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Impact of the European Carbon Border Adjustment Mechanism (CBAM) on the German Industry

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Abstract

The European Commission's proposal for a Carbon Border Adjustment Mechanism (CBAM) aims to address carbon emissions in imports to the EU. This thesis researches the financial implications for exporting countries due to CBAM's implementation, focusing on how it may alter production costs, demand dynamics, and global trading relationships. Using a quantitative research approach, the study analyzes existing carbon market landscapes and Germany's trade ties with non-European exporters in key sectors like iron, steel, aluminum, polymers and chemicals. It evaluates CBAM guidelines and assesses potential weaknesses in determining embodied CO2 emissions. Results suggest CBAM may not drastically shift production costs or demand patterns immediately. China, with inherent cost advantages, may maintain competitiveness, while India's advantages could diminish by 2035. However, uncertainties persist on CBAM's long-term impact on global trade dynamics. The analysis highlights CBAM's uneven financial burden across exporters, influenced by energy structures and production technologies. Weaknesses in CBAM's calculation methods are highlighted, recommending standardized guidelines to ensure accurate emissions reporting. This study prompts policymakers to evaluate CBAM's effectiveness in meeting climate goals while maintaining global trade equity.

Keywords: CBAM; carbon pricing; corporate ESG; decarbonization; European Carbon Border Adjustment Mechanism

1. Introduction

The Sixth Assessment Report of the IPCC paints a sobering picture of the impacts of climate change already being witnessed, including humanitarian crises and irreparable environmental damage. According to the assessment, to prevent a 1.5°C temperature rise, global emissions of greenhouse gases would have to fall by 43% by 2030. To achieve this, all sectors of the economy must rapidly reduce their emissions (IPCC, 2022). Late in 2022, world leaders congregated for the Conference of the Parties of the UNFCCC (COP 27), where they reinforced their pledge to prevent a 1.5°C temperature rise.

According to analysis by the International Energy Agency (IEA), however, there is a considerable discrepancy between what nations have committed and what can be accomplished with the current implemented policy. Many nations require additional policies to reach their targets (IEA, 2021, 2022b; UNFCCC, 2022). The European Commission, in an effort to expand its carbon pricing policy and reach its targets, released a proposal for a Carbon Border Adjustment Mechanism (CBAM) in July 2021. The CBAM basically involves imposing a carbon price to imports of specific products from non-European countries into the European Union (EU), proportionate to the items' "embodied carbon dioxide (CO_2) emissions," or the emissions of CO_2 created during their manufacturing. CBAM will initially cover several specific goods from some of the most carbon-intensive sectors, comprising iron and steel, cement, fertilisers, aluminum, electricity, and hydrogen, as well as some precursors and downstream products.

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The aim of this thesis is to examine the potential financial repercussions that may arise from the implementation of the Carbon Border Adjustment Mechanism (CBAM) for exporting countries. The research seeks to estimate to what extent CBAM will affect the production costs of goods, leading to changes in demand and trading relationships between countries in both the short and long term. Specifically, the analysis will investigate whether the financial burden resulting from CBAM will be equitably distributed among all nations or if it will disproportionately affect major trading partners.

To accomplish this, the study will analyze the current global landscape of the carbon market, including initiatives taken by non-European countries to price CO_2 emissions. Additionally, it will identify Germany's trading relationships with non-European exporters of goods in the scope of CBAM. The study will focus on goods such as iron, steel, aluminum, and polymers, which are likely to have a significant impact, given Germany's strong automotive industry.

The analysis will also identify key characteristics of the CBAM guidelines and evaluate its weaknesses, with particular focus on the actual determination of embodied CO_2 emissions in goods. It will highlight the fact that without a standardized method for calculating embodied CO_2 emissions, the effect of CBAM may be diminished in the short and long term. To illustrate this point, it will calculate the embodied emissions contained in goods exported to Germany in 2021 using different methods and compare the results.

Finally, this study will assess how the existing cost advantages of the major non-European trading partners of Germany will be affected by CBAM, depending on the method of calculation of embodied emissions in goods. It can be inferred that the production processes and technologies used in each country will have an impact on the individual financial burden of each country. The study will conclude by discussing potential shifts in demand for goods from one country to another and analyzing whether CBAM will have a significant effect on global trade.

2. Literature review

2.1. Carbon pricing

Governments can utilize carbon pricing, a policy instrument, as part of their overall plan to reduce greenhouse gas (GHG) emissions, such as CO_2. Once the CO_2 (referred to as "carbon") emissions are priced, there is a monetary incentive to lessen them or promote removals. Carbon pricing can alter production, consumption, and investment patterns, therefore promoting low-carbon growth by factoring climate change costs into economic decisions. Carbon may be priced using a wide range of policy mechanisms, which can each be customized to local conditions, priorities, and demands. Carbon pricing's climatic impact is determined by how extensively the price is implemented, the price level, and the availability of abatement possibilities (The World Bank, 2022).

As of April 2022, there are 68 carbon pricing instruments (CPIs) operating worldwide. These are either carbon taxes or emissions trading systems (ETS). A carbon tax is a policy tool that allows a government to charge a levy for emissions. The overall volume of emissions in one or more sectors of the economy is controlled or capped in an emissions trading scheme. The government then sells or distributes tradable emission permits to entities subject to the cap. Each allowance reflects the right to release a specific volume of emissions, which is usually one metric ton of CO_2-equivalent (tCO_2e), and the overall volume of allowances equals the emissions cap. During a compliance period, organizations must surrender permits for their emissions. They can either purchase extra allowances as needed or sell surplus allowances. This strategy is also known as a "cap-and-trade" scheme (United Nations Committee of Experts on International Cooperation in Tax Matters: Environmental Tax Issues, 2020).

The graph in Figure 1 depicts the global carbon pricing systems in operation as of 2022, whereas carbon pricing schemes are regarded as "scheduled for implementation" until they have been legally established by law and have a clear start date. Carbon pricing efforts are categorized as "under consideration" if the government has proclaimed its intention to work toward implementing a carbon pricing program and this has been explicitly acknowledged by official government sources.

The adoption of carbon pricing continues growing steadily in the Americas and Asia, but the global coverage remains low. Several jurisdictions, such as Brazil, Turkey or Taiwan continue to assess the potential to implement the CPIs. Implementing carbon prices remains a policy challenge, especially given rising energy commodity prices coupled with current geopolitical issues and the ongoing COVID-19 pandemic's impact on economies. The European Commission estimates the proportion of global emissions covered by the CPIs in operation to be approximately 23% (Joint Research Centre (European Commission), 2022).

The largest carbon market, by traded value, is the European Emissions Trading System (EU ETS). It was launched in 2005 as a major pillar of the European energy policy and was quickly followed by counterparts in New Zealand (NZ ETS), South Korea, California and the RGGI. The Regional Greenhouse Gas Initiative is abbreviated as RGGI[1]. Over the past years, carbon prices have reached record highs, as shown in Figure 2.

Following a combination of policy decisions, increased speculation, and broader economic trends - particularly global energy prices – it is fair to conclude that carbon prices react to market conditions. The spikes in the different ETS prices have been driven by more ambitious climate targets and reforms.

Germany, the EU ETS's largest emitter, successfully deployed its domestic energy ETS on January 1, 2021, at a fixed

[1] The Regional Greenhouse Gas Initiative (RGGI) is a cooperative, market-based effort among the US states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

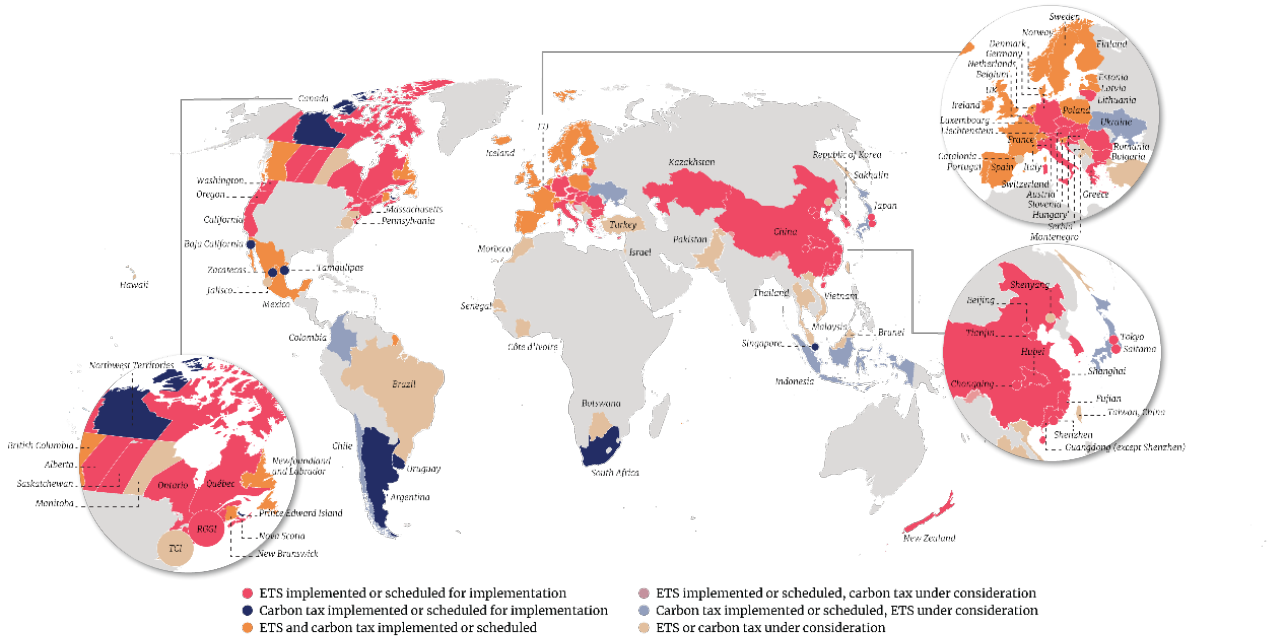

Figure 1: Map of carbon taxes and emission trading systems operating worldwide as of April 2022 (The World Bank, 2022)

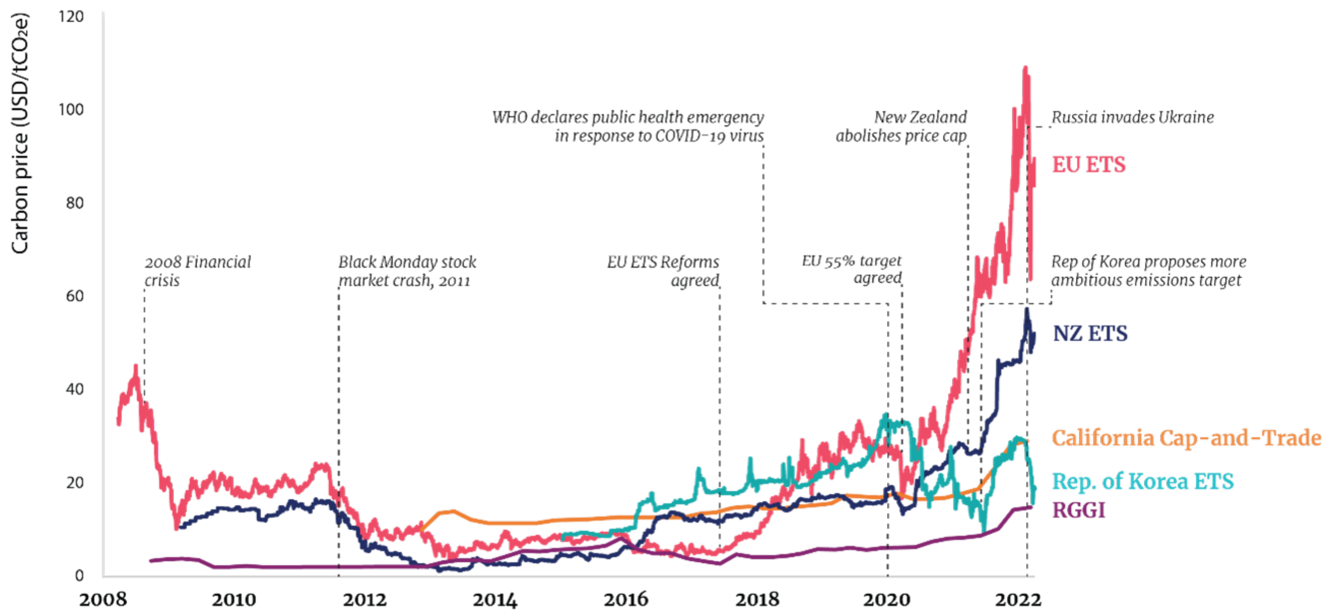

Figure 2: Price evolution in selected ETS, 2008-2021 (International Carbon Action Partnership, 2022)

fee of 25 euros *per* tonne CO_2 equivalent, with the sale of National Emissions Trading Scheme (nEHS) permits beginning in October 2021. All energy emissions that have not been regulated by the EU ETS (primarily heating and transport transportation) have been included. Such emissions are released by a range of sources, including heating, oil, natural gas, petrol, and diesel. Some fuels (such as coal and garbage) will be phased in later in 2023. From 2021 to 2025, the nEHS will be brought in progressively, with a set price on emission allowances. The set price will continue to climb over time. After that, allowance pricing will be determined by the market beginning in 2027. The cap on the emissions is based on Germany's mitigation goals for industries not covered by the EU ETS (Bundesministerium der Justiz, 2021; The World Bank, 2022).

Germany's domestic ETS and the EU ETS mirror a reality that all CPIs share, namely that its prices remain below what is required to meet the Paris Agreement's goals. According to the High-Level Commission on Carbon Prices, CPIs should range between 70-100 € /tCO_2e to keep global warming to below 2°C by 2030 (Stiglitz & Stern, 2017). Newer estimates indicate that even higher prices may be needed to reduce emissions to net zero by 2050, as required by the IPCC to reach the 1.5°C target. A poll of 30 environmental analysts conducted in 2021 estimates that prices ranging from 70 to 250 USD *per* tCO_2e would be required to meet this objective, with an average estimate of 100 USD *per* tCO_2e (Bhat, 2022).

The current state of carbon pricing worldwide reflects the gap between policy and commitments reported by the IEA. In most countries, higher carbon pricing and a further set of complementary policy actions will be required to meet both short-term mitigation targets and long-term net zero policies. This is especially true for promoting decarbonization in complex, energy-intensive sectors, where low-carbon technologies are underdeveloped (IEA, 2022b).

2.2. Carbon Leakage and the Carbon Border Adjustment Mechanism (CBAM)

As governments expand their carbon pricing aspirations, carbon leakage becomes a growing concern. Carbon leakage refers to the possibility that reduced emissions in one state will be reversed by higher emissions in another. This might be caused by increased output or relocation to a state with less rigorous emission regulations. Carbon leakage holds the potential to harm GDP, jobs, and tax revenue in the most audacious states, creating a deterrent to act. It also decreases the effectiveness of environmental legislation by relocating emissions to countries with poorly enforced regulations, potentially leading to an increase in global carbon emissions (Aichele & Felbermayr, 2015).

To date, there is little empirical evidence of carbon leakage. An econometric investigation of carbon leakage caused by the EU Emission Trading Scheme (ETS) on the cement and iron and steel sectors discovered no indication that the EU ETS has had any impact on net imports in these energy-intensive industries, arguing that so far, most jurisdictions have responded to leakage concerns by granting exemptions, refunds, or free allocation of allowances to sensitive sectors. These approaches have downfalls, however. Decreasing the carbon price weakens the motivation to use resources more efficiently or the switch to lower-carbon technologies and products (Chevallier et al., 2017; European Parliament and European Council, 2003; Felbermayr, 2020).

According to the OECD, overall carbon emissions embodied in international trade have increased by about 50% between 1995 and 2018. China, the United States, India, the Russian Federation, Japan, and Germany were the six greatest producers and consumers of carbon emissions in 2018, as shown in the Figure 3.

While emissions production and consumption have decreased in Japan, Germany, and the European Union (EU27) since 1995, there has been a large growth in China and India. China has the biggest absolute emissions, both in terms of consumption and production. While the OECD countries shown (United States, Japan, and Germany), in total, are net-importers of embodied carbon, the non-OECD countries shown (China, India and the Russian Federation) are net-exporters of embodied carbon emissions.

Numerous countries are examining trade measures to mitigate any possible carbon leakage caused by carbon pricing. One of those measures, proposed in academic and policy literature, is Border Carbon Adjustments (BCAs). BCAs address such worries about carbon leakage by employing trade mechanisms to guarantee that products from overseas manufacturers facing lower (or no) carbon costs are treated equally with domestically produced commodities. Despite its intuitive economic appeal, BCAs pose difficult regulatory decisions, including its scope of applicability (i.e., which policies, goods, sectors and countries), the methodology for assessing the carbon content of products, the type and price of the adjustment, and how the resulting revenues will be used. Any BCA must be designed in accordance with international accords controlling trade and climate policy duties (Cosbey et al., 2019; Horn & Mavroidis, 2011).

BCAs generate important questions about the accountability for climate action. Indeed, the principle that countries have a common but differentiated responsibility to tackle climate change, has long been rooted in global climate cooperation. Developing countries claim that wealthier countries that implement BCAs affect trade by unilaterally imposing carbon pricing on manufactured goods. On the other hand, there are calls for industrialized nations to accept responsibility for their consumption's carbon footprint, which a BCA would help to achieve (Ranjan Mishra, 2021; United Nations Conference on Trade and Development (UNCTAD), 2021).

The European Commission released its proposal for the CBAM in July 2021 and reached an agreement after revising it in December 2022. The CBAM is part of the EU's action plan, "Fit for 55", which seeks to reduce European emissions by at least 55% by 2030 and achieve net zero emissions by 2050 while ensuring competitive strength and avoiding carbon leakage. As previously mentioned, the CBAM basically involves imposing a carbon price to imports of specific products into the European Union–, proportionate to the items' "embodied emissions," or the emissions of greenhouse gases created during their manufacturing, as *per* draft regulations issued in July 2021. According to Article 21 of the CBAM regulation proposal, importers of included goods will be obligated to acquire emission certificates in relation to their embodied emissions. The price of such certificate would be equal to the price of EU ETS allowances. CBAM will initially cover several specific goods from some of the most carbon-intensive sectors, comprising iron and steel, cement, fertilisers, aluminum, electricity, and hydrogen, as well as some precursors and a small selection of downstream products, according to the first Annex of the regulation. CBAM will begin operations in October 2023, and initially, a simpler CBAM between 2023 and 2025 will apply to reporting obligations. The CBAM is designed to progressively replace the existing free allocation of permits as the primary mechanism under the EU ETS to address carbon leakage. The method will be phased in proportionally to the phase-out of the present free allocation, according to Article 31 of the proposed CBAM draft. Importers of such goods can minimize or at least lessen prospective CBAM expenses. According to Article 9 of the CBAM

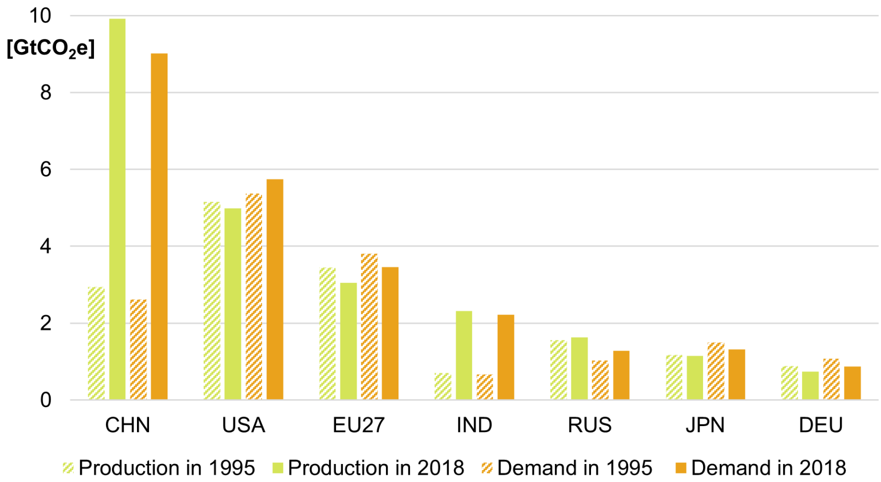

Figure 3: Production and consumption of embodied emissions in international trade per country, 1995 vs. 2018 (Organisation for Economic Co-operation and Development, 2021)

regulation proposal, goods that are subject to a direct carbon price (i.e. a carbon tax or ETS) in their country of origin are eligible for a rebate equal to the price already paid prior to export. In that way, according to EU regulating bodies, the CBAM will ensure a balanced treatment of such imports and it will encourage trading partners around the world to join the EU's climate efforts (European Commission, 2021; European Council, 2021; Pausch-Homblé, 2022).

Recent studies addressing CBAM outcomes suggest that, if implemented widely, it will reduce greenhouse emissions, thus being beneficial in terms of decreasing global warming (Balistreri et al., 2019; Clerc et al., 2021; Eugster, 2021; Kahn et al., 2019). On the other hand, legal challenges and trade conflicts are to be expected. The CBAM's compliance with the trade laws of the General Agreement on Tariffs and Trade (GATT) is not secured. Contrary to the EU's justification, the international community perceives CBAM as a significant barrier to trade camouflaged as a mitigation policy, claiming that the CBAM also violates the trade principles of the World Trading Organization (WTO). The CBAM may boost prices of goods, causing perhaps another trade disruption and affecting developing countries (Appunn & Wettengel, 2023; Dias et al., 2021; Gläser et al., 2021; Lim et al., 2021; Lowe, 2021; Sapir, 2021).

Although some lawmakers have advocated for CBAM exemptions in least developed countries, others argue that doing so would decrease the effectiveness of the mechanism. There is an alternative approach to fostering equity by using CBAM revenues to provide low-carbon development assistance to developing countries. While the initial EU proposal involved allocating the revenue to the EU budget, lawmakers agreed that the revenue will be redirected to least developed countries to offset the costs that the mechanism imposes on them, according to Article 24a of the updated CBAM proposal from December 2022 (Gore, 2021; Incir, 2022).

In July 2021, a survey of major German stakeholders including businesses, civil institutions, and research revealed that there is considerable support for CBAM and an anticipation that the mechanism will be eventually implemented. Industry stakeholders supported continuing the free allocation of allowances, refunds for EU exporters and using profits for domestic spending. Meanwhile, civil institutions rather favor phasing out free allocation, exempting low-income countries and countries without climate policies, and using revenues to fund the green transition in low-income countries (Kuehner et al., 2022).

Figure 3, which depicts the production and consumption of embodied carbon emissions in international trade by country, presents China, the United States. Russia, Japan and India as the countries with the highest amounts of produced and consumed emissions. These countries are highly likely to have large production industries in energy-intensive production sectors, which are targeted by CBAM. It can be deduced, therefore, that such countries may play a significant role as top trading partners for Germany's imports of CBAM goods, as their products are in high demand globally (World Trade Organization, 2022). China, for example, is the world's largest producer of steel and aluminum, and it also has an enormous capacity for chemical and polymer manufacturing. Similarly, the United States is the world's greatest producer of natural gas and a substantial manufacturer of aluminum and steel, while Japan has a considerable capacity for high-quality steel and chemicals. India is also becoming a significant producer of iron and steel, chemicals, and polymers (International Aluminum Institute, 2023; Japan External Trade Organization - JETRO, 2022; U.S. Energy Information Administration, 2022; World Steel Association, 2023).

2.3. CO_2 emissions embodied in CBAM goods

There is a further issue that has not been brought under the spotlight yet. The CBAM requires the development of methodologies to estimate the emissions embodied in goods. Importers of CBAM goods will be obligated to acquire emission certificates in relation to their embodied emissions. According to the CBAM proposal, embodied emissions of goods may be based on real emissions reported and validated by accredited verifiers or using default values, where importers are unable to demonstrate actual emissions. The use of default values may be problematic, as there are different approaches to determine such values. The following chapter discusses in detail this issue (European Commission, 2021).

According to Article 7 of the CBAM, embodied emissions in goods shall be calculated pursuant to the methods set out in its third Annex. The third Annex stipulates that embodied emissions of goods are to be based on real emissions or using default values. If real monitoring values for emissions cannot be supplied, a default value is used. The third Annex further determines that "only real values from the country where actual emissions occurred must be used as default values. In the absence of actual, country specific values, literature values may be used. Literature values shall be determined based on the best available data" (European Commission, 2021).

Default values, whether country specific or taken from literature, can be deliberately set lower than the likely embodied emissions. Exporters of goods could then benefit from the failure to provide reliable data on actual emissions, using default values and avoiding a major financial burden. The EU argues that "default values shall be set at the average emission intensity of the 10% worst performing installations in each exporting country and for each of the goods listed in Annex I other than electricity, increased by a mark-up, the latter to be determined in the implementing acts [of the CBAM]. When reliable data for the exporting country cannot be applied for a type of goods, the default values shall be based on the average emission intensity of the 5 % worst performing EU installations for that type of good" (European Commission, 2021).

To the greatest degree practicable, "best available data" used for default values should be based on accurate and publicly accessible information on the type of technology and methods utilized, energy source, and input materials. It is further determined in the third Annex that "default values shall be updated on a regular basis, depending on the most recent and trustworthy information. The EU also promises to "publish [additional] guidance for the approach taken to adjust for greenhouse gases used as process input". In the updated version of the CBAM it is clearly stated that "under no circumstances shall default values be lower than the likely embodied emissions and the exporter shall not benefit from the failure to provide reliable data on actual emissions so that default values are used". Although the calculation of embodied emissions seems accurate at first sight, the third Annex of the CBAM is, until this point in time, vaguely formulated. The exact methodology to calculate embodied emissions based on actual data or available literature still must be developed. (Carbon Market Watch, 2021).

3. Methodology

3.1. Outline

The research approach of this thesis employs a quantitative research method, as the embodied emissions of goods can be measured. The study relies primarily on secondary data, utilizing existing quantitative data rather than collecting new information. However, original quantitative data is generated through the analysis of secondary sources, including legal texts and press releases related to the Carbon Border Adjustment Mechanism (CBAM). All data used in the study is publicly accessible and external to the research project.

This thesis builds a model, on an Excel basis, to determine to what extent CBAM will impact the trading patterns of exports and imports between Germany and non-European countries. It seeks to determine if the financial burden of CBAM is unevenly distributed across exporters and determined by each country's energy production structure. To do so, the research is subdivided into individual research steps, shown in Figure 4.

The research commences by examining the EU's Carbon Border Adjustment Mechanism (CBAM) to establish the model's boundary conditions. The objective is to quantitatively replicate the legislative framework, ensuring that all calculations adhere to the specified regulations (see 2.3).

Subsequently, considering the CBAM rules and boundary conditions, trade statistics from the German Federal Statistical Office are utilized to determine the traded value, volume, and trading partners associated with CBAM goods (see 3.3.1). The next step consists in calculating the embodied emissions using the previous step and data from the OECD on intensity of emissions (see 3.3.2).

The results from the third step are then compared in the fourth step of the research, by using data from the IEA and the USGS on the metal industry (see 3.3.3). All data is then validated with literature values and values from existing calculation models, such as the GHG Protocol Tool in the following step (see 3.3.4).

The last step of the research analyzes the potential impact of the proposed CBAM on Germany's demand for energy-intensive goods, such as metals, as well as the impact on its major trading partners (see 3.3.5).

3.2. Data collection

3.2.1. Trade statistics

The International Monetary Fund's Dissemination Standards Bulletin Board (DSBB) allows users to access online datasets for all available categories for a country, even if compiled by multiple statistical agencies. The DSBB comprises data for Germany throughout the different sectors of its economy, such as the financial, the fiscal and the external sector. The latter one describes the features related to the economic interaction with other countries, such as balance of payments, external debt, and merchandise trade (International Monetary Fund, 2015).

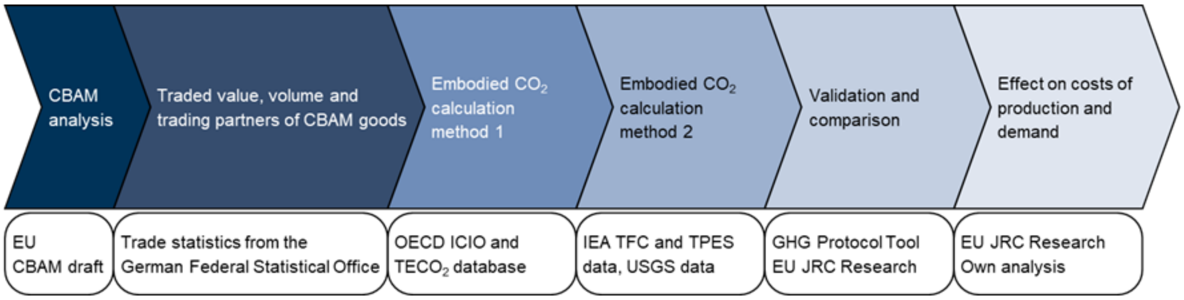

Figure 4: Research steps (above) and used data sources (below) in each step (Own illustration, 2023)

Statistics in Germany about merchandise trade are collected by the Federal Statistical Office. The goal of merchandise trade statistics is to track the movement of goods across borders between Germany and other nations. Since 1993, German merchandise trade data has been divided into two categories, Extra- and Intra-EU trade statistics. The quantities and values of imported and exported commodities are published primarily broken down by commodity types and countries.

The classification of commodities used for reporting imports and exports is the European Customs nomenclature, published in Germany as *Warenverzeichnis (WA)* (Federal Statistical Office (DESTATIS), 2019). The first Annex of the CBAM specifies exactly which traded goods are targeted according to its nomenclature, as seen in Table 1.

The Federal Statistical Office provides data on each imported good individually, according to its specific nomenclature. As determined in the first Annex of the CBAM, there are (initially) 104 goods included in the CBAM. The data on imports is presented as a monetary value, in accordance with international standards. The value of each good is based on its entry value at the German border. Generally, it is derived from the invoice value with some adjustments for transport costs. Tariffs and taxes or other charges which have been levied on import or export are not included in the statistical value. The yearly cumulated sum of imports, in thousand euros (T€), is provided for each country. Additionally, the yearly cumulated weight sum of each good is also provided in tons.

3.2.2. OECD TECO$_2$ database

The Organization for Economic Cooperation and Development (OECD) is known as a statistical agency that compares policy experiences and coordinates domestic and international policies. Since 2014, the OECD publicly releases its main statistical databases on subjects such as agriculture, population, and economic projections from industry and services. The Structural Analysis (STAN) database offers insights on industrial performance across nations. It comprises yearly measurements of production, labor input, and investment.

In the framework of this research, the Input-Output Tables (IOTs) of the STAN database provide helpful information. IOTs explain the sell and purchase interactions that exist within an economy between producers and consumers and show flows (sales and purchases) of final and intermediate commodities and services (Organisation for Economic Co-operation and Development, 2018).

More recently, the OECD merged the 2021 version of the Inter-Country Input-Output (ICIO) tables with the IEA's statistics on carbon emissions from fuel combustion to estimate the distribution across economies of final demand for embodied carbon that has been emitted along global production chains. Using information from both databases, the emission intensity of production is calculated for each industry in each country. In that way, the Trade in Embodied CO_2 (TECO$_2$) database presents a set of indicators to identify patterns of carbon demand and carbon production in each nation. The database includes indicators such as carbon emissions based on production (emitted by countries), emissions embodied in domestic final demand (consumed by countries), net exports of carbon emissions and the country origin of emissions in final demand. Policymakers, such as the EU, profit from such insights into the environmental implications of global industrial systems. The impact of international trade can be measured by allocating emissions to consuming and producing nations, thus disclosing whether nations are lowering or growing their emissions in production and consumption processes (Yamano & Guilhoto, 2020).

3.2.3. IEA World Energy Statistics and Balances

The IEA compiles data on energy commodities such as oil, natural gas, and coal to publish yearly information books on specific fuels. Such commodity balances are presented in a simple way, by presenting all the data in comparable physical units. This could be joules or cubic meters for natural gas or tons for coal, for example. Yet such commodities are consumed for their energy content and can be transformed into one another through different processes. Simple commodity balances must be integrated to create an overall view of the energy system. Energy balances fulfill this task by showing how one product is turned into another. Such balances highlight the many links between energy commodities and demonstrate how all sources of energy are consumed (Márquez Alberto & Villatoro Flores, 2022; Millard & Quadrelli, 2017).

In an energy balance, data elements on different commodities appear in a common physical unit. It enables, in the

Table 1: Statistical nomenclature of CBAM goods (Federal Statistical Office (DESTATIS), 2019)

CBAM good category and abbreviation	Statistical nomenclature *(Warenverzeichnis)*
A: Aluminum	WA76xx
C: Cement	WA2523xx
CH: Chemicals	WA29xx; WA280410 and WA2814xx
E: Electricity	WA271600
F: Fertilisers	WA3105xx
IS: Iron and Steel	WA72xx and WA73xx
P: Polymers	WA39xx

framework of this research, to see the total amount of energy consumed and the relative contribution of each source for the economy as a whole and for each sector of consumption. It also allows for the determination of energy transformation efficiencies, the development of aggregate indicators, and the forecasting of carbon emissions from fuel combustion (EUROSTAT, 2018). An energy balance may also be used to visualize the energy system using Sankey charts. The key data of an energy balance is the Total Primary Energy Supply (TPES), the Total Final Consumption (TFC) and the electricity generation by fuel type. The TPES measures the total supply of energy available for use in a country, while the TFC shows the energy that is used by final consumers, namely the energy used in households, transport, and businesses. Data on electricity production reflects the relative importance of each energy source in the generation mix. In the TFC, the product "electricity" comprises electricity generated from all energy sources, but in the TPES, just the appropriate primary equivalent quantity for each generation source is included (EUROSTAT, 2020).

Industry, transport, and the other sectors (mainly residential) are fed by energy sources such as oil and oil products, coal, natural gas, electricity, and biofuels. Oil and oil products are the major source of energy consumed, primarily in the transport sector, amounting to roughly 40% of the TFC. The industry sector, worldwide, consumes energy mainly in form of coal, natural gas and electricity. The obtained information from the IEA will be further used to estimate the embodied emissions of goods, for each country, based on their TFC.

3.3. Research methods

3.3.1. CBAM goods traded to Germany and trading partners

Determining the trading quantities and top trading partners for CBAM goods is of relevance in understanding the embodied emissions of the imports. Production of the same good in different countries can have vastly different carbon footprints due to differences in energy generation matrix, production processes, and regulations. By identifying trade nations and quantities, the embodied emissions of items may be calculated more easily. Furthermore, identifying the top trading partners can guide Germany in strategizing its trade policies and promoting sustainable trade practices. The government may collaborate with its trade partners to minimize carbon emissions from goods production and foster a more sustainable global economy.

Additionally, Article 9 of the CBAM specifies that a reduction in the number of CBAM certificates will be surrendered if the carbon price paid in the country of origin for the declared goods is considered. This means that importers can lower their CBAM liability by providing evidence of the carbon price paid in the country of origin. To calculate the reduction in the number of CBAM certificates to be surrendered, a methodology is required, which includes the conversion of the carbon price paid in foreign currency into Euros at the yearly average exchange rate. Therefore, knowing the country of origin and the carbon pricing policies in those countries is critical to accurately calculate the CBAM certificates and to implement the CBAM effectively.

The first step of the analysis consists in generating a matrix that comprises all CBAM goods imported and all the exporting countries. The German Federal Statistical Office, in compliance with the Federal Foreign Office, includes 262 countries, some of which are no longer one country, such as the Soviet Union or Yugoslavia. Furthermore, there are countries listed as confidential or "not determined". To account for this, the analysis filters out all countries that did not export even a single unit of CBAM goods to Germany during the period of 2012 to 2021.

According to the second Annex of the CBAM, the adjustment mechanism does not apply for the 28 country members of the EU, including the recently joined Croatian Republic. Additionally, the regulation does not apply to goods originating from Iceland, Liechtenstein, Norway and Switzerland. After filtering out all irrelevant countries the matrix comprises 122 exporting countries. The matrix of exported CBAM goods *per* country uses the latest (2021) and the earliest (2012) data available, to compare the recent development of trade[2].

The analysis continues by breaking down the CBAM goods per trading partner, considering the CPIs of the countries of origin of the goods. The goal is to prioritize the detailed calculation of embodied emissions of those trading partners with the highest financial impact, based on the traded value and/or CPI.

[2] There is no data available before 2012 for all the 122 countries listed in this matrix for all CBAM goods

3.3.2. CO_2 emissions embodied in traded goods according to OECD $TECO_2$

The OECD analyses carbon footprints of global production networks and provides estimates of carbon emissions embodied in final demand and international gross trade for all major economies. The most recent data was compiled over the period of 2005 to 2018 using a revised methodology to allocate territorial emissions (measured in a country) to economic output-based emissions. The database provides information on total embodied emissions in demand and production of a country and, on the intensity of the CO_2 emissions embodied in imports and exports. In addition to the overall factor of a country, the intensity factors are provided for specific industries, such as the metal industry or the chemical industry (Yamano & Guilhoto, 2020). Figure 5 depicts the comparison of the intensity factors of the CO_2 emissions embodied in the total gross exports of the overall industry [DTOTAL], the metal industry [D24T25] and the chemical industry [D19T23] for the selected trading partners in the year 2018.

The analysis shows that, when comparing the intensity of the CO_2 emissions of the total industry, Russia has the largest factor, followed by China and India. These, however, change when looking at the specific intensity factor for the chemicals and non-metallic mineral products [D19T23]. China emerges as the largest polluter *per* million dollars of a product, followed by India and Russia. The emissions intensities *per* country of the metal sector [D24T25] follow the same pattern that the total industry of the country follows. Russia is the largest polluter *per* unit of value, followed by India and China. The intensity of emissions of the metal products represents roughly three times the total industry factor *per* unit.

Due to the diverse nature of the products addressed by the CBAM, it is not feasible to calculate specific emissions *per* category without breaking them down into subcategories. Thus, the analysis is conducted by estimating emissions for distinct groups of goods. On the one hand, emissions from the metals sector, encompassing iron, steel, and aluminum, are computed. On the other hand, emissions from the chemicals, polymers, and fertilizers industries are evaluated separately. This approach enables a more comprehensive analysis.

To calculate the embodied emissions of exported goods in the metals sector per country, the specific factor [D24T25] is used. The value traded to Germany in 2021 of each good in the iron, steel and aluminum category (in M€) is multiplied by the factor [D24T25] to calculate the respective embodied emissions. This is done individually *per* country. It relies, however, on the premise that the exchange rate from USD:EUR equals 1:1. The factor [D24T25] accounts for both basic metal products and fabricated metal products, which are included in the CBAM goods from iron, steel, and aluminum. However, the emissions are also calculated separately with the factors [D24] and [D25], which account only for basic metal products and fabricated metal products, respectively. It is fair to assume that the factor [D24T25] provides a good compromise between both individual factors [D24; D25] as it considers both types of products, like the goods tackled by CBAM and listed in the first annex of the CBAM guideline (see 7.1.1). Additionally, the factor [DTOTAL], which represents the overall emissions intensity of a country's industry, is included for comparison purposes.

Analogous to the metals sector, to calculate the embodied emissions of exported goods in the polymers, chemicals and fertilisers sector *per* country, the specific factor [D19T23] is used. The emissions are also calculated separately with the factors [D20T21] and [D20], which account for chemical/pharmaceutical products and only for chemical products, respectively. In all three calculations [D19T23; D20T21 and D20], the embodied emissions of polymers are calculated with the factor [D22], which specifically portraits the intensity factor of CO_2 emissions in the rubber and plastics industry, where most of all CBAM goods classified as polymers belong (see 7.1.1). Additionally, the factor [DTOTAL], which represents the overall emissions intensity of a country's industry, is included for comparison purposes.

3.3.3. CO_2 emissions embodied in traded goods according to IEA

The aim of this chapter is to validate and compare the outcomes obtained from calculating the embodied emissions with the OECD $TECO_2$ database with the outcomes from the IEA database and from literature. Additionally, it seeks to estimate the short- and long-term impacts of CBAM on the demand and/or production shift, if any, by prioritizing the metal production in China, Russia, and India, which are the largest exporters and polluters. The possibility of production relocation to western countries is evaluated by including the United States in the study. The detailed effects of CBAM on Turkey have been extensively explored in other research works; hence it is excluded from this analysis (Acar et al., 2022). For clarity and ease of presentation, Korea has been excluded.

To calculate the embodied emissions in the iron, steel, and aluminum industry, CO_2 emission intensity factors *per* ton of good and *per* country are determined. The analysis intentionally employs the traded volume of goods instead of traded value, to identify any additional effects arising from price shifts and dynamics of goods in each country. The intensity factors of CO_2 emissions per ton are derived by calculating the total emissions produced in the relevant sector (i.e., aluminum or iron and steel) according to the TFC of primary energy of each country (IEA, 2023).

This total amount of emissions is then divided by the total amount of tons produced in that same year in each country. The global industry sector is known to primarily consume energy in form of coal, natural gas and electricity.

The graph in Figure 6 provides an illustration of the input data required to calculate the emission intensity of a good. It displays the primary energy input required to produce iron and steel in Petajoules as stacked areas, while the annual production of iron and steel according to the US Geological

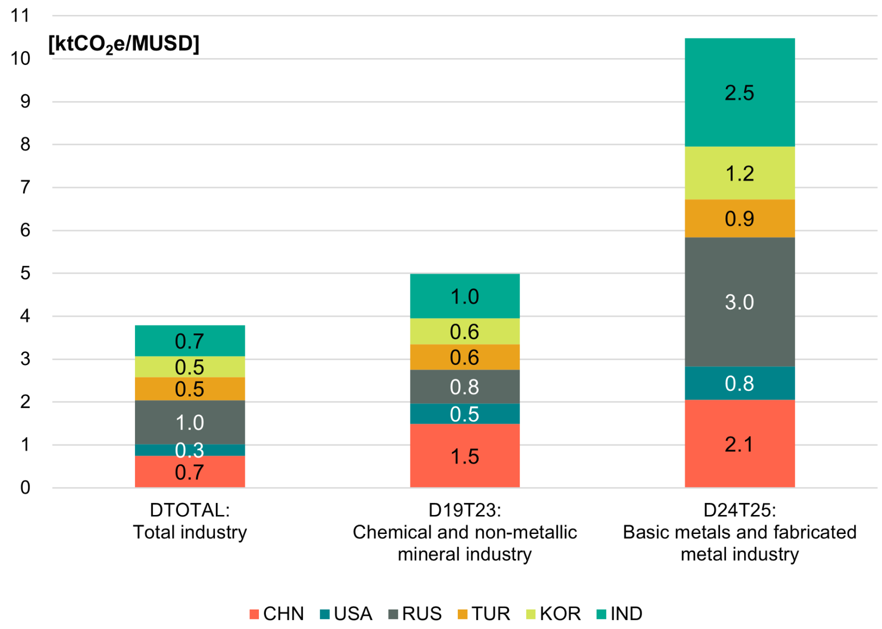

Figure 5: Comparison of the intensity factors of CO_2 emissions embodied in total gross exports, 2018 (Organisation for Economic Co-operation and Development, 2021)

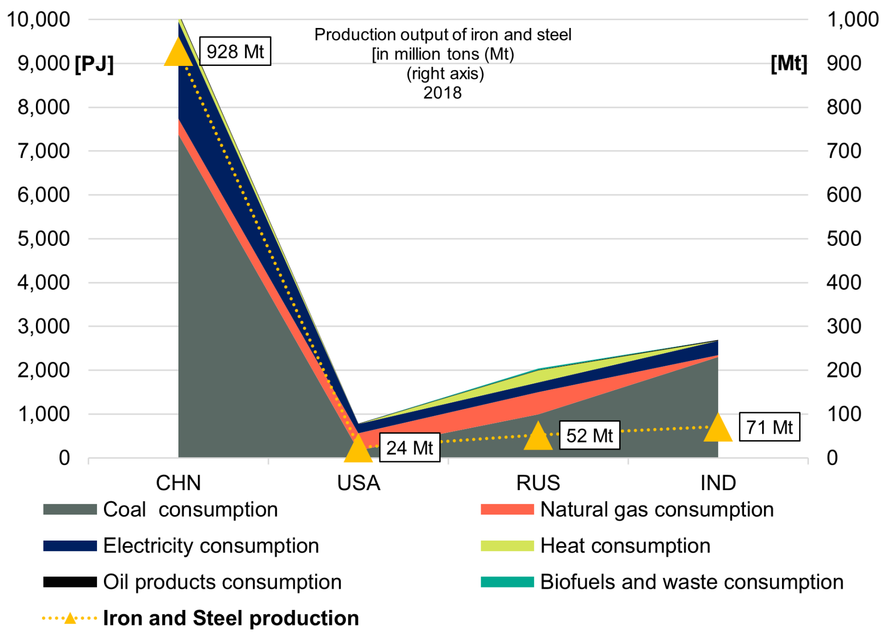

Figure 6: TFC of primary energy in the production of iron and steel (left axis) and production output (right axis), 2018 (IEA, 2023; U.S. Geological Survey, 2019b)

Survey of each country is presented as a data point for the year 2018 (U.S. Geological Survey, 2019b).

The graph illustrates that China is the dominant producer of iron and steel. However, a crucial point to note is that each unit of primary energy source consumed in the production of iron and steel has a CO_2 emission intensity, which must be considered to calculate the total emissions and intensity of iron and steel production *per* country. To do so, the analysis assumes an emission factor for each source of primary energy based on data from the German Environmental Agency (UBA), which again relies on the emission factor database from the IPCC (IPCC, 2023; Umweltbundesamt, 2022).

However, this only represents the initial step, as the production of iron, steel, and aluminum also requires electricity and heat as primary energy sources. To determine these factors, a weighted average is calculated based on each country's electricity generation matrix and the primary energy source emission factors. The objective is to estimate the extent to

Table 2: Emissions factors of primary energy sources; 2022 (IPCC, 2023; Umweltbundesamt, 2022)

Primary energy source	Explicit fuel name in the data source	Emissions factor [tCO_2e/TJ]	Emissions factor [gCO_2e/kWh]
Oil products	Rohbenzin (Crude gasoline)	73,3	263,9
Oil	Erdöl (Oil)	73,3	263,9
Coal	Steinkohle (Bituminous coal)	93,6	337,0
Natural gas	Erdgas (Natural gas)	55,8	200,9
Biofuels and waste	Biogas	0,04	0,2

which a country's electricity generation matrix affects the CO_2 emission intensity factors of iron, steel, and aluminum. It can be anticipated that the greater the proportion of fossil primary energy sources in a country's electricity generation matrix, the higher the CO_2 emission intensity factor per ton of iron, steel, and aluminum. The graph in Figure 7 depicts the primary energy sources utilized for electricity generation in China, the United States, Russia, and India in the year 2018.

The Figure 7 indicates one key takeaway, namely that India and China are likely to have the highest emission factor *per* unit of electricity. However, it is important to note that the graph is only intended to provide the reader with an idea of the relative cleanliness or dirtiness of each country's electricity generation, suggesting that the United States has the less polluting electricity generation.

To determine the emission factors for electricity in each country, the individual emission factors from Table 2 are weighted based on each primary energy source's percentage share in the electricity generation matrix for the year 2018. Moreover, the calculated factors are compared with data from the BP Statistical Review of World Energy 2019 on emissions of electricity in each country to ensure the plausibility of the results. (BP, 2019, 2022) The chart in Figure 8 presents the findings.

The comparison of the calculated electricity CO_2 emission factors *per* country with actual data reveals a significant deviation, suggesting that the initial calculation may be inaccurate. This discrepancy is observed across all countries, making it highly unlikely that the calculated values are entirely correct. Consequently, it appears that the electricity input required has approximately twice the amount of CO_2 emissions per kWh than initially calculated. After determining the emission factors for all primary energy input sources used in the production of iron, steel and aluminum, the intensity factor of CO_2 emissions for each group of goods can now be established.

3.3.4. Validation with GHG Protocol Tool and literature values

To validate the outcomes obtained, the investigation proceeds with computing the total emissions generated in each country's iron and steel industry, utilizing the GHG Protocol calculation tool. The GHG Protocol is an internationally recognized system that provides consistent and extensive frameworks to quantify and regulate GHG emissions from private and public sector operations and value chains (GHG Protocol & Gillenwater, 2005). To investigate the significant deviation in the results obtained (see 4.3), an additional step is taken to calculate the overall emissions produced in the iron and steel industry *per* country using the GHG Protocol calculation tool. This tool records the primary energy sources required for iron and steel production and automatically calculates the total amount of CO_2 emissions produced.

The next phase involves comparing the outcomes of this study with the current literature on CO_2 emission production in the iron and steel sector. A recent study by the European Joint Research Centre (JRC) provided estimates of GHG intensities in the iron and steel sector of the EU and its primary global trading partners. The report utilizes publicly available databases and transparent methodologies to determine the intensity factors in the iron and steel industry of the EU and its global partners. The goal of the study by the JRC is to enhance comprehension of carbon leakage risk and support the implementation of default values within the CBAM framework (Koolen & Vidovic, 2022). Additionally, the average worldwide intensity factor of CO_2 emissions to produce iron and steel (1,53 tons of CO_2e *per* ton of steel) according to (IEA, 2022a) is also compared.

The final step of the analysis consists in presenting the resultant embodied emissions for the selected countries according to the different methods discussed, as shown in Figure 23. The goal of the final step is to demonstrate that the financial burden posed by CBAM on exporting countries is uneven and, as shown in the analysis, depends strongly on the primary energy sources put in and the technologies used to produce goods. This raises the question if the uneven burden posed by CBAM will shift import and export patterns in the short- and long-term.

3.3.5. Effect of the CBAM on production costs and demand patterns

The goal of this chapter is to examine whether certain countries may experience a shift in their market position based on their production costs and sale prices. Specifically, the chapter focuses on the iron and steel industry by assessing each country's production costs and identifying their cost advantages and disadvantages. The aim is to determine the extent to which the uneven financial burden posed by CBAM may alter the production costs of iron and steel. To do so, the discussion begins in Table 3 by breaking down the production costs of the EU and its major trading partners (European Joint Research Centre et al., 2020).

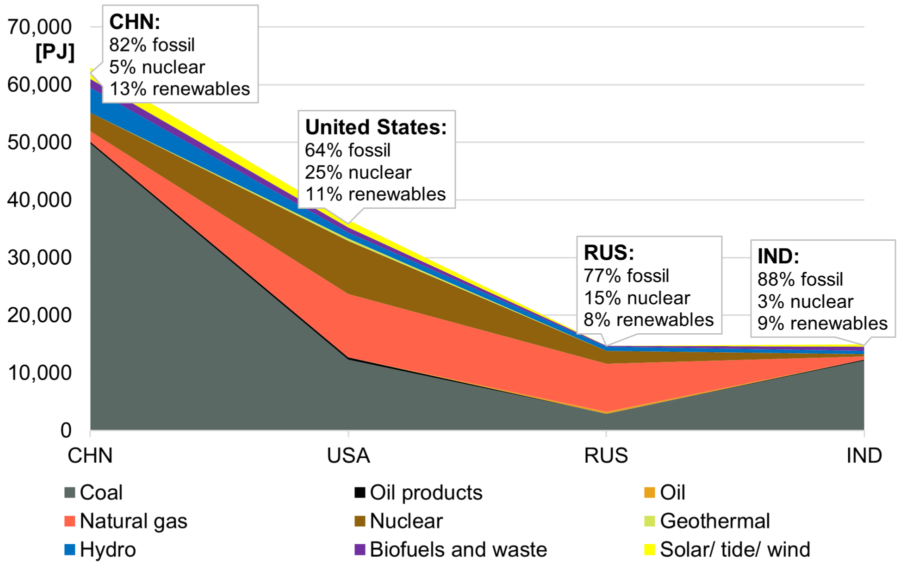

Figure 7: Primary energy consumption of electricity production per country, 2018 (IEA, 2023)

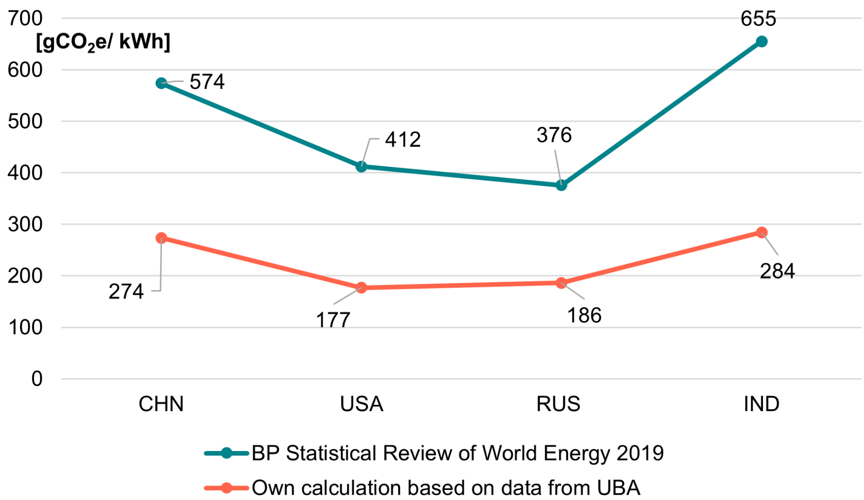

Figure 8: Comparison of electricity CO_2 emission factors per country, 2018 ((BP, 2022; IEA, 2023; Umweltbundesamt, 2022)

Table 3: Breakdown of the production costs of iron and steel, 2020 (European Joint Research Centre et al., 2020)

Cost breakdown	Cost components by Moya and Boulamanti
Energy	• Energy (Coke oven gas, Blast furnace gas, Basic oxygen furnace gas, Corex gas, Custom iron gas, Custom steel gas, Heavy fuel oil, Natural gas, Thermal coal, other fuel and Steam) • Purchased electricity
Labour	• Sum of all wages paid, employee benefits and payroll taxes
Raw material	• Iron ore, reductants, metallics and ferroalloys and purchased semis
Credits	• Savings from recycled scrap and self-power generation
Other (incl. CBAM)	• Other consumables (auxiliary and operating materials) • Other costs (overheads and sustaining capital) • CO_2 costs and future **CBAM costs**

Taking into consideration the cost structures of each producing country, the discussion proceeds to evaluate the additional costs that would be imposed by the CBAM. To do this, the intensity factors for CO_2 emissions presented in Figure 21 are utilized and converted into additional costs by setting the price of a CBAM certificate at 100 euros per ton of CO_2. For instance, an intensity factor of two tons of CO_2 per ton of steel would imply an additional cost of 200 euros per ton to be paid under CBAM. Consequently, this would raise the production costs, although the full impact of CBAM would not be realized immediately, as it will be gradually phased-in over a ten-year period from 2026 to 2035 (see 2.2). Thus, the full effect of CBAM is expected to be observed in the long-term rather than the short-term, suggesting that the impact on production costs may not be significant in the short run.

This study forecasts the shift in total production costs of iron and steel during the ten-year phase-in period of CBAM, spanning from 2026 to 2035. The forecast is based on the study carried out by the EU JRC (presented in Figure 25) and relies on certain assumptions. Firstly, the intensity factors of CO_2 emissions, derived from 2018 data, assumes a yearly decline of 1% for every country due to technological advancements and process efficiency improvements. Secondly, the study assumes a yearly 5% increase in labour costs. Material costs are set to increase 2,5% per year for all countries. The same applies to the energy costs in each country. It is also assumed that savings in production costs will increase by 1% each year for all countries because of their shared intention to improve recycling processes. The gradual phase-in of CBAM is assumed to take place over the ten-year period, with only 10% of the certificate price being paid in 2026, and this percentage increasing by 10% each year until reaching 100% in 2035. In the initial analysis, the price of a CBAM certificate is set at 100 euros per ton of CO_2 and is assumed to remain constant throughout the decade.

The analysis assumes that there will be no implementation of a carbon pricing instrument (CPI) in Russia and India during the period of 2026-2035. Additionally, it is assumed that the domestic CPI price in China and the United States will remain unchanged, as shown in Table 4. The European iron and steel industry is expected to pay the same price in the EU Emissions Trading System (EU ETS) as a CBAM certificate. As per the CBAM guidelines, the free allocation of certificates in the EU ETS for the domestic iron and steel industry will be phased out during the same period as CBAM is phased in (see 2.2). Therefore, it is assumed that the EU27 will only pay 10% of the certificate price in 2026, 20% in 2027, and so on, until reaching 100% in 2035. The intensity factors of CO_2 emissions in the iron and steel production considered in this analysis are [OECD D24T25] and [EU JRC] (see 4.2 and 4.3).

4. Results

4.1. CBAM goods traded to Germany and trading partners

The analysis throws the following results: the total amount of CBAM goods traded in 2012 summed up to roughly 14,1 billion Euro (B€), while in 2021 it accounted for 20,2 B€ , an increase of 43% (Federal Statistical Office (DESTATIS), 2022b). The imported amount of CBAM goods in 2021 represents 1,7% of the total imports of Germany in that year (1204 B€), according to (Federal Statistical Office (DESTATIS), 2022a).

Surprisingly, the traded volume of goods does not increase proportionally to the monetary value imported. In 2012, the 122 exporting countries shipped roughly 9,6 million tons (Mt). A decade later, the shipping volume of traded CBAM goods amounts to 10,9 Mt, an increase of 13,8%. The percentual increase of the traded monetary value is roughly thrice the increase of the traded volume, which can be due to different reasons, such as drastic price increases of certain goods or trade conflicts between major economies.

As mentioned previously, the 104 traded CBAM goods are subdivided into seven categories: iron and steel, cement, fertilisers, aluminum, electricity, chemicals, and polymers. The traded quantities of CBAM goods in 2021 and 2012 (striped) are shown in the graph in Figure 9 in B€ .

The import of polymers, such as plastics, polyesters, polyethers and polymers of ethylene add up to 6,9 B€ , roughly one third of all traded CBAM goods to Germany. The traded value of goods increased by approximately 60,5% in a decade. The import of polymers grew the most between 2012 and 2021, compared to the other goods. Imported polymers are mostly utilized in the packaging industry, as well as in construction and in the automotive industry (Gesellschaft Deutscher Chemiker, 2020).

Iron and steel imports add up to 5,4 B€ , second to polymers. The imports of iron and steel in Germany increased by 35,0% between 2012 and 2021. Two thirds of the imported iron and steel products in Germany are utilized in the construction and the automotive industry (Wirtschaftsvereinigung Stahl, 2021). The graph in Figure 10 shows the percentual share of traded value to Germany *per* category in 2021.

Figure 9 and Figure 10 display aluminum as the third largest group of goods imported. Like iron and steel, aluminum is mostly used in the automotive and construction industry. Additionally, aluminum plays an important role in the packaging industry. The imports of aluminum in 2021 add up to 4,0 B€ , an increase of 42,9% in comparison with the traded value in 2012 (Statista, 2021). Fertilisers and cement play a minor role in the matrix of imported CBAM goods. Importation of both goods decreased in the last decade for countries covered by CBAM. Electricity, according to the Federal Statistical Office, is not imported from the scoped countries.

Chemicals represent 18,5% of the imported CBAM goods, equaling 3,7 B€ in 2021. The group of chemicals in the CBAM goods is the most diversified one, as it brings under one hat commodities for several applications. These include carboxylic acids, hydrocarbons, ammonia and hydrogen. The principal chemical good imported to Germany in 2021 is saturated acyclic monocarboxylic acid (SAMA). It is an organic chemical used in manufacturing of detergents, disinfectants and antiseptics. It accounts for 16% of the imported chem-

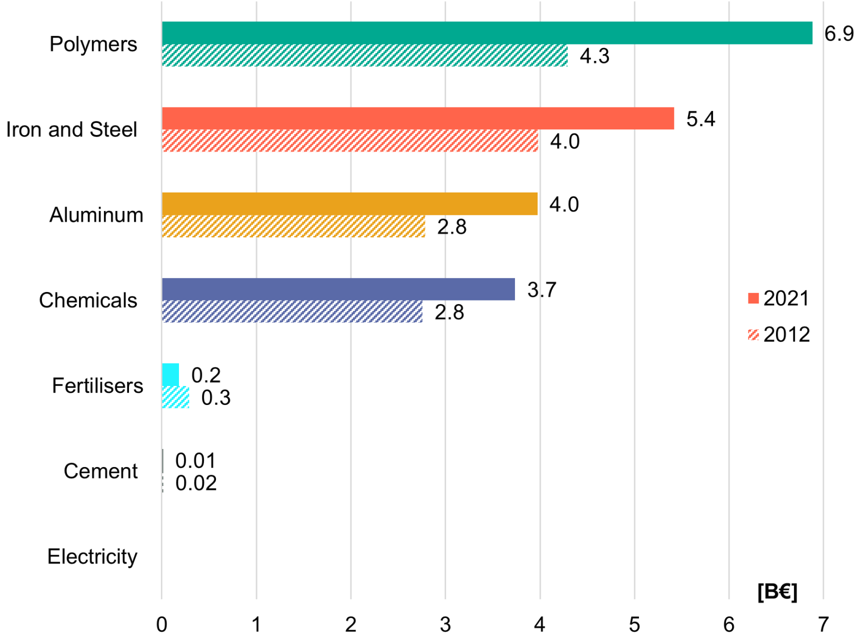

Figure 9: Import of CBAM goods to Germany, 2012 (striped) vs. 2021 (Federal Statistical Office (DESTATIS), 2022b)

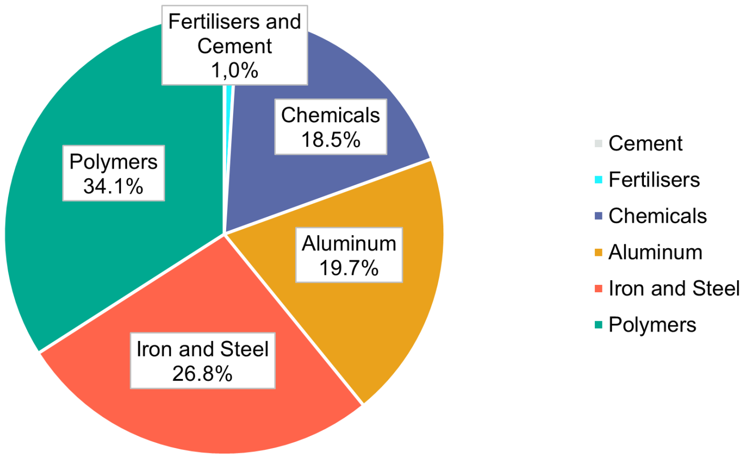

Figure 10: Percentual share of traded value to Germany per category of good, 2021 (Federal Statistical Office (DESTATIS), 2022b)

icals under the CBAM scope, or 0,6 B€ , closely followed by acyclic alcohols (14%) and cyclic hydrocarbons (9%). Surprisingly, hydrogen imports are beneath all imports (with 24 T€) of other chemicals in this group, accounting for 0,001% of the imports of chemicals.

Raw aluminum is the mostly imported good in the small group of aluminums (14 goods) and, furthermore, the largest imported good (in value) of all 104 CBAM goods. It adds up to 46,1% of the aluminums and represents 9,1% of the total traded value in 2021. The apparent benefit of employing aluminum, for example in the automotive industry, is that it is much lighter than its steel counterpart. Less weight translates into a better fuel economy for the automobiles and trucks, lowering pollutants and making it ecologically beneficial. Aluminum is resistant to corrosion and rusting, outlasting steel or other metals in environments such as rain or snow. With a low weight and high strength-to-weight ratio, aluminum provides an improved handling during assembly, appropriate for high-performance automobiles (Aluminium Deutschland e.V., 2021).

According to the data from the Federal Statistical Office, “other articles of iron and steel” are the main goods imported in this category, overall comprising 30 different goods. Its top good represents 29,0% of all iron and steel products imported and 7,8% of all CBAM goods imported. According to the Federal Customs Service, other articles of iron and steel comprise all goods forged, but not further machined as well as articles of iron or steel wire. Examples are ladders and steps, pallets and similar stackable transport equipment and several construction articles. Other important iron and steel products imported are constructions and construction parts made of iron and steel as well as tube or pipe fittings. Overall,

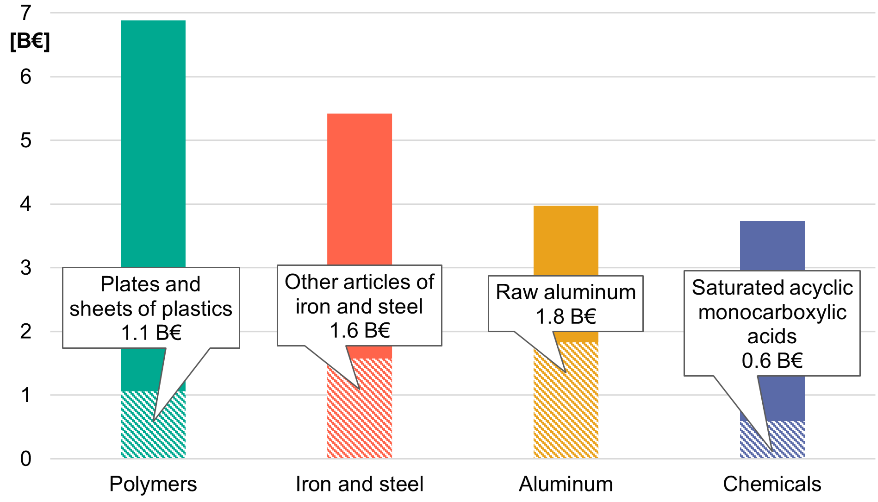

Figure 11: Principal imported good per group according to its imported value, 2021 (Federal Statistical Office (DESTATIS), 2022b)

steel is a highly advantageous material for use in the construction industry due to its strength, durability, versatility, cost-effectiveness, sustainability, and fire-resistant properties (Wirtschaftsvereinigung Stahl, 2021).

From the group of polymers, the dominant good imported is plastic in sheets and plates. It accounts for 16% of all imports of polymers and 5,2% of all CBAM goods. According to the Federal Customs Service, plastic in sheets and plates is an overall term that encompasses additionally film, foil and strip of unfoamed plastics, mostly out of polyethylene. Polyethylene is extensively used in the packaging, construction, and automotive industry. In the packaging sector, it is employed to produce bags, films, and containers for a range of products, including food and beverage and medical supplies. In construction, polyethylene is utilized for pipes, wire and cable insulation, and insulation for buildings. In the automotive sector, it is used for fuel tanks, hoses, and electrical components (Arbeitsgemeinschaft Verpackung und Umwelt, 2022).

Ultimately, the top three group of products in CBAM imports to Germany in 2021 – polymers, iron and steel, and aluminum – are all critical materials for sectors such as packaging, construction, and the automotive industry. Because of their adaptability, these materials are appropriate for a variety of applications in many areas. Germany's huge manufacturing economy is strongly reliant on these commodities, and the country's strict environmental standards require the use of high-quality raw materials.

In the context of emissions trading, it is important to note that many specific emission intensity factors are calculated based on the production of a certain number of tons of a given product. As a result, when trading emissions, the trading volume in tons, in addition to the traded value, becomes an important indicator to convey. Because the quantity of emissions released is directly related to the volume of a manufactured product, trading volumes in tons serve as a significant measure of the overall emissions produced by a certain industry or sector. Both the traded value and the trading volume in tons must be considered, as these two metrics provide complementary information that, when combined, provides a more complete picture of the emissions generated. By taking both elements into account, it is feasible to precisely quantify the environmental impact. The graph in Figure 12 displays the traded quantities of CBAM goods in 2021 and 2012 (striped) in Mt.

The data presented reveals that the volume of aluminum traded in tons increased by less than 10%, while the traded value increased by over 40% in the last decade, suggesting a significant shift in the pricing dynamics of this commodity over the period under consideration. Furthermore, the volume of steel traded in tons increased by 10% over the given period, while the traded value increased by 35%, indicating a substantial rise in the price of steel and iron. According to the figures shown in Figure 12, the growth in traded value between 2012 and 2021 does not follow a proportionate connection with the increase in traded volume in tons. This disparity raises the question of how much goods' prices have changed in the recent decade, as a rise in traded value does not always imply an increase in the actual number of items traded. Based on data from the Federal Statistical Office, the graph in Figure 13 shows the price shift of the CBAM goods from 2012 (striped) to 2021 in Euros per ton (€ /t).

The price of polymers rose drastically from 2012 to 2021 due to various factors such as increasing demand, rising production costs, and fluctuations in the price of raw materials. Additionally, supply chain disruptions caused by natural disasters and the COVID-19 pandemic also contributed to the rise in polymer prices. The price of polyethylene, the most widely used polymer, rose by more than 150% from January 2012 to December 2021 due to the factors mentioned above (Independent Commodity Intelligence Services, 2023) (Independent Commodity Intelligence Services, 2023). Further research out of the scope of this thesis is needed to identify how price variations have influenced trade volumes and val-

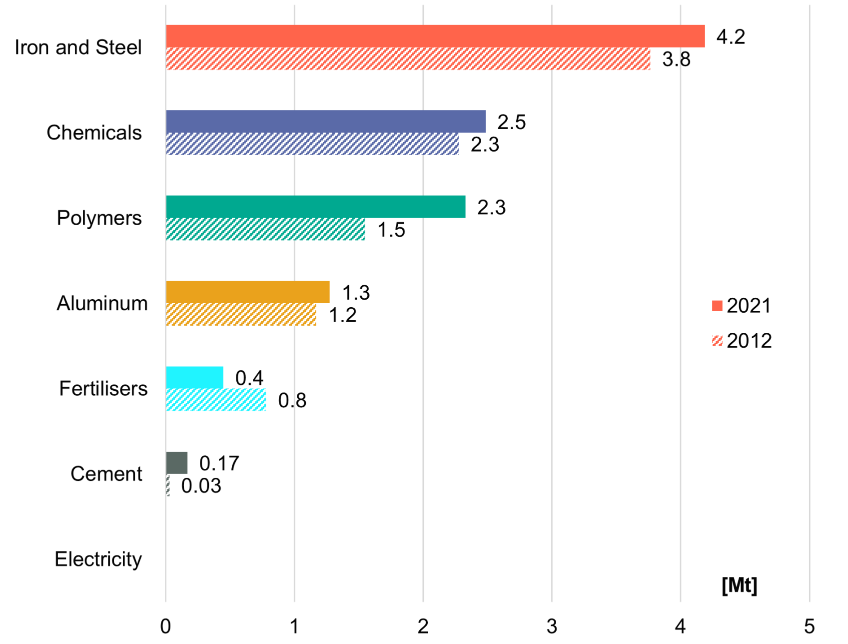

Figure 12: Import of CBAM goods to Germany, 2012 (striped) vs. 2021 (Federal Statistical Office (DESTATIS), 2022b)

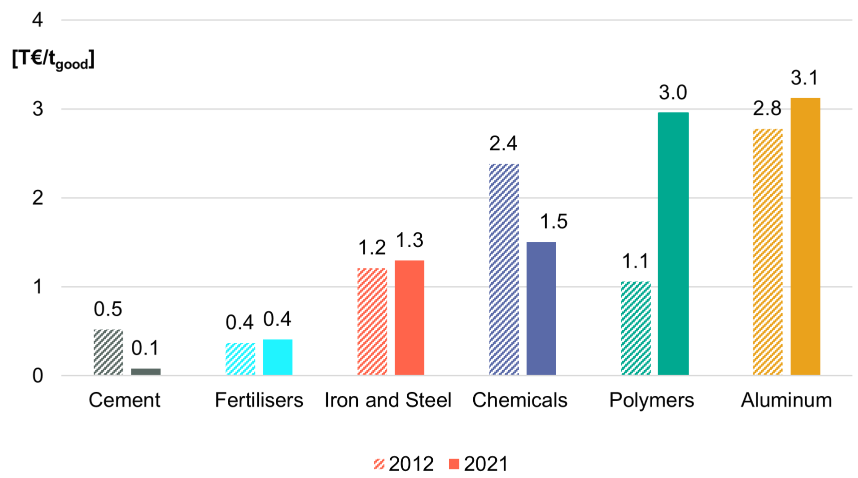

Figure 13: Price shift of CBAM goods, 2012 (striped) vs. 2021 (Federal Statistical Office (DESTATIS), 2022b)

ues, and how these trends may affect the larger economic environment in the future.

The top 15 countries that exported the highest amount of CBAM goods to Germany in terms of traded value in billion Euros are shown in Figure 14, with data comparing the years 2012 and 2021 (to contrast changes of exports in one decade). The countries listed exported, together, 89.4% of all CBAM goods in 2021.

As expected, the first country on the list is China, that exported 4,5 B€ worth of CBAM goods to Germany in 2021, compared to 2,2 B€ in 2012. This represents an increase of 104,5% in traded value. China alone exported in 2021 almost a quarter (22,8%) of all CBAM goods to Germany. Second is the United States, that exported 2,9 B€ to Germany in 2021, an increase of 38.1% in traded value compared to 2012.

Third is the United Kingdom, which surprisingly reduced its exports to Germany, decreasing 28.4% of its traded value. It is possible that the Brexit referendum in 2016 may have negatively affected the trade relationship between the United Kingdom and Germany. Uncertainty about future trade agreements and regulations may have led to a decrease in confidence and investment, which could have impacted exports. This, however, should be fully researched and is only one of many possibilities. Fourth on the list is Russia, which exported 1,8 B€ to Germany in 2021, an increase of 38,5%. Turkey closes the Top 5 exporters, increasing its traded value by 114.3% in a decade. Roughly two thirds of all CBAM goods imported to Germany were produced by the Top 5 countries. Ultimately, the data in the graphic suggests that there has been a significant increase in traded value for CBAM goods from most of the countries in the list between 2012 and 2021, with some countries experiencing more notable increases than others.

Figure 14 is of great significance as it further reveals a key aspect of the CBAM. As *per* the data provided by the World Bank in Figure 1, some of the top trading partners do not have any form of CPI, which puts them in a vulnerable position. These countries will bear the full financial burden of CBAM, according to Article 9, implying that goods that have not paid any kind of carbon fee in their home country will not receive any rebate or discount, a costly affair for these trading partners. As a result, big emerging markets such as Russia or Turkey may suffer more from the implementation of CBAM than countries like the UK or the United States. India, Taiwan, and the Arabian Peninsula will face a higher burden due to the lack of a carbon pricing system than Japan, Korea or South Africa. However, it should be noted that this statement assumes that all trading partners have similar emissions intensity of production, which is not the case (see Chapter 4.2).

The Table 4 shows the trading partners that have a carbon pricing mechanism, indicating the current price of one unit and the rebated price certificate per CBAM. The rebated price of the CBAM certificate is calculated by subtracting the domestic price of each CPI from the current price of one emission certificate in the EU ETS, according to Articles 21 and 31 of the CBAM. The current price of a CBAM certificate is set to 100 euros *per* ton of CO_2, based on data from the World Bank (The World Bank (IBRD and IDA), 2022). The selected countries for the analysis thereafter, according to the methodology presented in 3.3.1, are highlighted.

China and the United States are particularly selected for further analysis due to its massive trade value with Germany. Although both countries already implemented a domestic CPI and have rebated CBAM prices, it is expected that both countries carry an additional financial burden from CBAM. Great Britain is, in contrast, not considered, as its domestic CPI has equal prices *per* certificate than those assumed for CBAM. Russia and Turkey are interesting countries as both have neither implemented nor considered a domestic CPI (to the current standing) and display a similar traded value. Korea and India are also considered to compare the impact of a domestic CPI, which Korea has and India not, on countries with similar traded value. The chart in Figure 15 reveals the traded volume *per* group of CBAM goods in 2021 of the trading partners considered.

China emerges as the most prominent exporter of iron and steel and chemicals. The United States, similarly to China, export the most considerable share of polymers and a considerable share of chemicals. This may indicate different advantages or disadvantages in the production costs structure of each country, that lead to higher costs *per* unit and thus a lower demand from Germany. Meanwhile, Russia appears to be the greatest producer of aluminum and fertilisers. Turkey competes with Russia for the biggest share of aluminum production while Korea exports mostly polymers to Germany. India exports mostly chemicals and iron and steel.

4.2. CO_2 emissions embodied in traded goods according to OECD TECO$_2$

The chart in Figure 16 compares the results of the CO_2 emissions embodied in the metal sector *per* exporting country for the year 2021, depending on the intensity factor of CO_2 emissions used (see 3.3.2).

The chart clearly shows that China is the largest producer of emissions in the metals sector, which is not surprising given the traded value of its iron, steel and aluminum products and the high intensity of its emissions. In fact, China's emissions are higher than any other country included in the analysis. Russia follows behind as the second-largest producer of emissions in the metals sector, with emissions levels very similar to China's when comparing the factor [D24T25]. Overall, it is noticeable that the results of the analysis follow a consistent pattern *per* country, with the embodied emissions calculated using the intensity of emissions for basic metals [D24] being the highest, followed by [D24T25], [D25], and then [DTOTAL].

The most surprising aspect of this chart is that, except for China, the embodied emissions are nearly identical between all countries based on both factors [D24T25] and [D24]. Particularly in the cases of Russia and the United States the results are practically indistinguishable. However, the case of China stands out, as iron and steel emissions according to [D24] alone exceed all emissions based on [D24T25]. Furthermore, the overall result varies by almost 2 MtCO_2e in the case of China. The graphs in Figure 17 clearly illustrates the difference between China and all other countries compared.

The Figure 17 provides evidence that in countries other than China and India, the variables [D24T25; D24] and [DTOTAL; D25] exhibit a consistent pattern and are approximately equal. However, in the case of China and India, these variables range without any discernible similarity. It also reinforces the statement that the CBAM will pose an uneven financial burden on exporters, evidencing that China, Russia and India will have to bear the greater burden as, for example, a million USD worth of iron and steel exported will generate twice or even thrice as much emissions as the same unit produced in the United States or Turkey. This, however, does not necessarily imply that demand and production will shift, as the individual structures of the production costs must be considered as well. A million dollars' worth of a product in a country does not automatically contain the same produced volume than the same unit in another country. Price dynamics and price shifts, as mentioned above, play a significant role. The intensity of emissions portrayed in Figure 17 above must be, therefore, validated and compared with other methods of calculating embodied emissions.

The chart in Figure 18 compares the results of the CO_2 emissions embodied in chemicals, polymers and fertilisers per exporting country for the year 2021, depending on the intensity factor of CO_2 emissions use. The chart shows that China is the largest producer of emissions in this sector as well. China's emissions are again higher than any other country included in the analysis. The United States follows behind

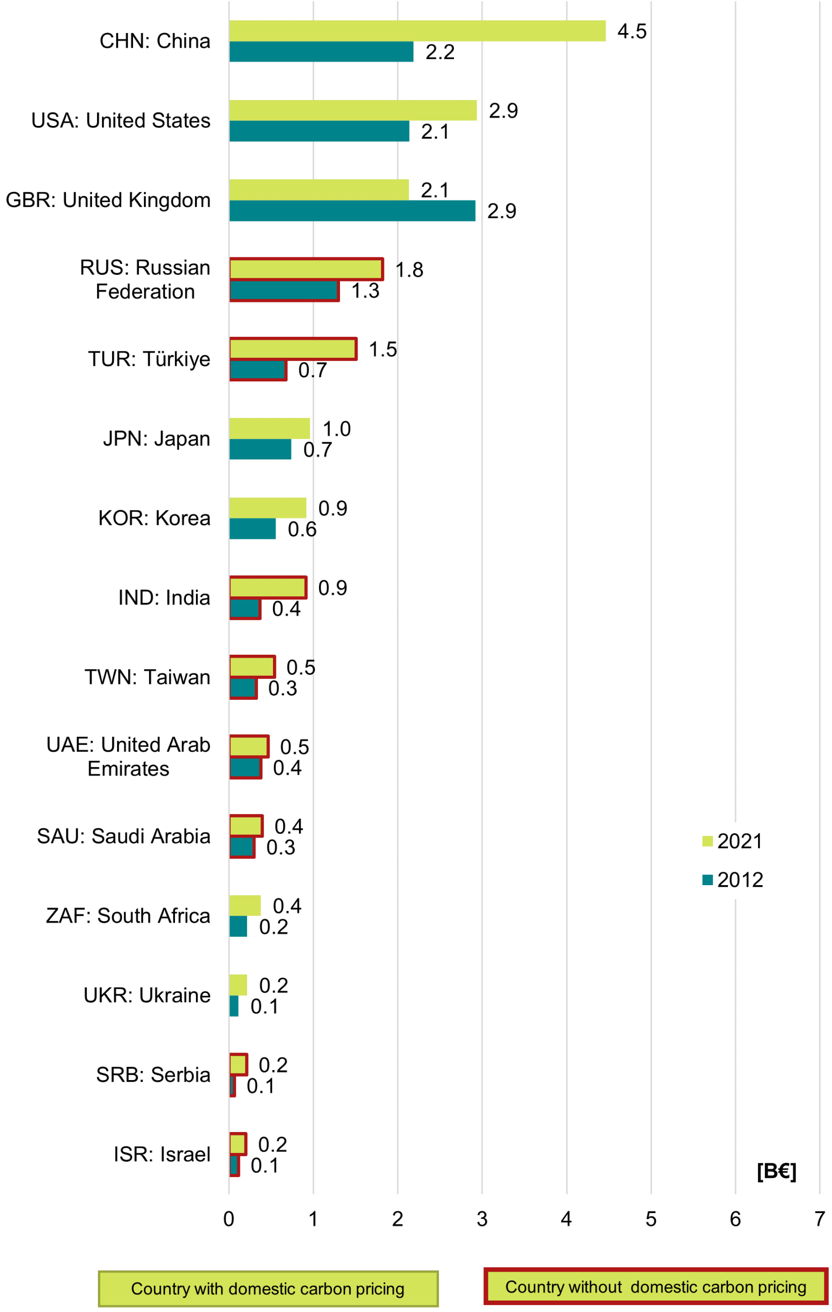

Figure 14: Top CBAM trading partners of Germany, 2021 vs. 2012 (Federal Statistical Office (DESTATIS), 2022b)

as the second-largest producer of emissions. Overall, it is noticeable that the results of the analysis follow a consistent pattern with smaller deviations *per* country. The embodied emissions calculated using the intensity of emissions for [D19T23] are often the highest, followed by [D20], [D20T21], and then [DTOTAL]. In this chart, except for China, the embodied emissions are in the same order of magnitude between all countries based on the factors [D19T23], [D20T21] and [D20]. Russia is the only country significantly affected by CBAM regarding the export of fertilisers.

All in all, the analysis reveals that Russia, China and India have the largest CO_2 emissions intensity, but China is the largest polluter *per* million dollars of products in the chemical and non-metallic mineral products category. The analysis suggests that the CBAM will impose an uneven financial burden on exporters. The approach used to calculate embodied emissions of exported goods in the metals sector *per* country considers specific factors for basic metal products and fabricated metal products. The results show that China is the largest producer of emissions in the metals sector, followed by Russia, while other countries have similar levels of embodied emissions.

Table 4: Assumed rebated CBAM certificate prices for each trading partner (The World Bank (IBRD and IDA), 2022)

Trading partner	Name of the domestic CPI	Price of Domestic CPI CPI [€ /tCO_2e]	Hypothetical rebated CBAM certificate price [€ /tCO_2e]
CHN	China national ETS	10	90
United States	California CaT	30	70
GBR:	United Kingdom ETS	100	0
RUS and TUR	Full CBAM certificate price: 100		
JPN	Japan Carbon Tax and Tokyo ETS	10	90
KOR	Korea ETS	20	80
IND	Full CBAM certificate price: 100		
TWN, UAE, SAU, ISR and SRB	Full CBAM certificate price: 100		
ZAF	South Africa carbon tax	10	90
UKR	Ukraine carbon tax	1,0	99

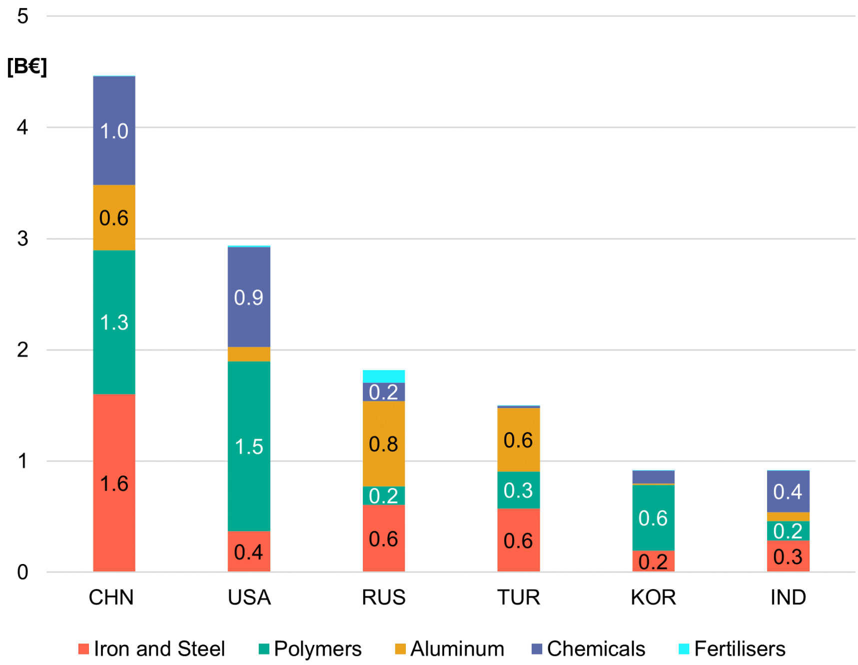

Figure 15: Cumulative traded value of selected countries, stacked per group of CBAM goods, 2021 (Federal Statistical Office (DESTATIS), 2022b)

4.3. CO_2 emissions embodied in traded goods according to IEA

The graph in Figure 19 presents a comparison of the intensity factors for each country in the production of iron and steel, as calculated through the method described in 3.3.3. Additionally, the intensity factors from the OECD $TECO_2$ database with the factors [DTOTAL] and [D24T25] are shown to validate the results from chapter 4.2.

The analysis reveals a notable disparity between the two calculation methods. On one hand, the [OECD D24T25] method shows a contradictory trend compared to the intensities obtained using [IEA PECM] and [IEA PECMBP]. It implies that China has the highest emission intensity per ton of iron and steel, while the [IEA PECM] and [IEA PECMBP] results suggest it has the lowest intensity among all countries. At first glance, this seems implausible. However, it could be due to the vast volume of production in China, or there might be inconsistencies in the primary energy input data provided to the IEA. Such speculation will not be explored further in this study. For India only, the results from both methods roughly coincide, indicating that the emission intensity of iron and steel production in India falls between 3,5 and 4,5 tons of CO_2 per ton of iron and steel produced. As for the United States, it remains unclear which factor better represents the production reality. The case of Russia is surprising, as the [OECD D24T25] factor is below the estimated intensities according to [IEA PECM] and [IEA PECMBP]. It is also evident that the emission factor of electricity per country plays a role

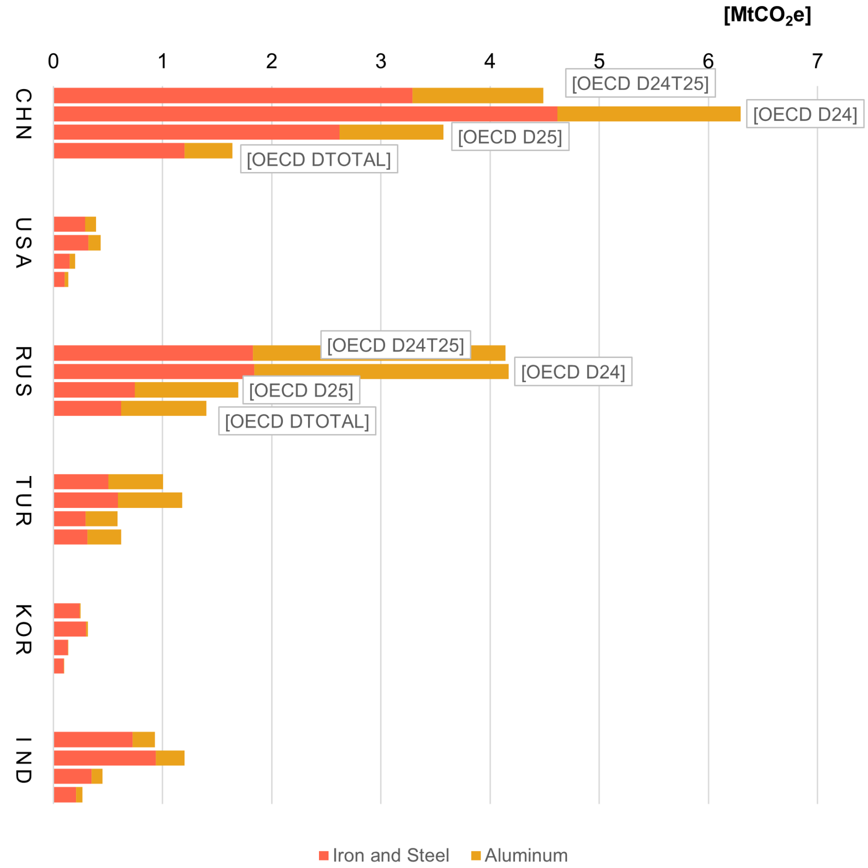

Figure 16: Embodied CO_2 emissions in the imported goods of iron, steel and aluminum depending on the factor used, 2021 (Organisation for Economic Co-operation and Development, 2021)

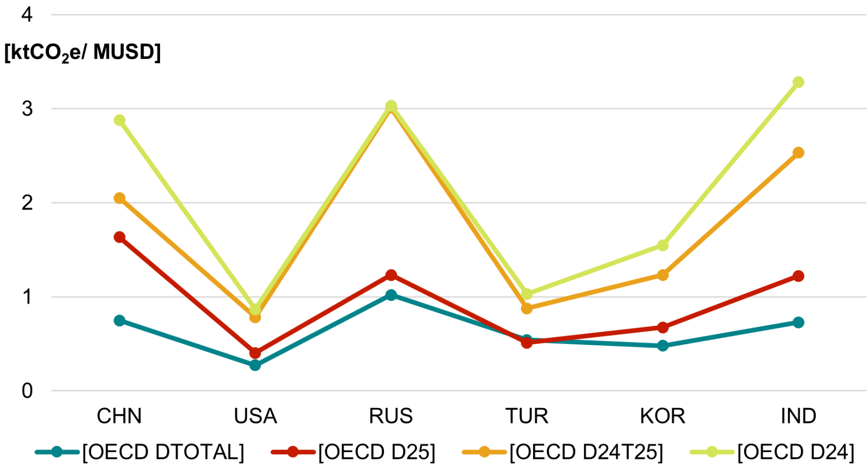

Figure 17: Comparison of the intensity factors of CO_2 emissions embodied in the metals sector, 2018 (Organisation for Economic Co-operation and Development, 2021)

in the intensity factors of CO_2 emissions for iron and steel. This implies that if the electricity emission factor is twice as polluting as originally determined, the intensity of iron and steel will be roughly half a ton of emissions higher per ton produced across all countries.

4.4. Validation with GHG Protocol Tool and literature values

The primary objective of this step is to identify the possible reasons for the deviation in the results. One hypothesis is that the fuel emission factors for each primary energy source, such as coal and natural gas, are incorrect. However, the results displayed in the graph in Figure 20 contradict this hypothesis.

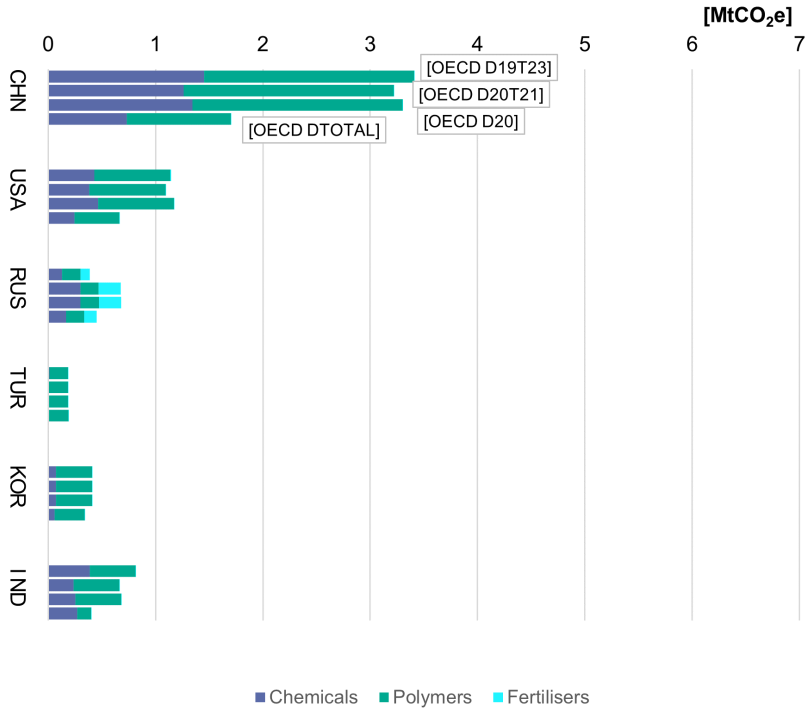

Figure 18: Embodied CO_2 emissions in the imported goods of chemicals, polymers and fertilisers depending on the factor, 2021 (Organisation for Economic Co-operation and Development, 2021)

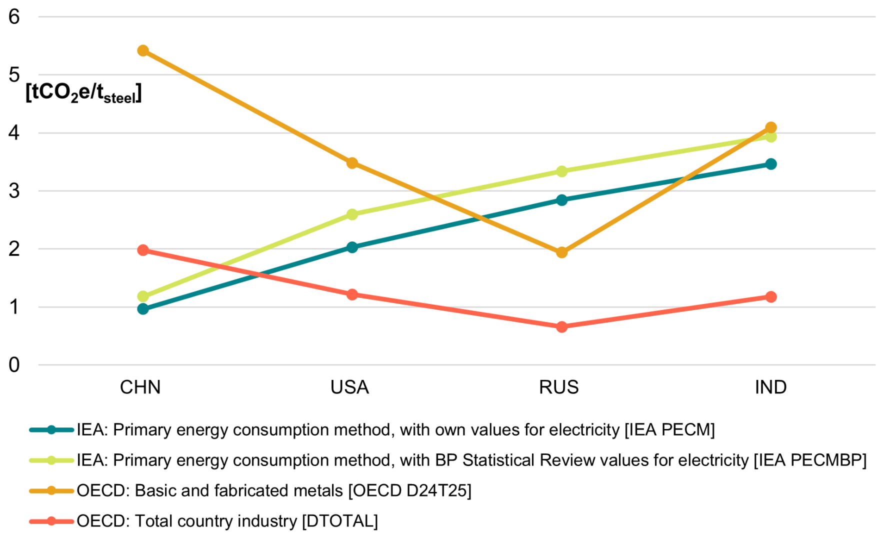

Figure 19: Comparison of intensity of CO_2 emissions factors of steel depending on the data source and method of calculation, 2018 (BP, 2022; IEA, 2023; Organisation for Economic Co-operation and Development, 2021; U.S. Geological Survey, 2019b)

Figure 20 suggests that the fuel emission factors assumed for each primary energy source are in a similar range of values, undermining therefore the possibility of low intensity CO_2 emission factors of iron and steel.

The next phase involves comparing the outcomes of this study with the current literature on CO_2 emission production in the iron and steel sector. The aim is to investigate the hypothesis that the entire assumptions and approach adopted are flawed in principle, and that the CO_2 emission intensity factors in the iron and steel industry may differ significantly. The results are shown in the chart in Figure 21 and compared.

The analysis shows that the intensities calculated are plausible and raises the question of how the factor [OECD D24T25] is higher than all other calculation methods. This will be further discussed in chapter 5.2. It is clear, however, that the intensities estimated for China according to [IEA PECM] and [IEA PECMBP] are too low and that a fair value for further research is the value [EU JRC]. Still, the analysis suggests that China has the lowest intensity factor of CO_2 emissions of the major trading partners, followed by United

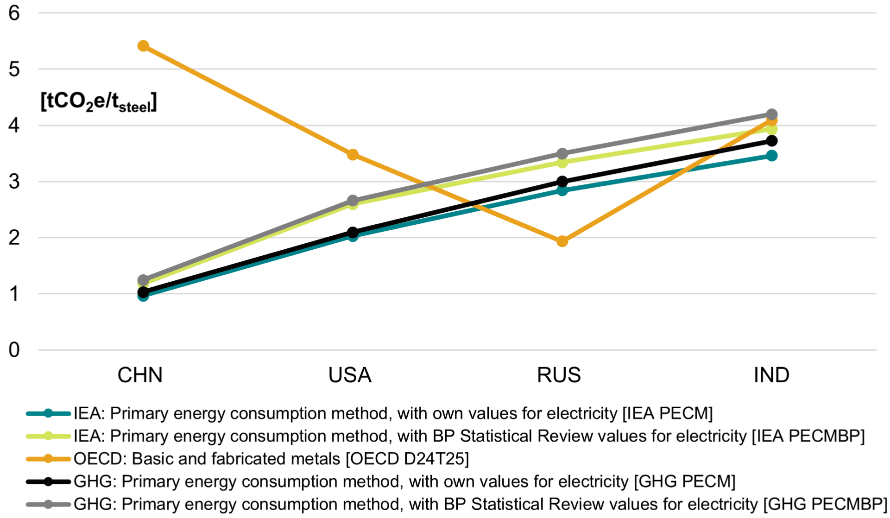

Figure 20: Comparison of intensity of CO_2 emissions factors of steel depending on the data source and method of calculation, 2018 (BP, 2019; GHG Protocol & Gillenwater, 2005; IEA, 2023; Organisation for Economic Co-operation and Development, 2021; U.S. Geological Survey, 2019b)

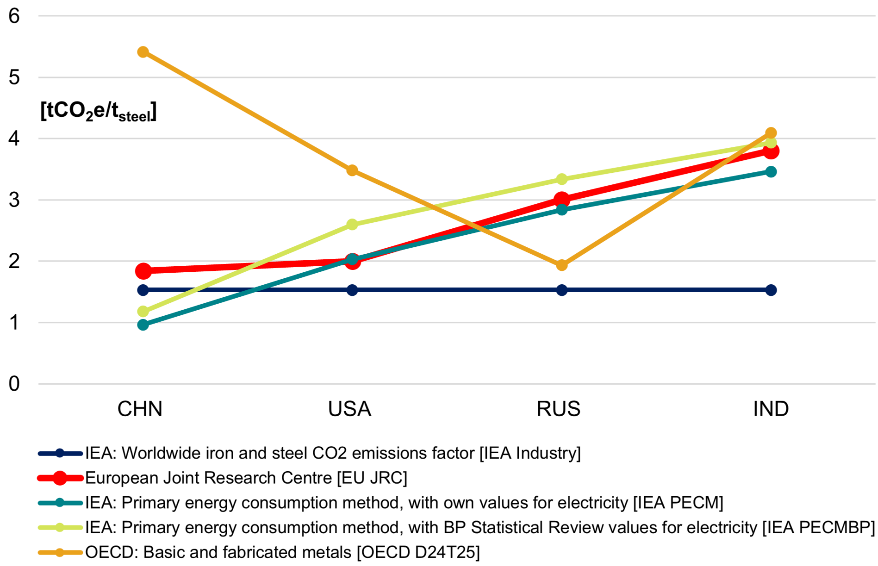

Figure 21: Comparison of intensity of CO_2 emissions factors of steel depending on the data source and method of calculation, 2018 (BP, 2019; GHG Protocol & Gillenwater, 2005; IEA, 2023; Koolen & Vidovic, 2022; Organisation for Economic Co-operation and Development, 2021; U.S. Geological Survey, 2019b)

States, Russia and India. The analysis further suggests that it is highly likely that the intensity factor of India lies somewhere between 3,5 and 4,5. Additionally, it can be assumed roughly that the intensity factors of Russia and United States lie somewhere between 2,0 and 3,5 tons CO_2 *per* ton of iron and steel, narrowing at least a range of intensities for further research. One could draw the inference that the factor [OECD D24T25] represents additional emissions, commonly known as scope 3 emissions. This could potentially explain the marked variation in the case of China and the United States. However, it is unexpected that the Russian value for [OECD D24T25] is considerably lower than other estimates, including the estimation from [EU JRC].

The same analysis, analogous to the iron and steel industry, is carried out for the aluminum industry (U.S. Geological Survey, 2019a), presenting the results in Figure 22.

The presented chart reveals that the intensity of CO_2 emissions in the aluminum industry is considerably higher when compared to the iron and steel industry. Additionally, the variances in intensities between countries are more pronounced in the aluminum industry, where the results from [D24T25] exhibit both lower and higher intensities than those reported in [IEA PECM] and [IEA PECMBP]. Except for the United States, the deviations of intensities among countries fall within the range of 5 to 7 tons of CO_2 *per* ton of aluminum produced. Notably, the values from [IEA PECM]

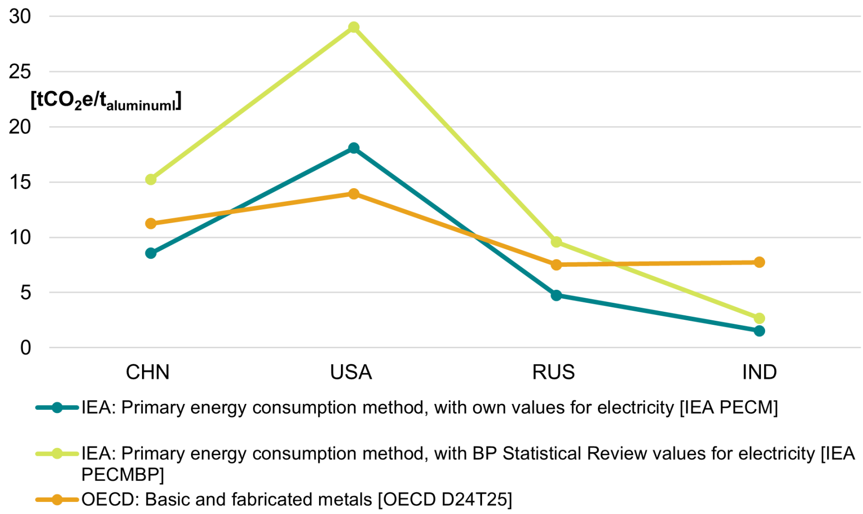

Figure 22: Comparison of intensity of CO_2 emissions factors of aluminum depending on the data source and method of calculation, 2018 (BP, 2019; GHG Protocol & Gillenwater, 2005; IEA, 2023; Organisation for Economic Co-operation and Development, 2021; U.S. Geological Survey, 2019a)

and [IEA PECMBP] for the United States are significantly higher than those from [OECD D24T25]. It is noteworthy that the substantial difference between [IEA PECM] and [IEA PECMBP] indicates that distinct emission factors for electricity have a significant impact. Therefore, the United States is presumed to have the highest electricity consumption per ton of aluminum produced, followed by China and Russia. In contrast, India relies less on electricity to produce iron and steel, according to [IEA PECM] and [IEA PECMBP]. Nevertheless, the values reported for India seem implausibly low and are likely miscalculated.

According to this analysis, the data on embodied emissions suggests that the exporting countries most affected by CBAM, when importing to Germany, will be China and Russia, followed by India. This statement, however, is to be proven in the next chapter as the additional production costs posed by CBAM may have a diminished effect due to the costs advantages that such countries have compared to western countries. Figure 23 reinforces the suggestion that the impact of CBAM is greatly dependent on the approach used for calculating the embodied emissions, as demonstrated in the iron, steel, and aluminum sectors. Except for India, the intensity factors per country exhibit substantial variation in all cases. The effect is particularly evident in China and Russia, perhaps owing it to the significant quantity of iron and steel traded with Germany.

The following chapter scrutinizes the analysis, emphasizing the potential implications of CBAM on the production cost structure of each country.

5. Discussion

5.1. Effect of the CBAM on production costs and demand patterns

This chapter analyzes the potential impact of the proposed CBAM on Germany's de-mand for energy-intensive goods, as well as the impact on its major trading partners, including China, Russia, and India. The breakdown of the production costs per country[3] is presented in Figure 24. The average production costs of the EU are also considered in this chart, for the sake of comparison. The average total production costs in EU27 are the second highest after the United States. Germany's major trading partners in the iron and steel industry, Russia; India and China have all lower production costs.

According to the data presented, Russia has the lowest production costs with a cost advantage of approximately 100 euro *per* ton of steel produced, compared to the EU27. This is primarily due to its position as the country with the second-lowest material costs and the lowest energy costs out of all countries analyzed. In addition, Russia benefits from low labor costs and other costs, positioning it competitively in the market. However, the data suggests that Russia, like the United States, does not prioritize savings from production by using recycled scrap or self-power-generation in its production plants.

Following Russia, India ranks second with slightly higher energy and other costs, but significantly lower material costs. Meanwhile, China has the highest material costs among all exporters examined, approximately 100 euro per ton higher than India. However, China compensates for this disadvantage through the lowest labor and other costs. Furthermore, China's savings from using recycled scrap and self-power-generation almost fully counterbalance its cost disadvantage in the raw materials procurement, according to the data provided.

The data reveals that in the comparison of iron and steel producers, the EU27 and the United States are the least com-

[3] In this chapter, the trading partners of Germany in the iron and steel industry are presented from left to right following the least costs of production, and not the hierarchy presented in the chapters before.

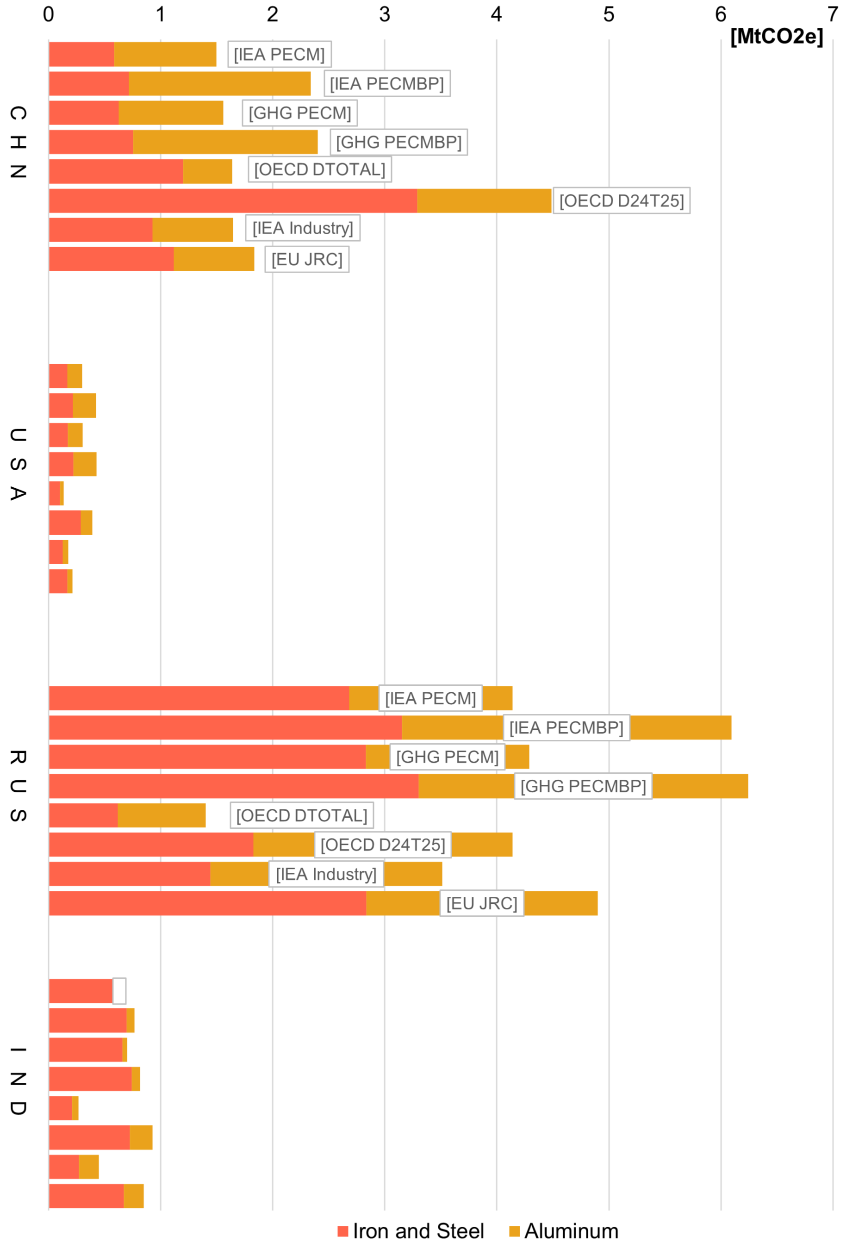

Figure 23: Comparison of embodied emissions in the iron, steel and aluminum industry imported to Germany in 2021 per country depending on the data source and the correspondent intensity factor of CO_2 emissions (BP, 2019, 2022; Federal Statistical Office (DESTATIS), 2022b; GHG Protocol & Gillenwater, 2005; IEA, 2023; Koolen & Vidovic, 2022; Organisation for Economic Co-operation and Development, 2021)

petitive. Although they have slightly lower material costs than China, their labor costs are the highest among all facilities examined. Moreover, European facilities have the highest energy costs while the United States exhibits lower energy costs than China and India. However, the EU27 has a significant advantage over other countries in terms of a high share of savings from recycled scrap and self-power-generation, which is crucial for maintaining competitiveness in the market.

To provide a visual representation of the potential impact of CBAM on production costs, this study forecasts the shift in total production costs of iron and steel according to the methods set in 3.3.5. The graphs in Figure 25 and Figure 26 present the results of the analysis.

Figure 25 and Figure 26 present an analysis of the impact of intensity factors of CO_2 emissions on the overall effect of CBAM during the 2026-2035 phase-in period. Based on the data presented in Figure 25, it can be deducted that CBAM may not significantly affect the structure of production costs. Moreover, there may not be a substantial shift in production and demand patterns in the short or long term, and China is likely to maintain its cost advantages. Russia will

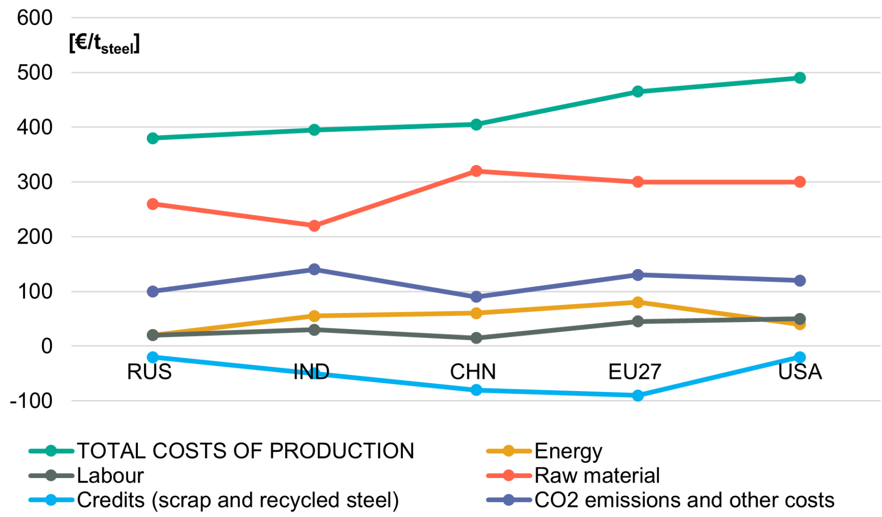

Figure 24: Breakdown of the costs of production of iron and steel per country; 2020 (European Joint Research Centre et al., 2020)

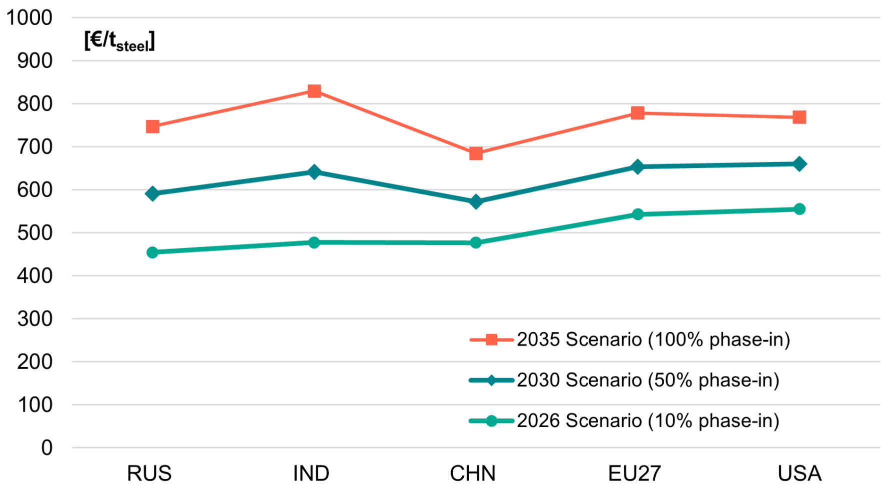

Figure 25: Shift of the total production costs of iron and steel over the phase-in period of CBAM (2026-2035) with [EU JRC] (European Joint Research Centre et al., 2020)

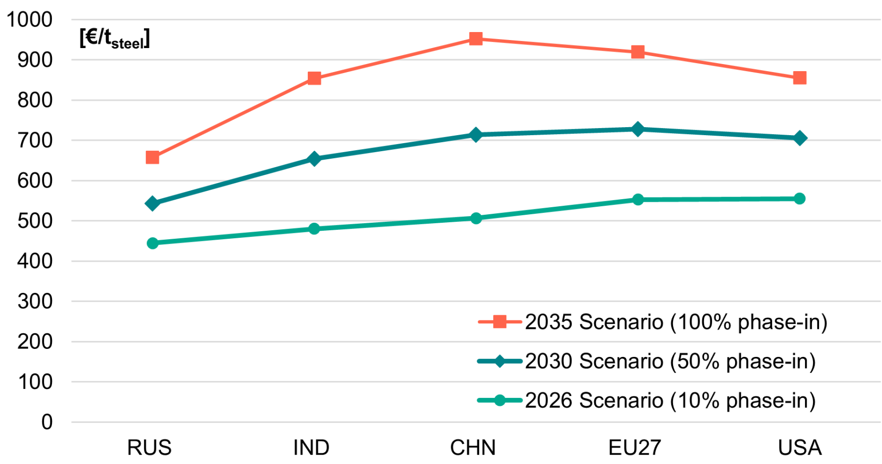

Figure 26: Shift of the total production costs of iron and steel over the phase-in period of CBAM (2026-2035) with [OECD D24T25] (European Joint Research Centre et al., 2020; Organisation for Economic Co-operation and Development, 2021)

remain more competitive than the EU27 and United States, with all three countries having a more leveled structure of costs. However, the data suggests that India may lose its current cost advantages and competitiveness by 2035. The data indicates that the impact of CBAM will likely become visible at the end of its phase-in period in 2035.

In contrast, Figure 26 indicates that there will be a short-term shift in demand. By 2030, China's production costs will be on par with those of the EU27 and the United States, while India and Russia will improve their price competitiveness. However, in the long-term, China's cost advantage will be offset by the high CO_2 emissions intensity and the resulting high costs associated with CBAM. As expected in all scenarios, the EU27 will continue to be one of the producers with the least cost advantages. The data suggests that the United States's price competitiveness will improve over time, reaching levels well below those of the EU27 and China. This suggests a possible shift in demand from China to the United States and India. According to the data, Russia's competitiveness will also improve over time, giving it the best market position in the long-term.

The main takeaway from comparing both figures is that it is uncertain whether CBAM will lead to a shift in demand in the short or long term. Without further research, it is difficult to determine whether the additional costs imposed by CBAM will undermine each country's cost advantages and structures to the extent that it will lead them out of their market position and competitiveness. According to the scenario analysis [EU JRC], there will be no shift in the long-term, as China's prices will remain significantly lower, India is not a major exporter and will have the worst competitiveness, and Russia's trading relations are under strong scrutiny. Even in the scenario [OECD D24T25] depicted in Figure 26, CBAM will only impact China's cost advantages to the point where it levels the cost of production with that of the EU27. The data suggests that there is no significant option to shift demand from non-EU imported goods to EU27 imports, as one of the major trading partners will always have significantly higher cost advantages.

In addition, the analysis carried out in this study is based on relatively bold assumptions aimed at enhancing the EU27's competitiveness. However, exporting countries are expected to respond quickly to counter the financial burden imposed by CBAM, for example, by implementing a domestic CPI in their production to pay rebated CBAM prices or by adjusting existing domestic CPI prices. A sensitivity analysis is conducted to assess the potential effect of trading partners' counteractions and to determine if there is a scenario where the EU27 emerges as the market leader or one of the most competitive producers.

The findings presented in Figure 27 indicate that a 10% annual increase in the price of CBAM certificates over the decade of 2026-2035 would render China uncompetitive, according to the data from OECD D24T25. However, China could easily maintain its market competitiveness by raising its domestic CPI price by 10% annually. If the US also raises its domestic CPI price, it could become the market leader, assuming the intensities of [OECD D24T25] and no future trading agreements with Russia. However, it is highly debatable whether the intensities determined in [EU JRC] will be used instead of those determined in [OECD D24T25]. In that case, as the data suggests, China will remain the market leader even if CBAM prices rise yearly and China doesn't adjust its current CPI price over a decade.

5.2. Remarks of the discussion

Throughout the research, it became apparent that there is a notable difference in the intensity factors of emissions between [OECD D24T25] and the other sources, as depicted in Figure 22 for the iron and steel industry. This section aims to investigate the possible reason for this deviation in intensity factors. To achieve this, the analysis takes a reverse look at the calculation process of the intensity factors.

The intensity factors [OECD D24T25] for iron and steel were derived by multiplying the CO_2 emissions embodied in total gross exports [EXGR_TCO2INT] of the OECD $TECO_2$ database for 2018 per country with the traded value of each good traded to Germany in 2021 in the iron and steel category. It is noteworthy that this calculation assumes an equal currency exchange rate from USD to EUR, as the CO_2 emissions embodied in total gross exports [EXGR_TCO2INT] of the OECD $TECO_2$ database for 2018 are presented in tons of CO_2 per million US Dollars. In contrast, the traded value of iron and steel into Germany is based on data from the Federal Statistical Office, presented in euros. This could potentially affect the outcome. However, the assumption of an equal exchange rate is justifiable as, according to the European Central Bank, the average exchange rate from USD to EUR in 2018 was approximately 1,18 (European Central Bank, n.d.).

Chapter 3.1 and 3.2 of this study have already highlighted the importance of considering price dynamics and shifts over time. It is important to note that a rise in the traded value of a good does not necessarily indicate a proportional increase in volume traded. Therefore, it cannot be assumed that a rise in traded value due to higher prices or price shifts will lead to a proportionate increase in embodied CO_2 emissions, especially if the traded volume for that same period did not change proportionally.

The calculation of total embodied emissions in the iron and steel industry according to [OECD D24T25] raises the question of whether emissions from the same type of good produced in two different countries with significantly different prices can be compared, as shown in the chart in Figure 28.

Take the case of WA7205 (grains and powders of pig iron, iron or steel). The data from this chart suggests that the same unit imported to Germany in the year 2021, once providing from China and once from Russia, had a price difference of a factor ten. This means, hypothetically, that a million dollars' worth of this product had a traded volume of 50 tons, in the case of China.

In the case of WA7205, which consists of grains and powders of pig iron, iron, or steel, data from the chart suggests

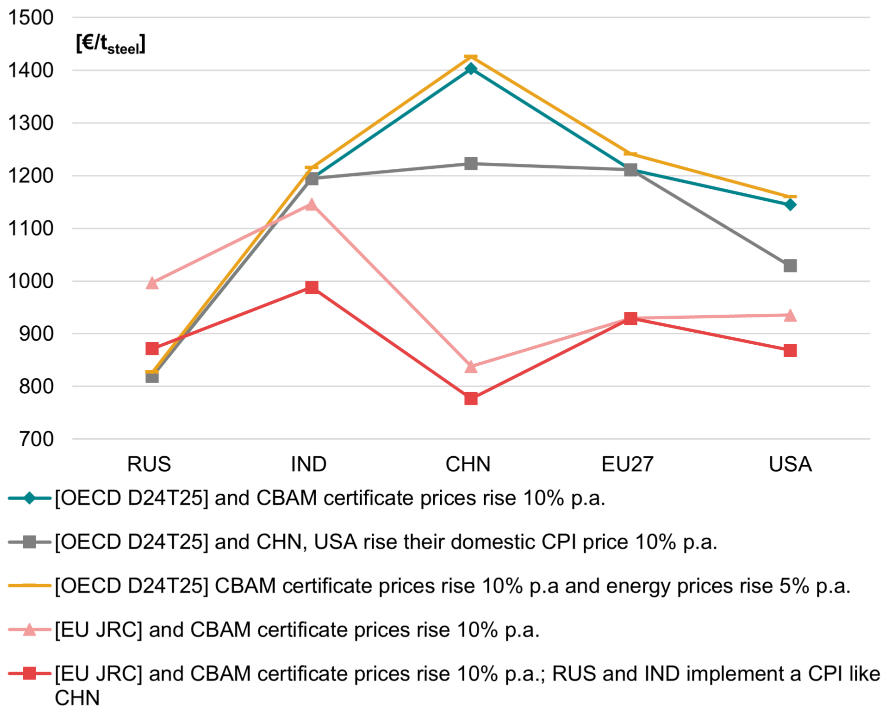

Figure 27: Sensitivity analysis, Effect of CBAM on the total production costs of iron and steel in 2035, [OECD D24T25] or [EU JRC] (European Joint Research Centre et al., 2020; Organisation for Economic Co-operation and Development, 2021)

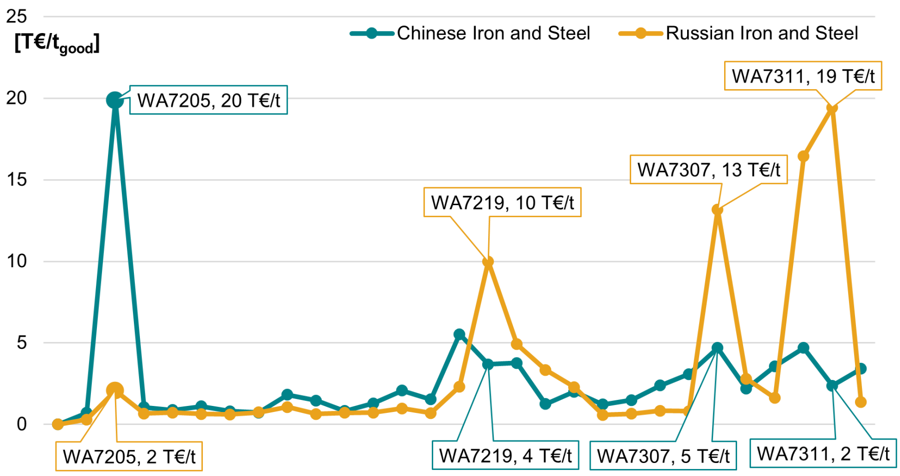

Figure 28: Comparison of the specific prices of iron and steel goods traded to Germany from China and Russia, 2021 (Federal Statistical Office (DESTATIS), 2022b)

that importing the same unit to Germany in 2021 from China and Russia resulted in a tenfold price difference. Therefore, hypothetically, a million dollars' worth of this product had a traded volume of 50 tons from China and nearly 500 tons from Russia. As a result, 50 tons imported from China to Germany had approximately 5,500 tons of embodied CO_2 emissions, assuming a factor of 5.5 $ktCO_2e/MUSD$, while 500 tons imported from Russia contained 3,000 tons of embodied CO_2 emissions, assuming a factor of 3.0 $ktCO_2e/MUSD$ according to the calculation from [OECD D24T25] (see 4.2). These intensity factors differ significantly from literature and research values, such as those presented in [EU JRC].

Considering that the OECD intensity factors are presented in emissions per monetary value rather than emissions per ton of physical product, and that the monetary value of the same good can vary between countries, the calculation of embodied emissions may be impacted. Thus, this thesis suggests the use of specific intensity factors based on the traded volume of a good instead.

6. Conclusion

According to the analysis presented in this thesis, it is unclear to what extent CBAM will impact the trading patterns of exports and imports between Germany and non-European countries, if at all. The data suggests that CBAM is unlikely to have a significant effect on the cost advantages of exporting countries, such as China, Russia, and India. Rather, it is probable that existing advantages related to low labor, material, or energy costs will remain bigger in the short and long-term. Thus, CBAM may only reduce a country's specific advantage compared to the cost of production within the EU. Major trading partners of Germany, particularly China and Russia, may need to tolerate or accept an inherent disadvantage that may lower their profit margins to maintain their market position.

Furthermore, the analysis indicates that the financial burden of CBAM is unevenly distributed across exporters and determined by each country's energy production structure and technologies used in production processes. The data suggests that there is no significant option to shift demand from non-EU imports to EU imports as one of the major trading partners will always have a significant cost advantage. This study's analysis is based on bold assumptions aimed at enhancing EU competitiveness. However, exporting countries are expected to respond quickly to counter the financial burden imposed by CBAM. For example, they may implement a domestic CPI in their production to pay rebated CBAM prices or adjust existing domestic CPI prices. According to the analysis carried, there is a scenario where the EU emerges as the market leader or one of the most competitive producers.

The analysis presented in this thesis also highlights weaknesses of CBAM that could significantly reduce its intended impact. Specifically, there is no clear, standardized definition for calculating the embodied emissions of energy-intensive products such as iron, steel, and aluminum, which may lead exporting countries to use the lowest available method and report fewer emissions than are actually emitted. Therefore, this thesis recommends that the governing bodies of the EU revise the third annex of their CBAM guideline to provide a concrete method for calculating embodied emissions. It is also suggested that they evaluate whether CBAM will have the desired impact and if it aligns with the goals of addressing climate change.

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