professional judgement.

2.1 Category 1: Trade and customs documents

Nine relevant trade and customs documents have been identified and systematically evaluated in accordance with the four previously defined criteria. Below the documents are shortly introduced, the results of the assessment are presented in Table 2.

1. **Certificate of Origin (COO):** This document verifies a product's country of origin, stating where it was produced, manufactured, or processed. It is often required by customs authorities during the import clearance process to determine the applicable tariffs or to ensure compliance with trade agreements.
2. **Statement of Origin**: Made out by an exporter, this declaration states that goods comply with the rules of origin under a specific preferential trade arrangement. It is typically included on an invoice or other commercial document and aims to facilitate trade with least developed and developing countries under the EU's Generalised Scheme of Preferences (GSP).
3. **Preferential Certificate of Origin**: Form A: Previously used in the context of the GSP, this certificate allowed products from developing countries to benefit from preferential tariff

treatment when imported into the EU. It had to be issued by customs or an officially authorized body in the exporting country.

4. **EUR-MED Certificate**: Used within the Pan-Euro-Mediterranean (PEM) agreements, this certificate of origin serves as proof that exported goods originate from a participating country. It supports the application of preferential tariffs by demonstrating compliance with specific origin rules in regional cumulation scenarios.
5. **Preferential Certificate of Origin**: EUR.1 Movement Certificate: This document is used for goods traded between the EU and partner countries with which it has preferential trade agreements. It certifies the origin of the goods and their eligibility for reduced or zero duties under the agreement terms.
6. **Suppliers' Declaration**: This declaration provides information on the origin status of goods supplied within the EU or between the EU and partner countries. It is often used to support a formal proof of origin like an EUR.1 or statement on origin when goods are further processed or traded.
7. **Certificate of Conformity (CoC):** A Certificate of Conformity certifies that a product meets the applicable safety, health, and environmental standards or technical regulations. While not a direct proof of origin, it may support origin claims by documenting the product's compliance with regulatory frameworks specific to its production location.
8. **Import/Export Declaration:** This formal document provides customs authorities with essential information on goods entering or leaving a country. It includes data such as the nature, origin, and value of goods and is critical for risk assessment, tariff calculation, and compliance enforcement.
9. **Single Administrative Document (SAD):** The SAD is the standard EU customs declaration form used for imports, exports, and transit procedures. It consolidates multiple customs forms into a single document to simplify and standardize customs processing within the EU and associated countries.

Table 2: Overview: Evaluation of reviewed trade and customs documents

Customs & trade documents	Coverage	Accuracy of information	Tamper proof	Reliability
Certificate of Origin (COO)[5]	Medium	Medium	High	High (verified by government authority)
Statement of Origin: Invoice declaration/Origin declaration[6]	Medium	Low	High	Low (issued by producer)
Preferential Certificate of Origin: Form A[7]	Medium	Medium	High	High (verified by government authority)
EUR-MED[8]	Medium	Medium	High	High (verified by customs authority)
Preferential Certificate of Origin: EUR.1 Movement certificate[9]	Medium	Low	High	High (verified by customs authority)
Suppliers' declaration[10]	Low	Medium	Low	Low (issued by producer)
Certificate of Conformity[11] [12]	Low	Medium	High	High (if, verified by a third party)
Import/Export declaration[13] [14]	Medium	Medium	High	High (verified by customs authority)
Single administrative document (SAD)[15]	Medium	Medium	High	Low (issued by producer)

Sources: Australian Border Force; European Commission; International Chamber of Commerce; U.S. Consumer Product Safety Commission; selected expert interviews.

As shown in Table 2 some custom documents (like e.g. self-declared statement of origin, second document in Table 2) are not verified by independent party and thus reliability cannot be confirmed and cannot provide evidence. Customs documents with "high" reliability can provide information on the country of origin of the product. Nevertheless, these documents only provide information from which facility the products were shipped. It is not evident if the goods were produced in another facility and were transferred to an intercompany before. Therefore, customs document without further documentation might not be sufficient, to verify the origin of a product from a specific factory or installation.

[5] International Chamber of Commerce (2020): ICC Certificate of Origin Guidelines for Customs and Importers

[6] European Commission (n.d.): Proof of origin

[7] European Commission (2016): The European Union's rules of origin for the Generalised System of Preferences – a guide for users

[8] European Commission (n.d.): Movement Certificate EUR.1 or EUR-MED

[9] European Commission (n.d.): EUR.1 movement certificate

[10] European Commission (2018): Application in the European Union of the provisions concerning the supplier's declaration

[11] European Commission (n.d.): Glossary – Certificate of Conformity

[12] U.S. Consumer Product Safety Commission (n.d.): General Certificate of Conformity

[13] European Commission (n.d.): Customs clearance documents and procedures

[14] Australian Border Force (n.d.): Export declaration

[15] European Commission (n.d.): Single Administrative Document (SAD)

Overall, trade and customs documents can be used to **determine the country of production**, e.g. documents that confirm the non-preferential origin (e.g. certificate of origin) of a good. Preferential proofs of origin (e.g. EUR.1, EUR-MED) and declarations of origin on invoices/delivery notes can also be useful, as the existence of a preferential origin often leads to a corresponding non-preferential origin, with the latter being of interest under CBAM.

Determination of a specific production facility / installation does not seem to be possible based on trade and customs documents by themselves. If at all, this can only be established on a case-by-case basis, most likely in cases in which the supplier is also the manufacturer of the good. Then, an identifier could be, for example, a manufacturer number, which is maintained by some companies and possibly stated on the customs declaration.

As an interim conclusion, trade and customs documents, especially those confirming the non-preferential origin of a good (i.e. certificate of origin), are helpful in determining the country of production of a good. On their own, however, they are not sufficient to determine a specific production facility in a manner sufficient under CBAM. Therefore, additional documents should be considered to determine the origin of a product imported in the EU.

2.2 Category 2: Business record documents

In the following potentially useful company-related documents has been identified and scrutinized according to the four above-mentioned criteria. Table 3 provides a summary of this assessment.

1. **Manufacturing Process Documentation**: This documentation outlines each step of the manufacturing process, ensuring transparency, consistency, and regulatory compliance. It helps verify that production occurred at a specific facility under defined conditions.
2. **Manufacturer's Declaration or Affidavit**: A formal statement by the manufacturer affirming details about the product's origin and production. This document is often required during customs checks and serves as a direct declaration of the product's provenance.
3. **Production Records**: These records include information on production dates, facility location, and batch numbers. They offer traceability and are key for confirming when and where a product was manufactured.
4. **Smart Meter Readings**: These digital records capture real-time data on energy consumption at specific facilities. They provide accurate, time-stamped usage information that helps verify operational activity and energy use patterns. The readings are linked to unique meter IDs and facility locations, supporting traceability and validation of production sites and timelines.
5. **Purchase Orders and Invoices for Raw Materials**: These documents prove the procurement of raw materials, showing the names and locations of suppliers. They are crucial for mapping the upstream supply chain.
6. **Quality Control Records:** Reports from inspections conducted during production that confirm adherence to quality standards. They can include facility-specific information, supporting the identification of the manufacturing location.
7. **Production Logbooks**: Daily records of production activities, including machinery use, material consumption, and labour inputs. These logs provide granular insight into the production process and its location.
8. **Shipping and Receiving Records**: These track the inbound receipt of raw materials and outbound shipment of finished goods. They help validate the timeline and flow of goods in and out of a specific facility.

9. **Facility Certifications and Licenses**: Official documents confirming that the production site meets required standards (e.g., ISO (International Organization for Standardization)). They authenticate the legitimacy and location of the facility involved in production.
10. **Audit Reports**: Third-party assessments of production processes and facility compliance. Of importance is here that the auditor is an independent party as only independent verifications can be regarded strong evidence for confirming the location and conditions of production.
11. **Environmental and Social Compliance Reports**: Reports showing compliance with environmental and social standards, typically including data about the production site. They support supply chain transparency and traceability efforts.
12. **Delivery Note**: A document listing the goods shipped, quantities, and sometimes the destination. When signed by the receiver, it can support the chain of custody by confirming delivery from a specific location.

Table 3: Overview of evaluation criteria for all reviewed business records documents

Company-related documents	Coverage	Accuracy of information	Tamper proof	Reliability	How can the document be used?
Manufacturing Process Documentation[16]	High	High	Low	Medium	In combination with ERP review
Manufacturer's Declaration or Affidavit[17]	High	Medium	Medium	Low	Not reliable
Production Records[18]	High	High	Low	Medium	In combination with ERP review
Smart Meter Readings[19]	Low	High	High	High	In combination with delivery notes
Purchase Orders and Invoices for Raw Materials[20]	Medium	Medium	Medium	Low	In combination with ERP review
Quality Control Records[21]	High	Medium	Medium	Medium	In combination with ERP review
Production Logbooks[22]	High	High	Low	Medium	In combination with ERP review
Shipping and Receiving Records[23]	High	Medium	Medium	Medium	In combination with ERP review
Facility Certifications and Licenses[24] [25]	High	Medium	High	Medium	In combination with ERP review

[16] European Commission (n.d.): Guideline for Standard Operating Procedures (SOP)

[17] ICE Cargo (2022.): What Is a Manufacturer's Declaration?

[18] InstantGMP (n.d.): Master Production Records & Batch Production Records Defined

[19] European Commission (n.d.): Smart grids and meters

[20] Corporate Finance Institute (n.d.): Purchase order

[21] International Organization for Standardization (2015): ISO 9001:2015 Quality management systems - Requirements

[22] GMP SOP (n.d.): Standard Operating Procedure: Production Logbooks

[23] Maersk (2023): Shipping documents you need when transporting your cargo

[24] National Institute of Standards and Technology (n.d.): Homepage

[25] International Organization for Standardization (n.d.): Homepage

Company-related documents	Coverage	Accuracy of information	Tamper proof	Reliability	How can the document be used?
Audit Reports[26]	Medium	Medium	High	High	Depending, on the information in report
Environmental and Social Compliance Reports[27]	Medium	Medium	High	High	In combination with ERP review
Delivery Note[28]	High	High	Medium	Medium	In combination with ERP review

Sources: Corporate Finance Institute; DHL Freight Connections; European Commission; GMP SOP; ICE Cargo; Inbound Logistics; InstantGMP; International Organization for Standardization; Maersk; National Institute of Standards and Technology; TÜV SÜD.

Upon analysis, it appears that the **business record documents (except the manufacturers declaration) can be used for tracing the origin of a product**, such as manufacturing process documentation, general production records, production logbooks and delivery notes, if the information is verified through review of the enterprise resource planning (ERP) system. While some of these documents exhibit extensive applicability, certain records exhibit deficiencies in tamper-resistance and reliability. This deficiency arises from the intrinsic nature of internal company documents, which may not undergo rigorous verification processes (e.g., Production Records, Production Logbooks, etc.). Smart meter readings, in contrast, are highly accurate and tamper-resistant but currently have limited coverage, reducing their overall applicability.[29] Generally, trade/customs documents primarily support tariff determination and typically identify exporting parties and countries. They rarely resolve installation identity. Business records (delivery notes, production logs, ERP extracts) capture transaction- and batch-level manufacturing data at the installation, enabling verifier triangulation of installation identity and quantities.

Among the various document types, delivery notes demonstrate suitability for verifying product origin. In contrast to some internal corporate records, delivery notes are routinely exchanged with external entities, have high accuracy of information – in contrast to facility certifications and licenses. Facility certifications (e.g. ISO) validate management systems and site legitimacy but do not provide evidence of the batch-level origin. Delivery notes, in contrast, document specific outbound movements from the installation and therefore provide traceability of the origin for the declared goods. Both evidence types are complementary and should be combined – and sometimes necessitate formal acknowledgment upon receipt, thereby increasing their reliability and resistance to manipulation. Moreover, delivery notes typically encompass detailed and precise information regarding the goods and their provenance, establishing them as a robust and credible source of evidence for tracing product origins.

In cases in which the supplier also manufactures the imported good, the commercial documents (invoices, delivery notes, etc.) - possibly also with a declaration of origin - **can be used to identify the manufacturer** of the good. In the case of merchandise, however, corresponding documents issued by the Tier 2 supplier (e.g. supplier's declaration, invoice, etc.) should be used. The same applies to CBAM-relevant preliminary products.

[26] TÜV SÜD (n.d.): Worldwide responsible accredited production

[27] International Organization for Standardization (n.d.): Building a sustainable path to ESG reporting

[28] DHL Freight Connections (n.d.): Delivery Note

[29] Knayer, T. & Kryvinska, N. (2023): How smart are our companies really? a case study of the current rollout of smart meters in Germany

Observations and suggestions

To ensure the precise allocation of emissions from an industrial facility that manufactures a good imported in the EU, it is essential to provide several documents. The verification of emissions under a 'reasonable assurance' audit[30] necessitates the integration of procurement and production documentation from the manufacturer, as well as comprehensive documents for the purpose of determining origin throughout the supply chain.

Required Documents

Based on the previous analysis, the following set of documents and additional features seem suitable for reliably proving the origin of a product imported into the EU:

- **Certificate of origin**: Necessary customs document. Provides information about the country of manufacture of a good.
- **Delivery note**: These documents must specify the plant address and company details. If the information is not available on the delivery note, one can request the corresponding invoice, which should contain the relevant data. In addition, if the origin is a particular hall or facility within the plant, production documents should supplement the delivery notes to ensure accuracy and traceability of the provided data regarding embedded emissions.
- **Production documents:**
  - **ERP (Enterprise Resource Planning) extracts**: If available, manufacturer should provide extracts from their EPR systems providing further details about the manufacturing of the good in question (e.g. facility of production, precursor materials used, production line, etc.). This information can be used by verifiers to cross-reference information contained on the delivery notes to validate their accuracy.
  - **Production documents**: Should ERP extracts not be readily available from the manufacturer because it does not have an according software system in place, manufacturers should provide other documents that can be used to cross-reference information contained on the delivery note of the good in question (e.g. purchase orders, invoices etc.).
- **System access**: In addition to the previously mentioned documents, direct access of the verifier to the information systems of the manufacturer can be an important element in the verification process. Direct inspection of the system is necessary to ensure alignment between delivery notes and system-generated data, thus verifying their authenticity and accuracy. In such cases, critical sample testing is emphasized, which can be conducted without onsite verification by leveraging virtual site visit techniques.

Verification Methodology

Adopting the described approach has several implications for the verification process:

- **System-based verification**: Delivery notes are more reliable than internal records due to external acknowledgment at receipt. Nevertheless, as delivery notes can be forged or incompletely populated, verifiers should verify the key data (installation, batch, dates, quantities) on the delivery note against the information in the ERP system and, where possible, customs declarations. This can be conducted through virtual side visit techniques, eliminating the need for physical site visits while maintaining the integrity of the verification process.

[30] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism, Annex VI 1(b)

- **Enhanced Reliability through Supplier and Importer Data Verification**: As an additional element of scrutiny, data should be - as far as possible - corroborated with both the supplier and the importer, using details from the delivery notes. Additionally, customs declarations can further increase data reliability through cross-verification.
- **Production and Storage Documents**: Monitoring warehouse movements can deduce what has been produced and stored, providing insights into specific facilities' output.
- **Challenges in Documentation**: In regions without automated EPR systems, manual documentation processes must be rigorously followed and verified, necessitating thorough and precise evidence collection to ensure documentation integrity.
- **Submission Protocol**: All relevant documents, including delivery notes and ERP extracts, should be submitted along a standardized communication template, preferably using the communication template published by EU Commission on CBAM embedded emissions. This template should facilitate the specification and inclusion of these documents to ensure completeness and consistency.

By adhering to these procedures systematically, the verification process for emission allocations is fortified, minimizing potential errors and discrepancies while ensuring compliance and data integrity within reporting practices.

3 Other verification challenges for complex goods under the CBAM: Selected sectoral examples and possible solutions

The verification of embedded emissions under the CBAM is an important step to ensure transparency and fairness in carbon pricing. Accurate carbon pricing prevents under- or over-estimation of carbon costs, thereby maintaining a level playing field where imported goods face the same carbon pricing as EU-produced goods. Equally important is preventing carbon leakage, which occurs when production shifts to regions with less stringent climate policies, undermining the EU's climate goals. Proper emissions verification closes gaps in the CBAM system and incentivizes global decarbonization efforts.[31]

However, challenges in the verification of complex goods[32] can arise, especially in the case when they are produced from simple goods originating from different countries. Furthermore, in cases where CBAM and non-CBAM goods are produced in a facility, it can be challenging to define the attributed emissions of a good due to overlapping production processes.

In the following, selected complex goods are identified for the analysis of potential verification challenges under the CBAM framework.

- **"Cement: 2523 29 00 – Other Portland cement"** accounts for majority of the cement imports[33] and is widely used in construction in EU.
- **"Fertilisers: 3105 - Mineral or chemical fertilisers containing two or three of the fertilising elements nitrogen, phosphorus and potassium; other fertilisers; goods of this chapter in tablets or similar forms or in packages of a gross weight not exceeding 10 kg"** is the most complex good under fertilisers category.
- **"Iron and steel: 7208 - Flat-rolled products of iron or non-alloy steel, of a width of 600 mm or more, hot-rolled, not clad, plated or coated"** is chosen due to the common use of this product in the automotive industry for instance for the construction of vehicle frames, body panels, and other structural components in the EU.
- **"Aluminium: secondary complex aluminium products"** are assessed in this study to address specific challenges in verifying emissions associated with the use of pre- or post-consumer scrap metal. The inclusion of scrap in production introduces variability in the embedded emissions due to the diverse origins and processes involved in recycling. This variability makes it challenging to establish a standardized approach for calculating emissions, which is crucial under the CBAM framework to ensure accurate carbon pricing and prevent potential loopholes in emissions reporting.
- The degree of verification complexity depends on the production processes and number of entities involved. To assess the challenges throughout the verification of complex products, three supply chain complexity levels are considered. The categories and definitions are:

[31] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism

[32] Complex goods are produced in a production process requiring input materials (precursors) and fuels with embedded emissions. Here the embedded emissions are released during the production of relevant precursor materials consumed in the production process.

[33] CEMBUREAU (2024): Position Paper „A Watertight Implementation Of CBAM – Tackling The Risks of Fraud And Circumvention In The Cement Sector", p. 6

- **Single origin goods**: Products manufactured entirely in one facility.
- **Goods with multiple facilities in one country**: Products manufactured through successive processes in multiple facilities within the same country.
- **Goods with cross-border supply chains**: Products involving facilities in different countries, each contributing to the manufacturing process.

These supply chain complexities are considered as different case constellations for each complex product where applicable.

By examining the CBAM regulation[34] and implementing regulation for the transition phase[35] and its Annexes defining sector specific rules (esp. *Annex II Definitions and production routes for goods, Annex III Rules for determining data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods and Annex IV content of the recommended communication from operators of installations to reporting declarants*), verification challenges for complex goods are classified as two key dimensions.[36]

- Challenges in verifying production process system boundaries and production routes, so no double counting of, or data gaps in emissions reporting and
- Challenges in verifying data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods.

For each selected complex good, these verification challenges are evaluated in the following section.

3.1 Verification challenges for Cement: 2523 29 00 - Other Portland cement

In 2023, around 150 million tonnes of cement were consumed in the EU, with other Portland cement accounting for roughly 60 percent of the total.[37] Given that it is the most commonly used type of cement in Europe, other Portland cement is chosen for assessment. A total of 3,871,207.88 tonnes of Portland cement was imported into the EU in 2023. The main countries exporting Portland cement[38] to the EU included Turkey, Ukraine, Tunisia, Vietnam, and Norway.[39] [40]

Several widely used general and sector-specific guidelines for GHG accounting exist for cement manufacturers. ISO 19694-1:2021, 'Stationary source emissions - Determination of greenhouse gas emissions in energy-intensive industries', establishes generic principles and requirements for calculating GHG emissions in energy-intensive industries. It is designed to be used alongside sector-specific parts and covers common methodological issues, site-level performance assessment over time, and the provision of reliable information for reporting and verification. Building on this, ISO 19694-3:2023-03, 'Stationary source emissions - Determination of greenhouse gas

[34] European Commission (2023): Regulation (EU) No 2023/956 of the European Parliament and of the Council of May 10 2023 establishing a carbon border adjustment mechanism

[35] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

[36] CBAM implementation regulation for transition phase is considered for this study because that is the only available implementation regulation as regards reporting obligations as of May 2025.

[37] CEMBUREAU (2025): Key facts and figures

[38] HS Code 252329: Portland cement (excluding White Portland cement)

[39] World Integrated Trade Solution (n.d.): EU imports of Portland Cement (excl. white) imports by country in 2023

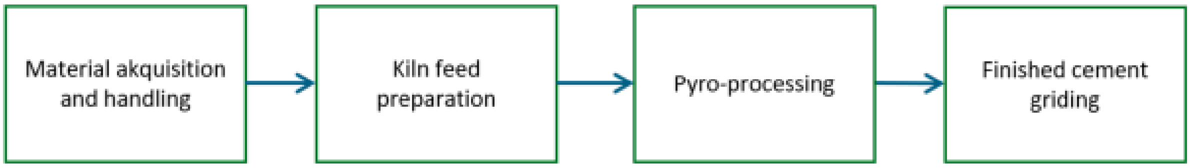
[40] European Commission, Access2Markets (n.d.): EU trade statistics (excluding United Kingdom)

emissions in energy-intensive industries - Part 3: Cement industry', provides a harmonised methodology for calculating and reporting cement-sector GHG emissions at plant, company, or group level. It covers relevant direct and indirect sources, thereby supporting clear system-boundary demarcation and consistent reporting bases. At the organisational level, ISO 14064-1 sets out the principles and requirements for designing, developing, managing and reporting a GHG inventory. This includes determining emission and removal boundaries, managing inventory quality and producing reports ready for verification. It is programme-neutral and emphasises principles such as relevance, completeness, consistency, accuracy and transparency. In terms of cement-specific practice, the Cement Sustainability Initiative's (CSI) 'Cement CO_2 and Energy Protocol' offers a harmonised method to quantify and report CO_2 from cement manufacturing. It addresses all direct sources and the main indirect sources, providing detailed boundary guidance for processes such as clinker production, integrated plants, and standalone grinding stations. The protocol distinguishes between “gross” and “net” emissions, transparently accounting for co-processing and alternative fuels in accordance with the Intergovernmental Panel on Climate Change (IPCC) and the GHG Protocol.

The implementing regulation requires installations in the cement sector to monitor and report emissions associated with the production of goods covered under the CBAM. The aggregated goods categories for cement include both finished cement products (e.g., white Portland cement, grey Portland cement, other hydraulic cements, and aluminous cement) and precursor goods (e.g., cement clinker and calcined clay).

The production of Portland cement under 2523 29 00, involves several key processes: **raw material acquisition and handling, kiln feed preparation, pyro-processing, and finished cement grinding** as seen in Figure 1. These steps ensure that the final product meets the required chemical and physical properties for its various applications.[41]

Figure 1: The key processes of Portland cement production



Source: Own illustration, adelphi.

The process begins with **raw material acquisition**, where the primary element is sourced from calcareous materials such as limestone, chalk, marl, seashells, aragonite, and natural cement rock. These materials are typically excavated from quarries or mines. Alongside calcium, other essential elements such as silicon, aluminium, and iron are also required. These are obtained from materials like sand, shale, clay, and iron ore, which are similarly extracted from open-pit quarries or mines. The second stage is the **preparation of the raw mix**, also known as the **kiln feed.** In this step, the various raw materials are mixed together in precise proportions to achieve the desired chemical composition and physical consistency.[42] Depending on the manufacturing process, some facilities use a **dry grinding method**, where the raw materials are ground without water, while others employ a **wet grinding process**, which involves adding water to create a slurry.[43] The next step is **pyro-processing**, where the raw mix is transformed into clinker. The Portland cement industry uses five methods for the pyro-processing step: **the wet process, the**

[41] U.S. Environmental Protection Agency (n.d.): Portland Cement Manufacturing, p. 11.6-1

[42] U.S. Environmental Protection Agency (n.d.): Portland Cement Manufacturing, p. 11.6-1

[43] Portland Cement Association (n.d.): How cement is made

long dry process, the semidry process, the **dry process with a preheater**, and the **dry process with a preheater and precalciner**. While all these methods achieve the same physical and chemical transformations, they differ in equipment design, operation, and fuel efficiency. Fuel consumption generally decreases in the order listed. In this step the raw material mixture is fed into a **rotary kiln**, entering from the elevated end, while combustion fuels such as coal, natural gas, or occasionally oil are introduced at the lower end. In the kiln the raw materials slowly move downward as the rotation of the kiln continuously mixes them. Meanwhile, the combustion gases flow upward. As the raw materials descend through the kiln, they are exposed to temperatures exceeding 1500°C, causing them to undergo chemical transformations that produce cementitious minerals. Once the clinker exits the kiln, it is cooled in a **clinker cooler**. This cooling process, which can recover up to 30% of the heat input to the kiln system, "freezes" the mineral structure of the clinker, preserving its desirable properties and making it easier to handle. The final step is **finished cement grinding**, where the clinker is ground into a fine powder and transformed into Portland cement. During this stage, up to 5% **gypsum or natural anhydrite** is added to regulate the setting time of the cement. Additionally, other specialty chemicals may be introduced to impart specific properties to the cement, depending on its intended application.[44]

Challenges in verifying production process system boundaries and production routes

Multiple interconnected processes, such as clinker production and cement milling, requiring operators to carefully define which physical units, inputs, outputs, and emissions fall within the system boundaries of each process. This task is further complicated by shared equipment, such as boilers, which necessitate precise allocation of emissions to avoid overlaps. The following box explains several cases for production processes and production routes for Portland cement manufacturing.

Box 1: Production processes and production routes

Case I (single origin goods): It is possible to define a joint production process if cement clinker and other Portland cement are produced in the same installation and all the clinker cement produced is used in cement production as shown in Figure 2. Verifying production processes will be less challenging here, as they will also define the system boundary of the entire manufacturing process.

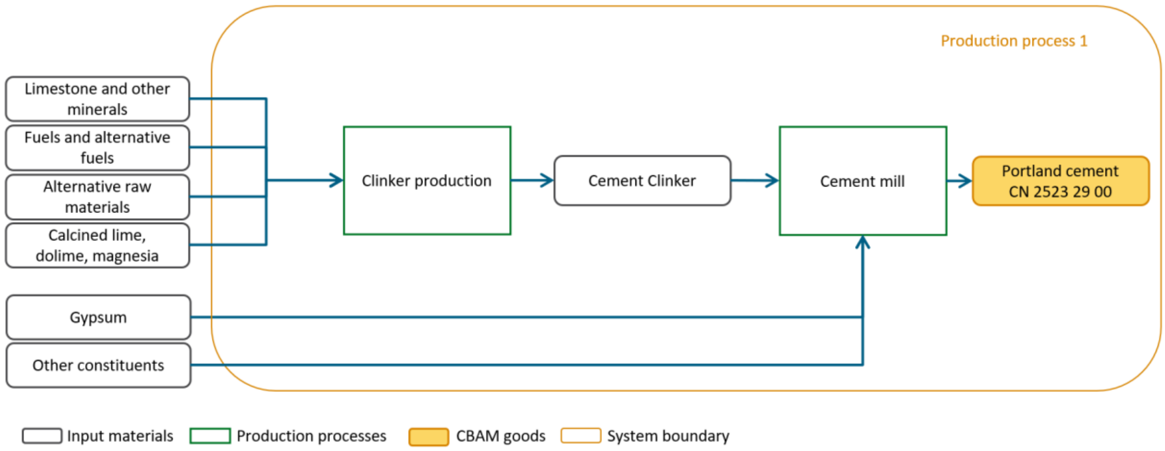
Case II (single origin goods): It is essential that the system is split into two production processes as shown in Figure 3 if clinker cement and other Portland cement are produced in the same installation and some of the clinker cement produced is being sold. It is certain that verification challenges will arise in production processes if equipment is shared between two processes.

Case III (goods with multiple facilities in one country or cross-border supply chains): If any of the precursor (e.g. calcinated clay and clinker cement) is gathered from other installations, the emission input from the purchased precursor should be considered for the relevant production process.

Source: Authors' depiction based on Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023.

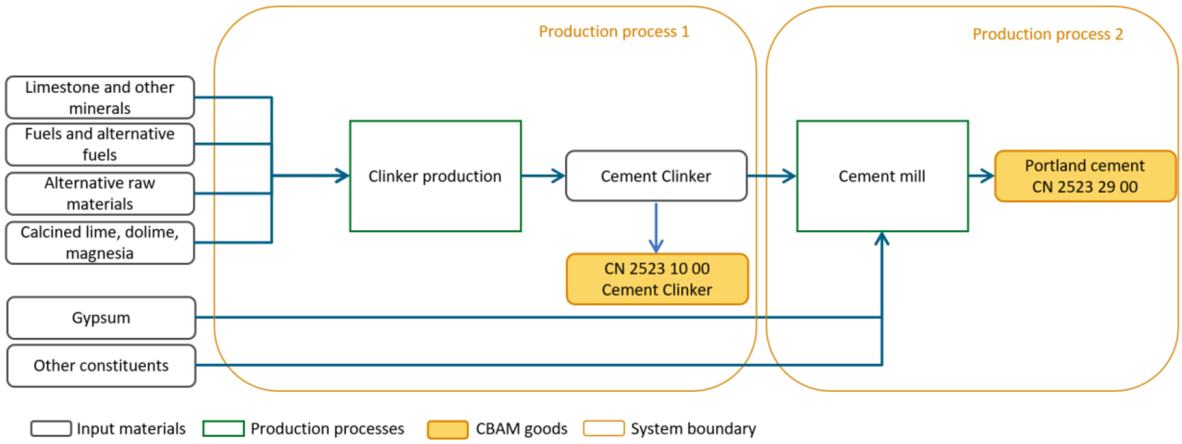
[44] U.S. Environmental Protection Agency (n.d.): Portland Cement Manufacturing, p. 11.6-1

Figure 2: Example - System boundary with one production process



Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

Figure 3: Example - System boundary with two production processes



Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

Challenges in verifying data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods

Implementing regulation[45] requires the following data to be communicated for "Other Portland cement" (CN 2523 29 00):

- The direct and indirect specific embedded emissions of each good
- If used embedded emissions of the relevant precursors (e.g., cement clinker and calcined clay)
- Clinker content of cement (mass ratio of tonnes cement clinker consumed per produced tonne of cement /clinker to cement ratio (CCR)).

The shares of direct and indirect emissions across the cement production processes vary. Indicative shares by process step are as follows: clinker production process (calcination) accounts for

[45] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

roughly 60–65% of total direct emissions[46], fuel combustion accounts for around 35–40%[47], and electricity about 5–6%[48]; cement grinding/blending accounts for predominantly indirect electricity, with negligible direct emissions. Accounting for both **direct emissions and indirect emissions**, in the transitional period is required, with **indirect emissions** from electricity reported separately for the specific installation or production process in the country of origin. Where precursors (e.g., clinker) are sourced cross-border, the verification of indirect emission could be challenging due to varying reporting standards and methodologies of different countries. **Ensuring accurate attribution** of direct and indirect emissions to specific processes, especially in cases where **precursors** like clinker are used, remains complex; variability in production routes (e.g., use of substitutes like calcined clay) adds complexity to defining boundaries and emissions calculations. The precursor products carry their own embedded emissions, which need to be accounted for within the system boundaries. When verifying the amount of precursor coming into or going out of the production processes, require specific attention to avoid double counting or omissions. This means more data sampling and applying additional analytical procedures during the verification.

Stock variations are commonly used for defining activity data of both process input materials (method A) and process output material (method B). For method A, the quantity of fuel or material consumed during the reporting period could be calculated as the quantity of fuel or material imported during the reporting period, minus the quantity of fuel or material exported, plus the quantity of fuel or material in stock at the beginning of the reporting period, minus the quantity of fuel or material in stock at the end of the reporting period. In the case of method B, the production levels of goods or intermediate products could be calculated as the quantity exported during the reporting period, minus the quantity imported, minus the quantity of product or material in stock at the beginning of the reporting period, plus the quantity of product or material in stock at the end of the reporting period. If any of the products of a production process returned into the same production process, this amount should be deducted from production levels to avoid double counting.[49] However, it could be challenging to verify the stock amounts at the beginning and end of years due to variant size of the stocks and inhomogeneous nature of the materials/fuels.

An additional risk has been highlighted by the European Cement Association (CEMBUREAU) that there is a risk of **misstatements or false declarations of clinker-cement ratios** in cement products.[50] EU cement standards classify cement types according to their clinker content, with Other Portland cement (CN 2523 29 00) including CEM I and CEM II. The clinker content of these two types can vary from 65% to 100%. In the case of an installation where different types of cement are produced, verification is carried out for both types of cement. The plant then ships the cement with the higher carbon content but uses the lower emission value against a higher carbon-intensive cement produced in the plant because both fall under the same CBAM category. To prevent this possible misuse, CEMBUREAU proposes adapting the EU's 10-digit Integrated Tariff (TARIC) codes. The additional two digits could help to identify the type of cement (CEM I or CEM II) and the clinker/cement ratio of the imported product in increments of 10 percentage points.

[46] IPCC (2023): IPCC Sixth Assessment Report, Working Group III: Mitigation of Climate Change, Chapter 11: Industry

[47] Joint Research Centre (2020): Deep decarbonisation of industry: The cement sector

[48] CEMBUREAU (2013): The role of Cement in the 2050 Low Carbon Economy

[49] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

[50] CEMBUREAU (2024): Position Paper „A Watertight Implementation Of CBAM – Tackling The Risks of Fraud And Circumvention In The Cement Sector“, p. 5.

3.2 Verification challenges for Fertilisers: 3105 - Mineral or chemical fertilisers

Fertilisers with CN code 3105 is the most complex good under fertilisers category. In 2023 a total volume of 3,767,563 tonnes of fertilizers were imported into the EU. The primary countries exporting fertilisers[51] to the European Union included Morocco, Russia, Norway, United Kingdom, Serbia, Egypt, and Tunisia.[52] The production of fertilisers containing nitrogen, phosphorus, and potassium (NPK) involves several key steps as shown Figure 4. Including **raw material processing, ratio formulation, ingredient mixing and granulation, drying and cooling**, as well as **screening and coating**.

Figure 4: Key production processes of fertilizers

Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

The first step, **raw material processing**, involves transforming nitrogen, phosphorus, and potassium into nutrients. **Nitrogen** from the air is combined with natural gas under high pressure and temperature to produce ammonia[53], also known as the **Haber-Bosch process**. In this energy-intense process[54], around 65% of the natural gas is used for the chemical reaction, while the rest powers production. Ammonia is then converted into nitrogen-based fertilizers like urea, ammonium nitrate, and urea-ammonium nitrate. **Phosphate rock** is crushed and converted into **phosphoric acid**, which is concentrated or mixed with ammonia to create various fertilisers, with by-products like calcium sulphate or calcium nitrate. **Potassium chloride** (muriate of potash) is extracted from **potash rock** and can be treated with nitric or sulphuric acid to produce potassium nitrate or sulphate of potash. If the phosphorus or potassium input materials are processed and mixed with nitrogenous fertilisers in the factory, the relevant direct emissions are relevant to the CBAM. The next step is **nutrient ratio formulation**, where nutrients are blended in precise proportions to meet the specific needs of different crops, based on their type and soil conditions.[55] The next step is **combining the nutrients**, either through mechanical mixing of powdered or granulated nutrients (dry blending) or by dissolving the nutrients in a liquid (slurry mixing). The resulting mixture is then formed into granules using methods such as pan granulation, drum granulation, or tower granulation. Next, the granules are passed through **rotary dryers for moisture reduction**, and **cooling drums** to avoid re-absorption of moisture. In the **screening** step, oversized and undersized particles are removed, while the remaining granules are subjected to various coatings.[56] These may include coating with anti-caking agents to

[51] HS Code 3105

[52] European Commission, Access2Markets (n.d.): EU trade statistics (excluding United Kingdom)

[53] Fertilizers Europe (n.d.): Fertilizers basic

[54] Zheng et al. (2021): Current research progress and perspectives on liquid hydrogen-rich molecules in sustainable hydrogen storage

[55] Risso (n.d.): How to calculate NPK fertilizer formula for plants

[56] Risso (n.d.): How to calculate NPK fertilizer formula for plants

prevent clumping [57] [58] or slow-release coatings to enhance nutrient delivery. After quality control, the fertilizer is packed and shipped to clients.[59]

Challenges in verifying production process system boundaries and production routes

Fertilizer production involves multiple steps, including raw material preparation, and production of mixed fertilizers, all of which should be included within the system boundaries. For defining system boundaries for fertilizers, operators must ensure that all relevant inputs, outputs, and emissions are captured. Relevant precursors, such as ammonia, nitric acid, urea, and even mixed fertilizers themselves, must be included in the system, as they carry their own embedded emissions. This adds complexity, especially when multiple precursors are used or produced on-site. A single production process can yield multiple fertilizer grades using different quantities of precursors, requiring separate determination of embedded emissions for each grade.

Challenges in verifying data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods

Verification of **attributed emissions** could be challenging, when there is shared equipment, such as boilers or steam grids, used across various production processes. For example, emissions from energy inputs like heat or electricity must be allocated proportionally among different processes. Direct emissions include CO_2 from fuel combustion and nitrous oxide (N_2O) from chemical reactions. Properly attributing direct CO_2 emissions from fuel combustion and nitrous oxide (N_2O) emissions from chemical reactions to the specific fertilizer production process is critical but technically demanding. Due to the high investment cost and need for technical capacity for running and maintenance, it not widely used by the installations. The implementation regulation requires the use of precise monitoring equipment, such as Continuous Emissions Measurement Systems (CEMS)[60] or equivalent setups, for measuring nitrous oxide emissions accurately. Large-scale producers may have such equipment in place due to regulatory or operational requirements, whereas smaller producers or those operating in regions with different environmental standards may not have the same infrastructure available. This can result in additional complexity when verifying emissions data.[61] [62] If lines on sites vent to a common stack, or if it is possible to combine stacks into one and a single CEMS at the combined duct could help the producers. If tail gases cannot be combined, one analyser with a heated multiport switching manifold to sample trains sequentially could be used. Outsourcing CEMS operations could be another option for small producers.

Relevant precursors such as ammonia, nitric acid, and urea must be included in the system boundaries as seen in Figure 5: System boundary for fertilizers. Each precursor carries its own embedded emissions, which must be accurately accounted for and attributed to the final fertilizer product. Verifying embedded emissions for precursors that are purchased or produced on-site adds complexity due to several factors, especially when multiple precursors are used in a single production process. Firstly, purchased precursors require detailed emissions data from external suppliers, which may not always follow CBAM-compliant monitoring systems. Secondly, for on-site production, emissions must be allocated proportionally to the specific process or product in which the precursor is used, especially in cases where shared equipment is involved.

[57] Risso (n.d.): How to calculate NPK fertilizer formula for plants

[58] Intratec (2022): NPK Fertilizer production (Phosphonitric Process)

[59] Risso (2018): How is NPK fertilizer manufactured?

[60] CEMS involves continuous measurement of greenhouse gas concentration and volumetric flow

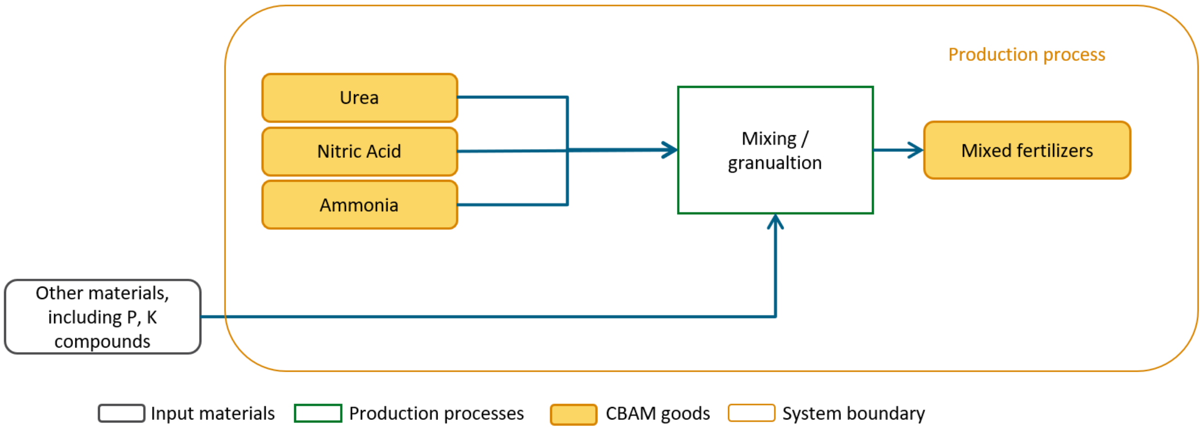
[61] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

[62] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

Finally, when multiple precursors are used in a single production process, cross-referencing emissions data and maintaining consistency across different production routes further complicates verification.

Inputs, outputs, and emissions must be carefully monitored to avoid overlapping boundaries between processes. For instance, when precursors are produced on-site and immediately consumed in fertilizer production, defining separate boundaries for precursor and fertilizer production may lead to **double counting or omissions**.

Figure 5: System boundary for fertilizers



Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

3.3 Verification challenges for Iron and steel: 7208 - Flat-rolled products

Flat-rolled products of iron or non-alloy steel are used in various industries, including automotive, construction, and manufacturing. These products are valued for their strength, flexibility, and ability to be further processed or coated for specific applications.

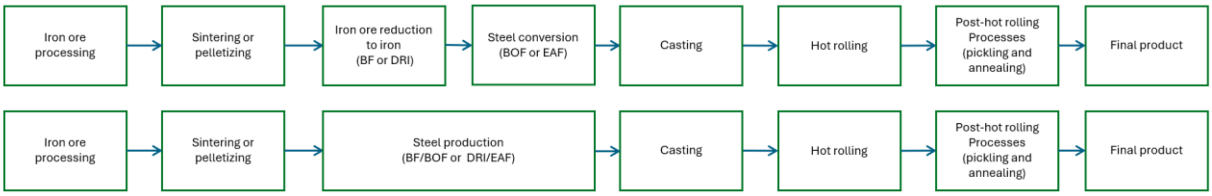
The primary countries exporting these products to the EU include China, Japan, South Korea, India, Vietnam and Turkey. In 2023, the EU imported 25.6 million tonnes of finished steel products and 78.6% of it was flat products. Around one million tonnes of these imported products were stainless-steel flat products and 148,000 tonnes of it was hot rolled sheets and stripes.[63]

The production of flat-rolled products of iron or non-alloy steel under CN Code 7208, involves several key processes as shown in Figure 6: Key production processes of flat-rolled products of iron or non-alloy steel. These products are typically produced in large steel mills where iron ore is first processed into **pig iron** or **directly reduced iron (DRI)**. The iron is converted into **steel** using methods such as the **Blast Furnace/Basic Oxygen Furnace (BF/BOF)** or **Electric Arc Furnace (EAF) methods**. In primary steel production, iron is produced either in the BF as part of the BF/BOF route, or in a DRI plant as part of the DRI/EAF or, more rarely, the DRI/BOF route. Primary steelmaking generally also involves a certain proportion of scrap. In secondary steel production, steel is produced in the EAF using scrap only; no iron ore is required and the reduction step in the BF or DRI plant is not needed. Pig iron from the blast furnace (BF) is converted to steel in a BOF, while direct reduced iron is typically melted and refined in an EAF. This steel is then **cast into slabs**, which are the basic form required for rolling processes. The slabs are reheated and passed through **hot rolling** mills, where they are reduced in thickness and shaped into flat-rolled products. This process occurs at high temperatures, allowing the steel to be easily

[63] EUROFER (2024): European Steel in Figures 2024

formed. After hot rolling, the flat-rolled products may undergo additional processes such as **pickling**, which involves treating the steel with acid to remove surface oxides and impurities. The steel may also be **annealed** to relieve internal stresses and improve ductility. The final products are usually **flat-rolled steel sheets or coils**, which are used in various industries, including **automotive, construction, and manufacturing**. Steel can be processed or coated for specific applications and is commonly used due to its strength and flexibility.[64] In Europe, 96% of the flat steel products are predominantly produced via the integrated BOF route, i.e., from primary steel.[65]

Figure 6: Key production processes of flat-rolled products of iron or non-alloy steel



Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

Challenges in verifying production process system boundaries and production routes, so no double counting of, or data gaps in emissions reporting.

The implementing regulation requires the installations to communicate the production processes and routes under each aggregated good.[66] Whether it is a single installation manufacturing all relevant precursor (pig iron, DRI, crude steel, iron or steel products) or an installation gathering some of the precursors from other installations to make CN 7208, all industrial processes (the 'production route') and the relevant process units, inputs, outputs and emissions should be identified by the operator. During the transitional period, given the complexity of production processes in the iron and steel sector, installations producing two or more of the sector's aggregated goods categories (i.e. sintered ore, pig iron, DRI, crude steel and iron or steel products) are permitted to monitor and report embedded emissions by defining one joint production process or 'bubble', for all the iron and steel aggregated goods categories covered, provided that the precursors produced are wholly used to make the finished iron or steel products. This simplification would ease the verification of process system boundaries. However, after the transition period or for installations where precursors are also sold, each production route should be identified by the complex good operator (See Box 3 for different cases). Especially verification of processes where physical units are used by more than one production process (e.g. boilers supplying steam to several processes, or air compressors providing compressed air) would be challenging.

Box 2: System boundary cases for 7208 - Flat-rolled products of iron or non-alloy steel, of a width of 600 mm or more, hot-rolled, not clad, plated or coated

According to CBAM implementation regulation for transition phase there are three types of system boundaries:

[64] EUROFER (2020): What is steel and how is steel made?

[65] EUROMETAL (2025): Evolution of green steel premiums in Europe: flats versus longs

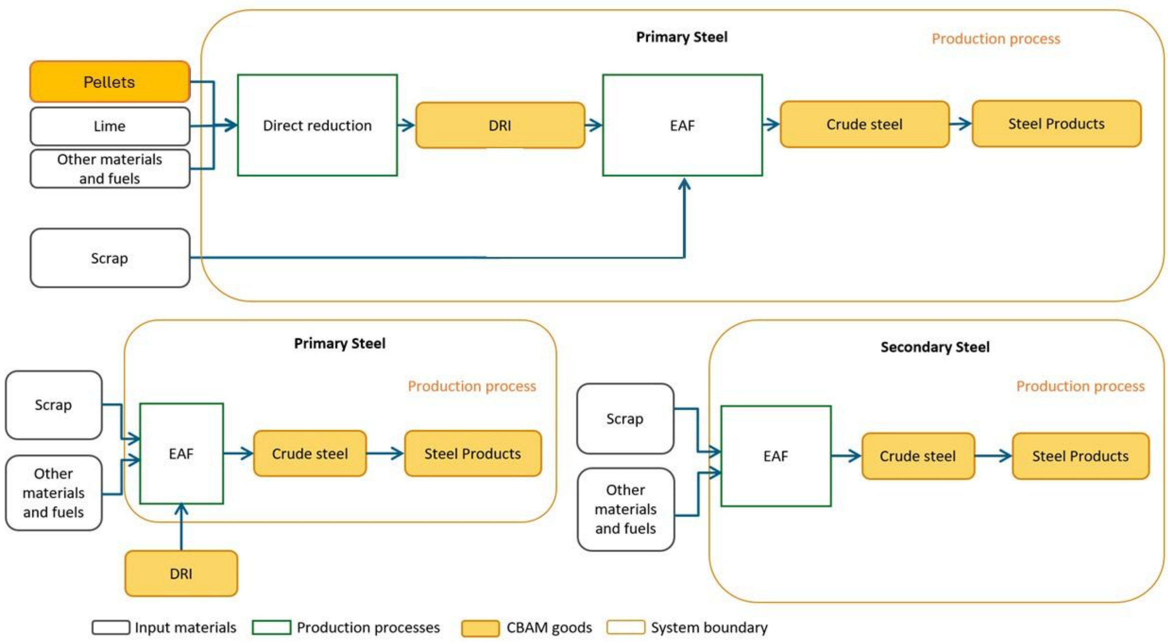
[66] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

- System boundaries cover as one process all steps of an integrated steel plant from production of pig iron or DRI, crude steel, semi-finished products as well as final steel products (single origin goods with BF/BOF, DRI/EAF or DRI/BOF, primary steel)
- System boundaries cover the production of crude steel, semi-finished products and final steel products (single origin goods with scrap/EAF under the secondary steel route or DRI/EAF under the primary steel route with DRI precursor)
- System boundaries cover the production of final steel products starting from crude steel, semi-finished products or from other final steel products which are either received from other installations or produced within the same installation but under a separate production process (goods with multiple facilities in one country or cross-border supply chains)

Source: Authors' depiction based on Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023.

If an installation also produces non-CBAM goods alongside CBAM goods, only production process system boundaries need to be defined for the processes relating to CBAM goods within the installation. However, the verification of input and output of these separate production process system boundaries would not be straightforward due to the common-use physical units. As an example case, an installation manufactures and sells both semi-finished products, e.g. DRI and final steel products. It is likely that the fuel consumption, e.g. natural gas, until the point of semi-finished product is not measured but rather the total fuel consumption of the plant is monitored. Using design parameters of the process units against the outputs could be useful to breakdown the total fuel consumptions.

Figure 7: System boundaries for flat-rolled products of iron or non-alloy steel



Source: Own adaptation based on Guidance document on CBAM implementation for installation operators outside of the EU, European Commission, 2023.

Challenges in verifying data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods

Implementing regulation[67] requires the following data to be communicated for 7208 - flat-rolled products of iron or non-alloy steel, of a width of 600 mm or more, hot-rolled, not clad, plated or coated:

- The specific embedded emissions of each good.
- If used embedded emissions of the relevant precursors (sintered ore, crude steel, pig iron, DRI, iron or steel products).
- The main reducing agent used in precursor production.
- Tonnes scrap used for producing 1 t of the product.
- % of scrap that is pre-consumer scrap.

Indirect emissions (only to be reported during the transitional period) – It is common to generate electricity within the iron and steel production plants especially within blast furnace operations, where waste gas from the blast furnace is used. To avoid double counting of emissions from waste gas used to generate electricity, it is necessary to make a deduction from direct emissions. In this process, verification will be challenging if the amount of waste gas used for electricity production is not measured.

Activity levels for goods produced are used to calculate the specific embedded emissions for the reporting period. In this case of an installation where at least one of the precursors is produced in the plant, not only the total production of flat-rolled products of iron or non-alloy steel but also the total production of precursors should be known. However, if the precursors are not separately sold, the amount of production of these precursors are not usually monitored.

Moreover, no embedded emissions should be attributed to steel scrap from production processes, which is recycled internally to another process. To avoid any double counting of production, only the quantity of final product leaving the system boundaries of the production process should be counted in the activity level. Consequently, all attributed emissions of the production process are accounted for on saleable goods, while scrap and waste have zero embedded emissions.

The carbon content of both input and output materials constitutes a critical parameter in the verification process. Laboratory analysis may be employed to determine the carbon content of manufactured products (such as precursors or complex goods) as well as of scrap metal. For each batch of material or fuel subject to analysis, a representative sample must be obtained. Analytical results may only be applied to calculations concerning the specific batch from which the sample was taken.

However, verifying the carbon content of scrap metal through laboratory analysis poses significant challenges. The heterogeneous nature of scrap-with varying shapes, sizes, and material compositions-makes it difficult to obtain a truly representative sample.

Additional complexity arises in the verification of precursor materials, particularly when these are produced across multiple installations within a single country or along cross-border supply chains. Although installations producing precursors are required to provide relevant data-

[67] European Parliament and Council of the European Union (2023): Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023

ideally using the electronic template specified in the Implementing Regulation-they are not obliged to have this data externally verified prior to transmission to producers of complex goods.

This lack of upstream verification increases the overall verification risk and necessitates more extensive verification procedures by accredited verifiers, potentially resulting in greater time and cost expenditures.

Box 3: Precursors

Annex III of implementing regulation provides the monitoring requirements for precursors.

Case I (single origin goods): If the precursor is produced within the installation, but in a different production process, data sets to be required:

- specific embedded direct and indirect emissions of the precursor as average over the reporting period, expressed in tonnes CO_2e per tonne of precursor,
- quantity of the precursor consumed in each production process of the installation for which it is a relevant precursor.

Case II (goods with multiple facilities in one country or cross-border supply chains): If the precursor is gathered from other installations, data sets to be required:

- the country of origin of the imported goods,
- the unique installation identifier, if available,
- the applicable United Nations Code for Trade and Transport Location (UN/LOCODE) of the location,
- an exact address and its English transcript,
- the geographical coordinates of the installation
- the production route used,
- the values of applicable specific parameters required for determining the embedded emissions,
- specific embedded direct and indirect emissions of the precursor as average over the most, recent available reporting period, expressed in tonnes CO_2e per tonne of precursor,
- the start and end date of the reporting period used by the installation from which the precursor was obtained and
- the information on the carbon price due for the precursor, if relevant.

The installation producing the precursor shall provide the relevant information, preferably by means of the electronic template mentioned in the implementing regulation.

Source: Authors' depiction based on Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023.

Biomass may serve as an alternative fuel in production processes. However, verifying the biomass content and the associated emissions presents notable challenges. If the biomass does not originate from municipal solid waste, its emissions may only be considered climate-neutral ("zero-rated") when specific sustainability and GHG savings criteria are met. These criteria are defined in the revised Renewable Energy Directive (RED II). Ensuring compliance with RED II requirements is therefore essential for accurate emission accounting and may require detailed documentation of biomass origin, processing, and supply chain emissions.

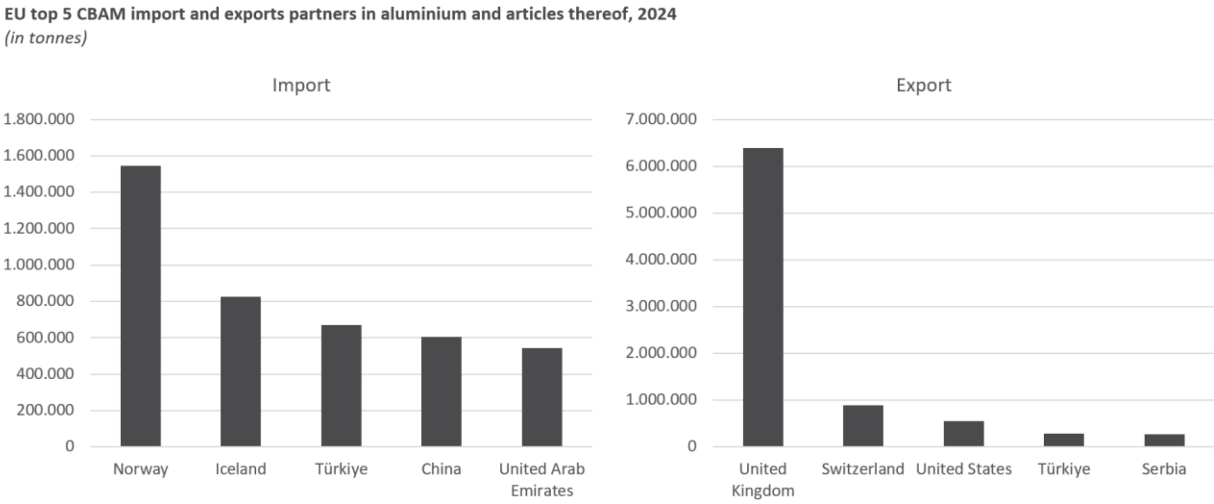
3.4 Verification challenges for Aluminium: 7601-7616 - Unwrought aluminium and products

Aluminium was selected for the assessment due to its widespread application across numerous industries, making it a critical product in the context of the CBAM. Its relevance is further underscored by the global scale of its production and trade. Moreover, aluminium products often involve scrap metal as an input, offering a representative case for evaluating GHG accounting challenges associated with recycled materials. The recycling process for aluminium is well-established internationally and allows for indefinite recyclability without significant loss of material quality, presenting both opportunities and complexities for accurate emissions quantification.

In 2024, the European Union imported approximately €29.5 billion worth of aluminium and related articles and exported €18.4 billion, resulting in a trade deficit of €11.1 billion. Compared with 2019, imports of aluminium increased by 29.9% (+€6.8 billion) and exports rose 21.3% (+€3.2 billion). These monetary increases occurred despite a decline in the physical weight of exports by 1.7% and imports by 6.2%, suggesting that the value increase was primarily driven by rising prices. The top five sourcing countries were Norway, China, Türkiye, Iceland and Switzerland and the top five exporting countries were the United Kingdom, United States, Switzerland, Türkiye and India (see Figure 8).[68]

Specifically, in 2023, the EU imported about 3.24 million tonnes of alloyed and unwrought aluminium, valued at approximately $9.13 billion.[69] Additionally, imports of aluminium waste and scrap amounted to $1.1 billion. Other aluminium products, such as tubes and pipes, contributed $216 million to the total import value.[70]

Figure 8: Top CBAM aluminium import and export partners



[68] Eurostat (2025): EU recorded a trade deficit of €11.1 billion in aluminium

[69] Worldbank (2025): European Union Aluminium unwrought, alloyed imports by country in 2023

[70] Trendeconomy (2024): Aluminium waste and scrap | Imports and Exports | 2023

Please note that the EFTA countries (Iceland, Liechtenstein, Norway and Switzerland) are exempt from CBAM.
Source: Own illustration based on Eurostat (2025).

The verification of emissions for secondary complex aluminium products, particularly those derived from recycled scrap metal, poses significant technical and procedural challenges under CBAM. In secondary aluminium production, the recycling process inherently involves multiple stages and diverse facilities, making it challenging to establish consistent and accurate emissions data. The following part focuses on the primary challenges encountered in this sector, emphasizing the challenges in delineating process boundaries, capturing accurate emissions data, and integrating disparate data sources.

The aluminium production pathway of interest consists of two main (sub-)products. The first is unwrought aluminium, which is derived from primary aluminium and/or secondary aluminium as key precursors. The second includes more complex aluminium products, such as plates, rolled sheets or strips where the precursor is unwrought aluminium – see Table 4.

Table 4: Aluminium production route and relevant precursors

Aluminium production route	Relevant precursors
Unwrought aluminium (CN 7601) *Primary aluminium* *Secondary aluminium*	*For primary aluminium*: No relevant precursors *For secondary aluminium*: Unwrought aluminium from other sources, if used in the process
Aluminium products (CN 7603 - 7616)	Unwrought aluminium (differentiated between primary and secondary aluminium, if known), other aluminium products (if used in the production process).

Source: European Commission, 2023. Guidance document on CBAM implementation for installation operators outside the EU.

The uncomplex product, unwrought aluminium, is produced via two distinct production routes. In the primary smelting route, aluminium is produced through the electrolysis of alumina in electrolytic cells, where carbon anodes, either pre-baked, which require frequent replacement, or continuously baked anodes, are consumed. This process generates carbon dioxide, carbon monoxide and perfluorocarbons as the liberated oxygen from alumina reacts with the carbon. The system boundaries of primary aluminium production include raw material preparation (including the storage of additives), the entire electrolytic cell process and the casting plant, which covers holding furnaces and conveying systems. Notably, the materials consumed in this route, such as alumina, carbon anodes, cryolite, and other additives, are treated under CBAM as raw materials with zero embedded emissions.[71]

In contrast, secondary melting involves the production of aluminium primarily from post-consumer scrap collected through recycling. This process begins with the sorting and pre-treatment of scrap, which may involve de-coating, de-oiling, drying, and pre-heating, followed by melting in a suitable furnace (rotary, reverberatory, or induction). Subsequent steps include alloying, melt treatment (for instance, through salt addition or chlorination), and casting into ingots, blocks, billets, or slabs, with typical fuel sources being natural gas, Liquified Petroleum Gas (LPG), or fuel oil. The system boundaries for secondary melting cover the complete furnace operation (including charging, melting, and holding) and the casting plant steps.[72]

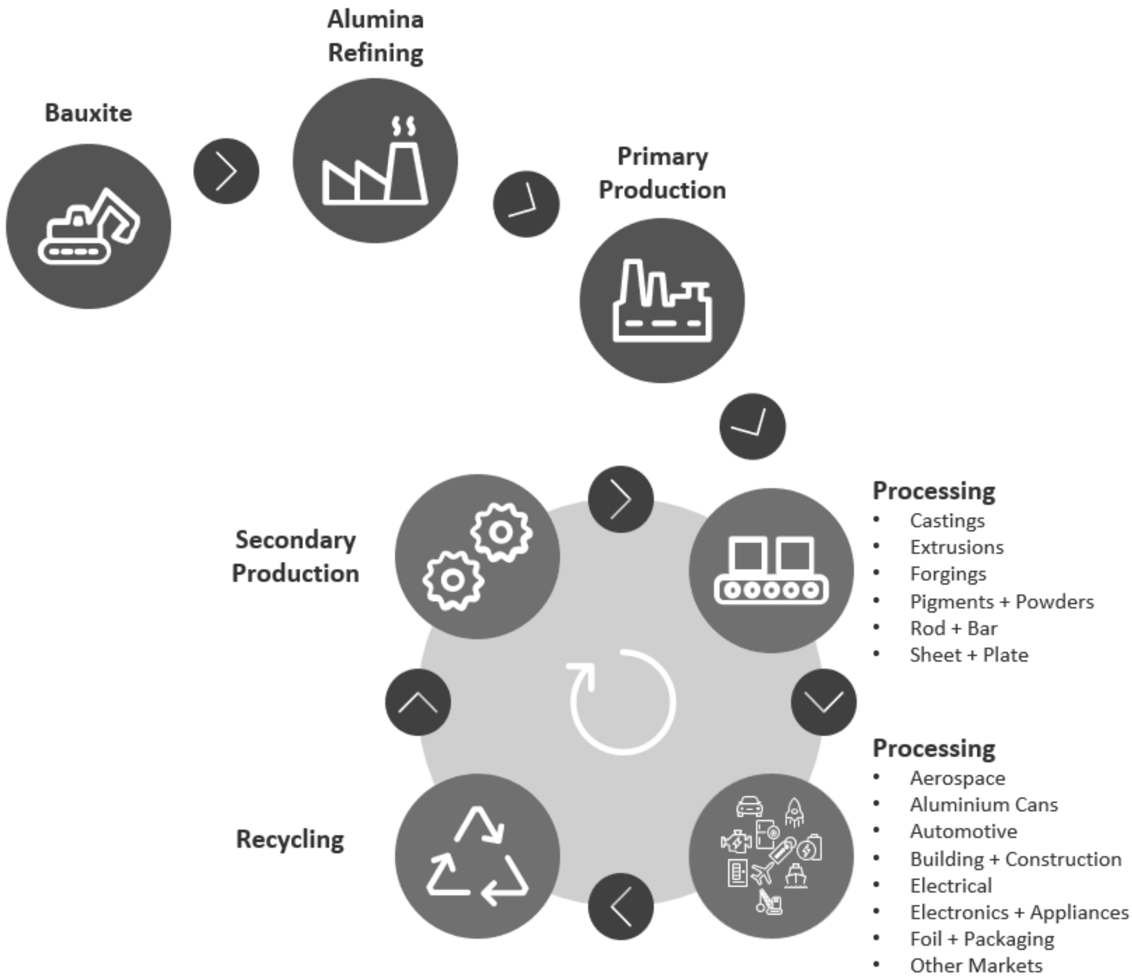
Aluminium products, defined as complex goods produced from further processing of unwrought aluminium (alloyed or unalloyed), are manufactured using forming processes such as extrusion, casting, hot and cold rolling, forging, and drawing, followed by finishing activities like sizing,

[71] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

[72] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

annealing, and surface treatment - see Figure 9. Relevant precursor materials in this context include both unwrought aluminium and semi-finished aluminium products. However, primary and secondary aluminium are to be treated separately due to their differing embedded emissions. Indirect emissions arising from electricity consumption during these processes must also be monitored.[73]

Figure 9: Aluminium production process



Source: Own illustration based on Aluminium association (2024): Semi-Fab LCA Technical Toolkit.

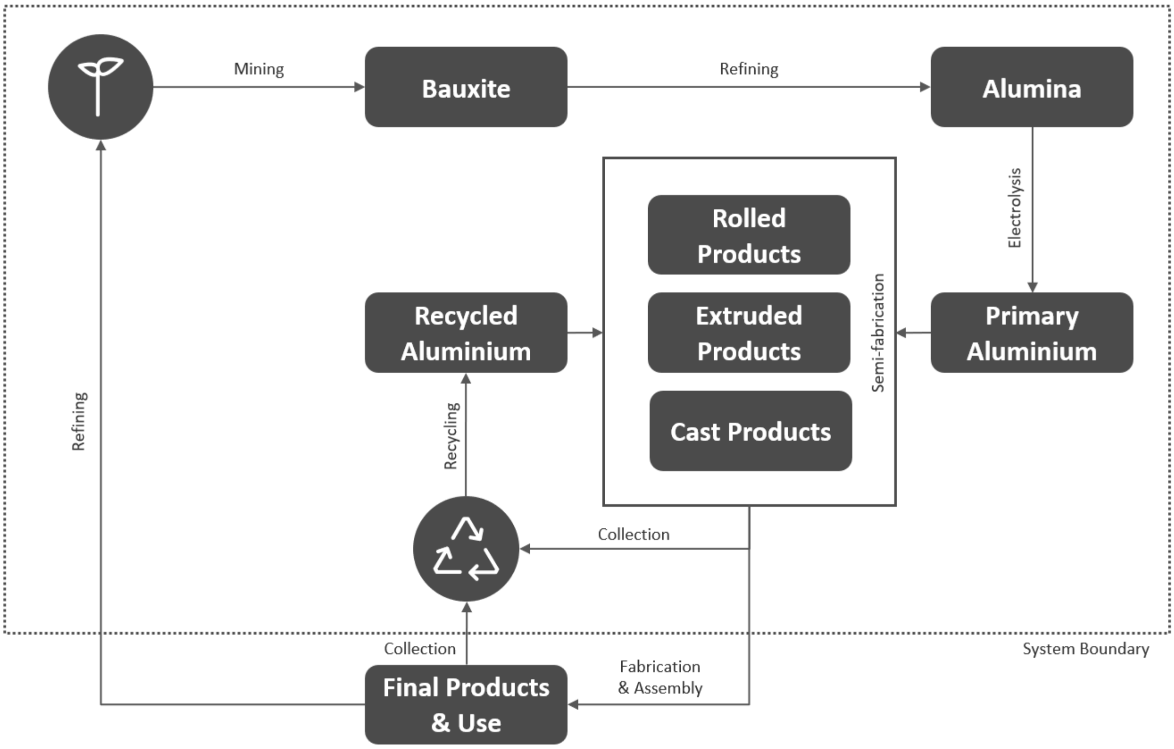
Challenges in verifying production process system boundaries and production routes

One of the foremost challenges for GHG verification is accurately defining the production process boundaries. In secondary aluminium production, scrap metal originates from various end-of-life products and off-spec materials (material that does not meet the quality materials of manufacturers) and off-cut materials (leftover quantities of material remaining as production waste or return), each with its own material composition profile. The processes of sorting, remelting, and alloy adjustment are often fragmented, taking place at different operational stages that may be in separate facilities. This fragmentation makes it challenging to clearly define where one process ends and another begins, complicating the accurate allocation of emissions to specific stages without overlap or omission. Furthermore, when recycled scrap re-enters the production cycle, there is an inherent risk of double counting emissions if the embedded carbon in the scrap is not

[73] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

correctly isolated from emissions generated during reprocessing. The GHG emissions are often analysed using the LCA methodology. It is common standard to assess the emission from cradle-to-grave, which means all emissions from mining until recycling. However, the system boundary of CBAM excludes the mining step from the system boundary resulting in a situation where common LCAs of companies cannot be used for CBAM calculation without adjusting the results – see Figure 10 for an example of an LCA system boundary of aluminium production.[74]

Figure 10: Example of a Life Cycle Assessment system boundary of aluminium production



Source: Own illustration based on Aluminium association (2024): Semi-Fab LCA Technical Toolkit.

Another significant challenge arises from the variability in the chemical composition and physical condition of the scrap metal. Recycled aluminium can exhibit considerable heterogeneity due to differences in the original alloy composition, contamination levels, and the extent of degradation from previous use. This variability directly affects the emission factors used in the carbon footprint calculation. Standard default values may not capture these nuances accurately, leading to either an underestimation or overestimation of the true emissions. The lack of a uniform method to analyse and adjust for these differences in scrap composition adds another layer of complexity to the verification process.[75]

Challenges in verifying data including on emissions at installation level, attributed emissions of production processes, and embedded emissions of goods

Accurate emissions verification relies heavily on the quality of data obtained from various measurement instruments and monitoring systems. In secondary production facilities, direct emissions from melting furnaces, refining units, and alloy adjustment processes are largely measured using a range of sensors and metering devices. However, these instruments can differ widely in terms of calibration, sensitivity, and measurement intervals. Inconsistent measurement

[74] Aluminium association (2024): Semi-Fab LCA Technical Toolkit

[75] Institut de Recherche Technologique (2023): Technical Report „Market development for secondary casting alloys beyond motor blocks – study on casting alloy market and recycling"

practices across facilities - whether within a single country or across borders - can lead to significant data gaps and uncertainties. Moreover, the transient nature of recycling operations, with fluctuating energy inputs and process conditions, makes it even more challenging to capture a consistent and representative set of emissions data.[76]

Solutions for challenges in verifying boundaries and data

In the context of implementing CBAM requirements for aluminium and other energy-intensive products, ISO standards can play a supporting role across several phases of the MRV (Monitoring, Reporting, Verification) process. ISO 19694-4:2023[77], the IPCC Guidelines[78], and methodologies published by the International Aluminium Institute (IAI)[79] provide a detailed, sector-specific methodology for quantifying direct greenhouse gas emissions from primary aluminium production processes, such as electrolysis and anode baking. This is particularly relevant during the monitoring phase, where accurate and installation-specific emissions data must be collected. ISO 19694-1:2021[80] complements this by offering a general methodological framework applicable to stationary sources in energy-intensive industries, guiding the definition of system boundaries, data quality requirements, and calculation procedures. These standards help ensure that emissions data are not only technically sound but also traceable to specific installations, which is a key requirement for proving product origin under CBAM. Furthermore, ISO 14064-1 supports the reporting and verification phases by providing a structured approach to organizational-level greenhouse gas accounting, including principles for transparency, consistency, and completeness. While CBAM is a legally binding EU regulation focused on compliance and enforcement, the ISO standards are voluntary but internationally recognized tools that can enhance the credibility, comparability, and auditability of emissions data. Their integration into CBAM implementation can help bridge the gap between regulatory requirements and operational practices, especially in cases where third-country producers must demonstrate the carbon intensity of products from specific installations. For primary aluminium production, specific reference should be made to the methodologies of the IAI, which collects internationally applicable emissions data in line with IPCC guidance.[79]

Additional solutions for verifying data are elaborated on in the sections “Considerations for validating pre- and post-consumer aluminium scrap” and the general section “Observations and suggestions”.

Distinction between pre-consumer and post-consumer scrap aluminium in GHG calculations

A critical aspect of accurately calculating GHG emissions in the aluminium recycling sector lies in distinguishing between pre-consumer and post-consumer scrap. Pre-consumer scrap, generated during the manufacturing process or from off-spec production, typically maintains a higher quality and a more consistent chemical composition compared to post-consumer scrap. In contrast, post-consumer scrap originates from end-of-life products and is subject to degradation, contamination, and variability in composition. This differentiation is essential because the carbon

[76] World Aluminium/International Aluminium Institute (2020): Good practice guidance: Measuring perfluorocarbons

[77] International Organization for Standardization (2023): Stationary source emissions - Determination of greenhouse gas emissions in energy-intensive industries Part 4: Aluminium industry

[78] Intergovernmental Panel on Climate Change (2006): IPCC Guidelines for National Greenhouse Gas Inventories. Metal Industry Emissions, Volume 3, Chapter 4

[79] International Aluminium Institute (2021): Aluminium Carbon Footprint Methodology. Good Practice for Calculation of Primary Aluminium and Precursor Product Carbon Footprints

[80] International Organization for Standardization (2021): Stationary source emissions - Determination of greenhouse gas emissions in energy-intensive industries Part 1: General aspects

footprint attributed to recycling processes can vary significantly depending on the quality and origin of the scrap used.

The importance of this distinction stems from several factors. First, the emissions embedded in pre-consumer scrap can be higher since these materials directly can stem from primary aluminium which has significantly higher GHG emissions than secondary aluminium (see Tables 5 and 6). Although, the recycling of pre-consumer scrap can often be accounted for using standard emission factors with a higher degree of confidence because it has not undergone the individual processing, melting and casting processes of post-consumer scrap where it may exhibit a wider range of contaminants and impurities, which can alter melting efficiencies and require additional energy for processing. Consequently, the GHG calculations for processes involving post-consumer scrap must incorporate more complex adjustments, potentially using default factors or laboratory-based verifications to account for these variances[81]. Nevertheless, an additional note in the CBAM regulatory guidelines specifies that if the product contains more than 5% alloying elements, the embedded emissions should be calculated as if the alloying elements were unwrought aluminium from primary smelting, which can simplify this challenge in this specific case.[82]

These different process steps are the reason why it is defined in the CBAM regulation that GHG emissions for post-consumer scrap is considered zero[83] with the result that it would be beneficial for importers of scrap aluminium to label as much aluminium as possible as post-consumer scrap aluminium. The resulting challenge is in setting up robust auditing processes to verify and validate the correct labelling of pre- and post-consumer scrap aluminium.

Table 5: Primary aluminium environmental footprint (1000 kg, cradle-to-gate)

Inventory parameter	Unit	Bauxite mining	Alumina refining	Electrolysis	Cast house	Total
Primary energy demand	Gigajoule (GJ)	0,61	32,87	99,93	1,91	135,32
Global warming potential	Kg CO_2e	48,49	2801,58	5489,62	115,62	8455,31

Source: The aluminium association (2024): Semi-Fab LCA Technical Toolkit.

Table 6: Secondary aluminium environmental footprint (1000 kg, cradle-to-gate)

Inventory parameter	Unit	Scrap processing, melting and casting	Dross & Salt Cake Recycling	Primary Ingot	Total
Primary energy demand	Gigajoule (GJ)	9,14	0,04	0,00	9,18
Global warming potential	Kg CO_2e	524,59	2,13	0,00	526,71

Source: The aluminium association (2024): Semi-Fab LCA Technical Toolkit.

Despite the clear need for differentiation, significant challenges remain in its practical implementation. One of the primary challenges is the accurate identification and segregation of scrap

[81] Aluminium association (2024): Semi-Fab LCA Technical Toolkit

[82] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

[83] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

types within the supply chain. In some recycling operations, pre-consumer and post-consumer scrap may be co-mingled during collection or processing, leading to challenges in attributing specific emissions to each category.[84] Thus, a rigorous verification of claimed proportions of pre-consumer and post-consumer scrap aluminium is essential.

Multi-facility and cross-border challenges

Production of complex aluminium products often involves operations spread across multiple facilities, sometimes spanning different national jurisdictions. Each facility may adhere to different monitoring standards and reporting practices, which complicates the process of data harmonization. In cross-border supply chains, the differences in regulatory frameworks, emission factor calculations, and data collection methodologies further exacerbate the challenge. Operators face the arduous task of reconciling disparate datasets to form a coherent picture of the overall emissions associated with the final product. Without a standardized approach, the risk of misalignment and data inconsistencies remains high, undermining the credibility of the emissions verification process.

Specific challenges for the different cases

Case I (Single-origin goods): For aluminium goods produced entirely within one facility, verification of GHG emissions focuses on defining system boundaries and ensuring comprehensive emissions monitoring. Emissions from processes such as scrap melting and rolling must be accurately attributed to the final product. Misclassification of scrap aluminium - whether pre-consumer or post-consumer-can lead to discrepancies in emissions reporting.

Case II (Multiple facilities in one country): When production spans multiple facilities within a single country, challenges arise in integrating emissions data across installations. Transport emissions may complicate monitoring, because they are not included in CBAM, but are mostly included in product carbon footprints and LCA's and due to logistical overlaps. Accurate attribution of emissions to specific production processes is critical to avoid data gaps or double counting. Robust data management systems are essential to consolidate emissions data from multiple facilities.

Case III (Cross-border supply chains): Cross-border supply chains introduce additional complexity due to varying carbon pricing systems and regulatory standards across jurisdictions. Emissions data for precursor materials, such as unwrought aluminium, must be obtained from non-EU suppliers, which can be challenging.[85]

Considerations for validating pre- and post-consumer aluminium scrap

It is critical to establish precise production process boundaries. This is essential to avoid overlap and double counting of emissions. Implementing standardized measurement protocols, in line with international frameworks such as ISO 14067[86], ISO 19694-1[87], ISO 19694-4[88], and the IAI's Carbon Footprint Methodology[89], can mitigate the variability in data acquisition.

[84] Friedrich et al. (2023): Mapping study on aluminium melt purification from post-consumer scrap

[85] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

[86] International Organization for Standardization (2018): ISO 14067 2018: Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification

[87] International Organization for Standardization (2021): Stationary source emissions - Determination of greenhouse gas emissions in energy-intensive industries Part 1: General aspects

[88] International Organization for Standardization (2023): Stationary source emissions - Determination of greenhouse gas emissions in energy-intensive industries Part 4: Aluminium industry

[89] International Aluminium Institute (2021): Aluminium Carbon Footprint Methodology. Good Practice for Calculation of Primary Aluminium and Precursor Product Carbon Footprints

To face the challenge of validating pre- vs. post-consumer aluminium scrap and to detect gaps or inconsistencies in reporting and thereby close potential CBAM loopholes, several standard document types can be examined.

The first document types are delivery notes (see part "content and methodology – verification of product origin") with included scrap codes. Some delivery notes use reference standardized scrap classifications as per DIN EN 13920-(1-16):2003, listing categories such as castings, extrusion remnants, or wire offcuts. Suppliers also use ISRI codes[90], for example "new aluminium can stock" for pre-consumer material and "post-consumer aluminium can scrap" for post-consumer material. Verifiers could require delivery notes using those standards and should verify that these codes align consistently with declared batch numbers.[91]

The second document types are supplier declarations under ISO 14021:2016. According to this international norm, suppliers issuing self-declared environmental labels must specify, by mass or volume fraction per shipment, the shares of pre-consumer (manufacturing off-cuts) versus post-consumer (end-of-life) scrap delivered. Verifiers could confirm completeness of these declarations and conduct spot checks against retained sample material to ensure reported ratios reflect actual composition.[92]

The third document types are certificates issued by different organizations. This could be, for example by the Aluminium Stewardship Initiative's Chain of Custody Standard V2.1 (ASI CoC Standard) or the Recycled-Content Certificates by the Scientific Certification Systems organization according to the Scientific Certification Systems (SCS) Recycled Content Certification Standard V8.0. The ASI CoC Standard requires certified entities to document recycled content methodology, including how pre- and post-consumer scrap is distinguished and tracked. Verifiers should cross-check CoC certificates with warehouse records and delivery documentation, ensuring that mass-balance calculations have been correctly applied and no double-counting between categories has occurred[93] (Aluminium Stewardship Initiative, 2022). The SCS Recycled Content Certification Standard details audited percentages of pre- and post-consumer material, supported by underlying audit reports and mass-balance worksheets.[94] The European Aluminium Association's Program Rules similarly require separate disclosure of the two scrap fractions in Environmental Product Declarations.[95]

To validate if an aluminium scrap material is post-consumer or pre-consumer aluminium scrap, verifiers could require one of the document types as documented proof and review the associated audit findings of the certifications. Also, they should ensure that batch numbers of imported aluminium scrap match the delivery notes and issued certificates or documents. By systematically reviewing these documents and performing cross-checks against physical inventories, verifiers can uncover potential reporting inconsistencies and ensure that pre- versus post-consumer scrap declarations are accurate, transparent, and fully compliant.

These solutions are likely to require significant investment in technology and regulatory coordination between importers, producers and verifiers to be effectively implemented. Addressing

[90] Institute of Scrap Recycling Industries (2024): ISRI Scrap Specifications Circular No. 1.

[91] DIN EN 13920-1:2020 (2020): Aluminium and aluminium alloys - Delivery conditions for sheets and plates - Part 1: Delivery conditions for anodized, painted or plastically laminated sheets and plates; narrow strips.

[92] International Organization for Standardization (2016): ISO 14021: Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling).

[93] Aluminium Stewardship Initiative (2022): Chain of Custody Standard V2.1

[94] SCS Global Services (2024): Recycled Content Certification Standard V8.0

[95] European Aluminium Association (2020): EPD Program Rules for the Environmental Product Declarations of Aluminium Products

these challenges is imperative for achieving transparent and reliable emissions reporting in the aluminium recycling sector.

Observations and suggestions for all complex goods

While the challenges are multifaceted, several strategies can be adopted to address them. Establishing **clear and precise production process boundaries** is critical to avoid overlap and double counting of emissions. Developing **sector-specific guidelines** is essential for ensuring consistency in defining system boundaries and emissions reporting. Additionally, harmonized standards to account for GHG emissions in the upstream value chain should be adjusted or extended to align with CBAM requirements, excluding mining steps where necessary. This ensures that companies can adapt their existing practices without significant overhauls, reducing the burden on operators.

Enhanced collaboration among facilities and the **adoption of a centralized data management system** would facilitate better data integration and traceability. Moreover, the **use of independent third-party audits and regular consistency checks** can help validate the accuracy of the reported emissions and reconcile discrepancies arising from cross-border operations. Verifiers can play a pivotal role in ensuring compliance with CBAM requirements as they verify the accuracy of emissions data. The use of default values for embedded emissions should be justified, and monitoring methodologies must adhere to best practices, including calculation-based and measurement-based approaches. Verifiers should also confirm the effective carbon price reported by operators, including any rebates or free allocations.[96]

Capacity building and training are vital for ensuring the effectiveness of the verification process. Specialized training programs for verifiers can equip them to handle the complexities of multi-facility operations and cross-border supply chains.

Cross-border supply chain complexities require **international collaboration** to harmonize emissions reporting standards and verification procedures. Agreements between countries can facilitate this process, ensuring consistency across jurisdictions. The use of unique installation identifiers, along with detailed information on production routes, including geographical coordinates and emission factors, can further streamline verification efforts.

For the metal recycling sectors, distinguishing between **pre- and post-consumer scrap** is critical for accurate emissions calculations. Specific proof of documents could be used to validate the type of the scrap metal.

Finally, verification support tools may enable the overall process, as long as the impartiality and independence of the verifier remain fully intact. **Centralised platforms** may be used to enable the structured upload of emissions data and to run automated, formal consistency checks. These platforms can also facilitate communication between installations and verifiers, promoting transparency. **Periodic independent audits** can further ensure the accuracy of reported data and identify areas for improvement.

By implementing these solutions, stakeholders could address the challenges associated with verifying complex goods under CBAM, ensuring transparency, consistency, and compliance with the mechanism's objectives.

[96] European Commission (2023): Guidance document on CBAM implementation for installation operators outside the EU

4 Conclusion

The challenges of verification under CBAM demonstrate the delicate balance required to achieve environmental goals while overcoming practical implementation obstacles. The aim of CBAM is to create a level playing field for carbon pricing between EU-produced and imported goods, thereby promoting transparency and reducing carbon leakage. However, its success hinges on overcoming verification challenges stemming from the complexity of global supply chains, diverse production processes and varying regulatory environments.

A key challenge lies in reliably identifying and verifying the origin of products and their associated emissions. Although trade and customs documents, such as certificates of origin, offer some insight into a product's origin, they frequently fail to pinpoint the specific manufacturing facility. Similarly, although business records such as delivery notes or production logs offer more granular data, their reliability may be compromised by a lack of tamper-proof mechanisms and standardised global practices. These limitations necessitate a multi-document approach that integrates various sources of information to enhance verification accuracy.

The verification process becomes even more complex for goods with multi-facility or cross-border supply chains. In sectors such as cement, fertilisers and steel, for example, attributing emissions to specific products or processes is complicated by shared equipment, diverse production routes and the inclusion of precursors with their own embedded emissions. Accurate data collection and allocation can benefit from measurement-based methods such as CEMS, which measure emissions directly. However, CEMS also have limitations, including potential leakage losses before measurement points and higher uncertainties compared with calculation-based methods. In addition, suitable flow-measurement technologies - which are well-developed in Europe due to ETS requirements - may not be available with sufficient accuracy in some third countries. Although CEMS monitoring for N_2O is mandatory in Europe, it is not globally available, particularly in regions with less stringent regulatory frameworks.

To address these challenges, CBAM implementation must emphasize robust verification methodologies. This includes ERP system-based verification, cross-referencing supplier and importer data, and leveraging virtual site visit techniques where feasible. Additionally, standardized communication templates and enhanced cooperation between stakeholders in the supply chain can improve data consistency and reliability.

In conclusion, the CBAM has the potential to contribute significantly to global decarbonisation efforts; however, its effectiveness will depend on the successful resolution of key verification challenges. By fostering collaboration, investing in monitoring technologies, and refining regulatory frameworks, the EU can ensure that CBAM achieves its dual goals of environmental integrity and equitable carbon pricing.

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