EU Environmental Policy:

Cost-Benefit Analysis of the Carbon Border Adjustment Mechanism

in Fertilizers for Sustainable Agriculture

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Abstract

The Carbon Border Adjustment Mechanism (CBAM), a policy within the European Union's (EU) Green Deal, will require EU importers to pay for carbon emissions associated with imported goods. Following implementation in 2026, shifts in EU demand could reduce carbon emissions, however EU importers will bear the cost of the increased prices. This study examines and weighs the economic costs and environmental benefits of the CBAM in a fertilizer sector-specific policy analysis, testing whether the reduction of imported carbon emissions justifies the cost to EU consumers.

To evaluate this trade-off, EU import demand is modeled and analyzed before and after the cost of CBAM credits are included in the import price. Economic costs are measured by determining changes in price and quantity demanded post-implementation. These estimates are evaluated through a welfare analysis which calculates the importer surplus loss for EU importers. For environmental benefits, decreases in fertilizer demand are converted to equivalent carbon emission reductions. This decrease is then valued using the social cost of carbon (SCC) for a direct dollar-to-dollar comparison between environmental benefits and economic costs.

The baseline scenario results show that the cost of the CBAM, equal to $4.04 billion, outweighs the benefit, equal to $2.58 billion, by $1.46 billion annually, when using a CBAM credit cost of $73.5 and a SCC value of $254. However, sensitivity analysis reveals that the CBAM benefit outweighs the cost when CBAM credits cost $91.8 or the SCC is valued at $700, leading to a legislative imperative to value carbon emissions at an ecologically reasonable level.

This study will help prepare all relevant stakeholders for the coming market shift, with the understanding that the implications of the CBAM's impact on the fertilizer sector are of particular note due to the interaction with the agricultural industry. In light of new EU

agricultural policy goals aimed at reducing the use of synthetic fertilizers, the CBAM's impact on demand for fertilizer imports could provide an opportunity for organic fertilizers as a substitute good on the fertilizer market, in alignment with the EU's overarching carbon neutrality goal.

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Section 1: Introduction

As the continued degradation of our environment brings the climate at odds with business as usual, policymakers are faced with the responsibility to act; for the protection of our environment is the protection of our infrastructure, our economy, our food sources, and our livelihoods (IPCC, 2022). However, the decision to enact environmental policy is not easy, as the environmental degradation associated with every market interaction has never been entirely accounted for in our mainstream economic models (Miles, 1995; Costanza, Perrings, & Cleveland, 1997; Washington & Maloney, 2020). For policymakers to see past conventional economic metrics to acknowledge our fundamental responsibility to sustain the environment we inhabit requires a surprising amount of fortitude. After all, policymakers must consider the economic costs of our welfare (Tessaro, 2022). Yet as the increasing frequency of interruptions in production processes due to climatic extremes continues, the tangible benefits of environmental policy become more evident, increasing the urgency for the implementation of effective environmental policy packages on a global scale.

Leading this global shift toward comprehensive climate action, the European Union (EU) has maintained its position at the forefront of environmental policy on the international stage with their 2019 European Green Deal (EGD) (Oberthür & van Homeyer, 2021). This multi-sectoral policy package is defined by the EU's ambition for climate neutrality by 2050. This ambitious plan is driven by green initiatives in the transportation, industry, construction, and energy sectors; and is supported by biodiversity restoration strategies, with efforts to transition to a more sustainable agri-food system (EC, 2019).

The EGD additionally includes a landmark climate policy called the Carbon Border Adjustment Mechanism (CBAM). This policy aims to reduce carbon leakage, a common consequence of environmental policy in which emissions-intensive production is moved offshore to maintain cost competitiveness by avoiding environmental regulations. The CBAM will regulate the carbon emissions associated with the production of goods that are imported to the EU within six emissions-intensive trade-exposed (EITE) industries which are most vulnerable to carbon leakage, namely: cement, iron and steel, aluminum, electricity, hydrogen, and fertilizers.

Beginning in 2026, the CBAM will require EU importers to purchase certificates to cover the cost of the virtual carbon emissions they import. Each CBAM certificate will be set at the price per tonne of carbon emissions equivalent to that of the EU's Emissions Trading System (ETS) regulations. However, any carbon price paid at the origin of production will be deducted from the overall cost of the CBAM. With the CBAM working in conjunction with the already established ETS, the EU incorporates the environmental cost of carbon emissions directly into market prices, effectively internalizing this externality for goods both produced and consumed within the regulated sectors in the EU (EU, 2023a; EU, 2023b).

The CBAM is unique because it implements a border carbon adjustment (BCA) framework – a framework discussed in policy circles for over two decades – that could significantly affect global trade patterns as producers, consumers, and policymakers adjust to the newly priced carbon emissions in international markets (Cosbey et al., 2019). Border carbon adjustments have been debated over their World Trade Organization (WTO) compliance, as environmental policies generally should not interfere with international trade, except when protecting an exhaustible natural resource (GATT, 1994, art. XX(g)). In this case, the EU is asserting that clean air is a natural resource which is being exhausted, leading the CBAM to be WTO compliant (Englisch & Falcao, 2021). Following this argument, the goal of the CBAM must be to benefit the environment by reducing carbon emissions, which fits into the overarching

EGD climate neutrality goal. In the time running up to the 2026 implementation of the CBAM, the question then becomes: will the environmental benefit of this policy outweigh the cost of its varied impacts on trade? This cost versus benefit question becomes particularly nuanced when considering the asymmetric effects of the CBAM across different trading partners, as their environmental policy frameworks vary.

Due to the nature of the CBAM's pricing mechanism, EU import demand will respond differently within each of the EU's trade relationships, as their trade partners utilize different energy sources and production technologies with varying carbon emission levels (JRC, 2023). Additionally, import demand from trading partners which utilize a domestic carbon pricing regulation will likely be less affected, as their carbon price is subtracted from the overall CBAM price. The varying effects of the CBAM across the international market raises questions about the magnitude of its impact on each of the EU's trade relationships, prompting discussions about equity in the EU's pursuit of climate neutrality (Eike et al., 2021).

The likely shift in demand toward lower-carbon products will provide incentives for trade partners to adapt, either by introducing their own domestic carbon pricing regulations, through low-carbon technological improvements, or through shifting production towards more sustainable product variations (Erdogu, 2025). However, with increasing environmental barriers to trade, smaller and less agile economies are at risk of being left behind in the green industrial transition as they may struggle to implement the necessary technology or environmental policy adaptations (Magacho, Espagne, & Godin, 2024). This provides an opportunity for the EU to extend the environmental benefits of the CBAM by incentivizing or supporting green industry among their trade partners, particularly in sectors where production processes have significant environmental impacts beyond carbon emissions.

In the specific context of the fertilizer industry, the CBAM's trade effects intersect with broader EU environmental priorities, introducing additional nuance to the cost versus benefit question beyond general trade considerations or carbon emission reductions. It has been well documented that synthetically produced fertilizers are harmful to the environment, with their carbon-intensive production and routine over-consumption negatively impacting water and air quality, soil health, biodiversity, and long-term agricultural yield (Cai et al., 2019; IPCC, 2022; Litskas, 2023). The inefficient use of fertilizers in agriculture is an area for improvement targeted in multiple EGD agricultural policies, which aim to reduce the proportion of synthetic fertilizers used in agri-food production, to increase organic farmland, and to close the agricultural nutrient loop in order to establish a circular bioeconomy (EC, 2020a; EC, 2020b; EC, 2021). This then illuminates an additional environmental benefit of the CBAM, as any changes to EU import demand for synthetic fertilizers could potentially provide a market opportunity for sustainable, organic, bio-based fertilizers to supplement the needs of agricultural producers. However, these shifting market conditions must be anticipated in order for the necessary incentives and support structures to be designed in order to increase the availability and accessibility of organic fertilizers.

The purpose of this research is to determine the impact of the CBAM on EU import demand for fertilizers, testing the hypothesis that price elasticities vary significantly by fertilizer types and trading partners, resulting in asymmetric economic and environmental impacts. By disaggregating the impacts of the CBAM across both product types and trading partners, this analysis provides a more nuanced understanding of which segments of the fertilizer supply chain bear the greatest economic costs and which contribute most to emissions reductions. This analysis culminates in a comparison of the economic costs of this policy to EU consumers with the potential environmental benefits derived from a reduction in EU demand. The resulting quantitative assessment provides policy-relevant metrics for evaluating whether the CBAM effectively balances emissions reduction with economic feasibility, while supporting the EU's broader environmental and agricultural goals.

This analysis is completed by estimating the EU's trade partner-specific price elasticities of demand for imported fertilizers through a log-log import demand model, analyzing 27 years (1995-2021) of trade between the EU and their major fertilizer trading partners. These elasticities directly inform the estimates of how import demand responds given the CBAM price increase, assuming importers bear the full burden of the policy. The CBAM price increase per tonne of carbon emissions is set at equivalent to the average cost of an ETS carbon allowance during the most recent phase of the EU environmental policy (2021-2024). From the resulting shift in demand, the cost and benefit of the CBAM is evaluated. The cost is quantified as importer surplus loss to EU importers given the price increase. The benefit is calculated as the reduction in carbon emissions imported to the EU, with each prevented tonne valued at the most recent social cost of carbon (SCC) estimate from Barrage and Nordhaus (2024). The government revenue generated from this policy is also included as a benefit of the CBAM, assuming these funds are reinvested into an environmentally beneficial initiative (EC, 2023a).

The EU's CBAM represents a significant shift in global trade policy as the costs of carbon emissions will be internalized into the market transaction of imports of emissions-intensive goods, like fertilizers, forcing trade partners and importers to adapt. The fertilizer industry is uniquely central in the role of food security and environmental degradation, making it a crucial sector for analysis in the evaluation of the efficacy of the CBAM to balance environmental goals with economic considerations. Understanding the trade-offs between reducing carbon emissions and interfering with the status quo of the EU fertilizer import market is essential to inform policymakers as they design parallel support structures and to prepare industry stakeholders as they adapt to this new trading environment.

The current literature on the impact of the CBAM focuses mainly on the overall impact of the policy across trade in all EITE sectors (Böhringer et al., 2021; Böhringer et al., 2022; Fouré et al., 2016; Kuik & Hofkes, 2010), while largely neglecting fertilizer-specific economic analyses which are crucial for effective policy implementation. This gap is particularly significant given that fertilizers occupy a unique position at the intersection of industrial production, international trade, and agricultural sustainability.

This study fills a critical gap by offering a quantitative economic assessment of the CBAM's impact on the fertilizer sector in a cost-benefit analysis framework, contributing specific market implications that broader multi-sectoral studies cannot capture. This analysis considers the impact of the CBAM price increase on each trade relationship, subdivided by general fertilizer product category, providing meaningful results according to the carbon emission intensity of each product category from each exporting country. This then provides estimates of changing demand for EU trade partners, while illuminating the potential economic loss to EU consumers. Furthermore, this analysis provides EU policymakers with information about the potential impacts of the CBAM on crucial trade relationships, in conjunction with supplemental information to develop support structures for their agricultural producers during the coming market shift and sustainable agricultural transition. Ultimately, this study provides a clear picture of the expected impact of the CBAM on the fertilizer import market through a balanced cost-benefit analysis that considers both economic and environmental impacts.

The remainder of this study provides a review of relevant literature on EU climate policy, border carbon adjustments, fertilizers, and carbon valuation strategies, followed by a section detailing the methodology employed for the cost-benefit analysis, before presenting the empirical results of the analysis with country- and product-specific CBAM impacts, and concluding with a discussion of policy implications for global trade relationships and sustainable agriculture in the EU.

Section 2: Literature Review

To establish the broader context informing this study, this literature review provides foundational context from four key strands of literature. First, the inner workings of the EU's carbon emission regulation structure are discussed in *EU Climate Policy Framework: ETS and CBAM*. This foundation is essential as it outlines the regulatory mechanism through which the CBAM internalizes carbon costs into market transactions in conjunction with the EU's ETS, effectively establishing an understanding of the EU's carbon pricing strategy. Next, the global context surrounding environmental policies like the CBAM are presented in *Global Impacts of BCAs*. Understanding the established literature on potential international implications is crucial for evaluating how the CBAM affects global trade patterns and how trade partners must adapt to this new trading environment. Then, a discussion of the CBAM's interactions with the agricultural sector and EU agricultural policy objectives through its regulation of imported fertilizers are described in *EU Agriculture, Fertilizers, and CBAM*. This section bridges the EU's climate policy with their agricultural sustainability goals, highlighting the fertilizer industry's unique centrality to both food security and environmental concerns. Finally, estimations of the monetary value of environmental policies are illustrated in *Estimates of the Social Cost of Carbon*. A discussion of these carbon valuation frameworks provides the necessary foundation for the cost-benefit analysis to appropriately value a reduction of carbon emissions in terms of environmental benefit. Together, these four literature components provide the necessary context to discuss a cost-benefit analysis of the CBAM's impact on the EU fertilizer import market. Additionally, this review of the established literature reveals the gaps in understanding the specific impacts of the CBAM on international climate policy, international trade, the EU fertilizer import market, and sustainable agriculture initiatives.

EU Climate Policy Framework: ETS and CBAM

The environmental degradation of global common-pool resources, like clean air, has been a point of discussion in international policy arenas for decades. However, developing effective environmental policy utilizing multilateral environmental agreements is uniquely challenging, leading to varying levels of success, and leaving global agreements on greenhouse gas (GHG) emission regulations fragmented (Kalfagianni & Young, 2022; Young, 2019). This fragmentation leaves states and regions to work alone to implement the necessary regulations for the common good. The EU has continually sought to position itself as a leader in global discussions of climate policy, likely to capitalize on the economic advantages of being a first-mover in the green industrial revolution and due to a desire to shape global environmental governance (Schreurs & Tiberghien, 2007; Oberthür & Pallemaerts, 2010; Oberthür & von Homeyer, 2023). However, global agreements like the Kyoto Protocol and Paris Agreement, which were largely facilitated by the EU, have had varying levels of success and failure in reaching their objectives (Maslin, Lang & Harvey, 2023). The difficulties associated with environmental agreements on a global level have spurred the EU to lead by example, by developing the world's most advanced network of domestic climate change mitigation policy efforts and regularly updating their policies and commitments with increasingly ambitious climate goals (Kulovesi & Oberthür, 2020; Oberthür & Dupont, 2021).

Following the EU's Kyoto Protocol commitment to reduce GHG emissions by 8%, the EU launched the world's first Emissions Trading System (ETS) in 2005 (European Commission, 2002). The EU ETS is a cap-and-trade market-based policy which sets an absolute limit, or "cap", on the production of GHG emissions across the region and auctions tradable emissions allowances to companies within the regulated industries. The results of the weekly auctions of

ETS carbon emissions allowances reveal the weekly price per tonne of CO_2. These auctioned allowances can then be traded within the regulated industries on a secondary market to reach an economically efficient allocation. However, the internalization of the price of carbon emissions into the cost of production creates an unintended incentive for emissions-intensive industries to move their production offshore, in order to maintain competitiveness on the market. Therefore, an integral part of the EU's ETS policy structure is the supplement of free emissions allowances to emissions-intensive trade-exposed industries (EITEs). These free allowances ensure that EITEs maintain their competitiveness on the global market, reducing the likelihood of carbon leakage. Although the quantity of free allowances is decreased yearly along with the overall ETS emissions "cap", the absolution of EITEs from GHG emission regulation impairs the EU's ability to reach their goal of climate neutrality (EU, 2023a), a fundamental limitation that ultimately prompted the development of the CBAM as a more sustainable policy approach to address carbon leakage.

The design of the ETS follows the carbon accounting principle of 'polluter pays,' ensuring that EU industry is responsible for the carbon they emit within EU borders. However, there has been a growing call for climate policy to utilize a 'consumer pays' principle called consumption-based carbon accounting, which holds consumers responsible for the carbon emissions embedded in goods that are purchased regardless of where they are produced. Consumption-based carbon accounting has gained acclaim due to estimations that internationally traded goods are responsible for almost a quarter of the world's carbon emissions (Peters & Herwich, 2008a; Davis & Caldiera, 2010; Peters, Davis, & Andrew, 2012; Steininger, et al. 2014; Jakob, Steckel, & Edenhofer, 2014). Globally elongated supply chains, due to international trade, create a disconnect between the industrial producers of carbon emissions and the consumers of the products; and as products are traded across country borders, embedded carbon emissions would be left unaccounted for without the use of consumption-based carbon accounting (Ahmad & Wyckoff, 2003; Afionis & Sakai, 2022). On average, these virtual carbon emissions are imported in greater volumes to the most industrialized countries, firmly establishing the EU as a net-importer of virtual carbon emissions (Peters & Herwich, 2008b; Liu, et al., 2015).

For the EU to begin addressing the issue of imported virtual carbon, while maintaining the competitivity of the EU's EITEs and mitigating the possibility of carbon leakage, the implementation of the Carbon Border Adjustment Mechanism (CBAM) seeks to improve upon the free allocation strategy of the EU ETS. The CBAM will establish a price on the carbon emissions associated with the production of imported goods, by requiring EU importers to purchase, and later surrender, CBAM certificates to cover their imported carbon emissions, within six EITEs. The price of CBAM certificates will be set at the weekly auction price of EU ETS carbon allowances, ensuring World Trade Organization (WTO) compatibility in this regard. However, if an importer can prove that a price has been paid for the carbon emissions associated with production at the origin of the goods, then the carbon price already paid will be deducted from the EU ETS carbon price. Once the CBAM transitional phase (2023-2026) ends, the CBAM will replace ETS free allowances, bringing the EU closer to the climate neutrality goals laid out in the EGD (EU, 2023b; European Commission, 2019). However, this shift away from ETS free allowances will expose EU industries to the full cost of their carbon emissions, potentially leading to competitiveness concerns on the global market if major trading partners do not adopt similar domestic carbon pricing regulations.

The EU's CBAM, functioning on the carbon accounting principle of 'consumer pays', will act as an extension of the ETS 'producer pays' regulation, to ensure that the carbon emissions associated with both the production and consumption of goods are accounted for in the regulated industries, to support the EU's quest for carbon neutrality. This combination of carbon emission policies puts the EU at the forefront of global climate policy development, setting an example for their contemporaries. However, there are many questions about how the CBAM will impact international trade patterns within each of the regulated EITE industries when the policy is fully implemented in 2026, including the extent of trade disruptions, its effectiveness in reducing global emissions, and the potential retaliatory measures from trading partners that could affect EU exports.

Global Impacts of BCAs

The CBAM is a unique environmental regulation because it will effectively act as a non-tariff barrier to trade through its requirement for EU importers to pay for the carbon emissions associated with imported goods. As a non-tariff barrier, the CBAM must comply with WTO rules that prohibit discriminatory trade measures, unless justified under specific exceptions. Due to the interaction of border carbon adjustments (BCAs) with international trade, environmental policies like the CBAM have long been debated. Proponents of BCAs present two key benefits: creating a level playing field for domestic producers already subject to carbon pricing regulations and advancing environmental goals by reducing carbon leakage. Critics, however, question BCAs' economic implications, raising concerns about compliance costs, potential trade protectionism, and equal treatment of imported goods as required by WTO principles. Despite extensive discussions, there remains a lack of overall consensus on whether the economic cost of a BCA is worth the potential environmental benefits (Zhong & Pei, 2023).

The EU CBAM, as an environmentally motivated non-tariff barrier to trade, will be a wildcard on the global stage; at its best, incentivizing trade partners to develop or improve their carbon pricing mechanisms, and at its worst, incentivizing retaliation and trade wars (Böhringer et al., 2016; Weko, et al., 2020; Huang, Liu & Zhao, 2022; Fleming & Giles, 2021). Major trade partners, such as China, India, Japan, and the U.S., have publicly criticized the introduction of the CBAM; with some looking to take legal action against the EU, citing the WTO's trade protectionism policies, to prevent the CBAM from disrupting the status quo of international trade (Overland & Sabyrbekov, 2022). If these WTO dispute proceedings are successful for the CBAM's major critics, the result could be authorized retaliatory tariffs against the EU or forced modifications to the CBAM's regulatory framework. Beyond the criticisms from these large economies, there are concerns that the CBAM would inequitably impact developing countries, particularly those which are dependent on a carbon-intensive export industry for economic stability and maintain a limited capacity to transition to lower-carbon technology. Any disregard of the 'common but differentiated responsibilities and respective capabilities' principle of the United Nations Framework Convention on Climate Change (UNFCCC) by the CBAM could cripple countries with smaller economies if there is a lack of proper consideration in the policy's design (UNFCCC, 2021; Eicke, et al., 2021; Perdana & Vielle, 2022; Magacho, et al., 2023; Böhringer, et al., 2016).

A key aim for the EU's introduction of the CBAM is to ensure that industries are not pushed to move production offshore by ambitious climate policy, thereby creating carbon leakage and undermining the effectiveness of EU environmental policy (Copeland & Taylor, 1994; Copeland & Taylor, 2005; Böhringer, et al., 2017; Grubb, et al., 2022). Within the current research, there is disagreement over the projected effectiveness of a BCA to diminish carbon leakage. Several studies describe the CBAM's effectiveness as inadequate, primarily due to challenges in implementation such as difficulty in accurately measuring embedded carbon, the current limited sectoral coverage, and potential evasion (Antimiani, et al., 2016; Kuik & Hofkes, 2010; Böhringer, et al., 2017). Alternatively, there are plenty of advocates for BCAs as tools to significantly reduce carbon leakage, who point to their ability to level the competitive playing field and provide incentives for global emission reductions; however these findings are tempered by the complicated interactions between ideal global environmental policy and concerns over inequitable distributions of the economic burden of climate change mitigation (Böhringer et al., 2012; Böhringer et al., 2018; Böhringer et al., 2021; Cosbey et al., 2019; Fouré et al., 2016; Larch & Wanner, 2017; Mehling, et al., 2019).

Reviewing the literature on the global impacts of BCAs, like the CBAM, highlights several key gaps that are directly related to this study's objective of assessing the impact of the CBAM on EU import demand for fertilizers. Despite the decades long debate over the use of BCAs, there is no clear consensus on the overall effectiveness of a BCA to bring more environmental benefits than economic costs. Furthermore, the majority of existing literature analyzes the potential economic impacts of a BCA from a broad, multi-sectoral view. Very few studies address any aspect of the relationship between the CBAM and the agricultural sector, and none of these closely analyze the potential economic impacts. This limits the relevance of the existing literature, leaving a clear need for more fertilizer sector-specific economic analyses which delve into the varying impacts of the CBAM on EU consumers and their trade partners. Addressing these gaps through a focused cost-benefit analysis of the CBAM's impact on synthetic fertilizer imports provides critical insights into the policy's effectiveness and illuminates upcoming market shifts that can be capitalized on for greater environmental benefits in the agricultural sector.

EU Agriculture, Fertilizers, and CBAM

The modern agricultural system, buoyed by advancements in synthetic chemical fertilizers, is increasingly made up of industrial-scale, specialized production facilities due to a shift in agricultural priorities toward higher single crop yields for export post-World War II (Kimbrell, 2002). This new priority and the resulting industrial agricultural system decoupled the symbiotic relationship between livestock and cropland, furthering the need for synthetic additives to dominate natural processes (Ghimire, et al., 2021). The production of synthetic additives is highly carbon intensive, and it has become increasingly evident that the over-use of synthetic fertilizers can cause acute and long-term health impacts and create vast ecological damage, like biodiversity loss, soil erosion, degraded soil health, and water pollution (Zadeh, 2018; Sharma & Singhvi, 2017; Dhankhar & Kumar, 2023; UNEP, 2022). This intensified system of agriculture has been identified as a remnant of a time when energy and fertilizers were cheap, the climate was assumed to be static, and the social and environmental cost of externalities were not a big concern (Steiner & Franzluebbers, 2009; Ghimire, et al., 2021). Now, with the rising costs of synthetic fertilizer, along with research showing economically and environmentally sustainable substitutes to synthetic fertilizer, the time is ripe for a transition to sustainable agricultural practices (Bidoia, 2024; Oger, 2022; Sporchia & Caro, 2023).

The impact of EU carbon pricing on global trade patterns of fertilizer is increasingly relevant as the CBAM directly intersects with the EU's broader climate strategy aimed at the agricultural sector. The agricultural sector accounts for approximately 13.2% of the EU's total GHG emissions – 5.6% of which is directly related to fertilizer usage and manure management – providing a great opportunity for the EU to employ a variety of climate change mitigation strategies (EEA, 2023; Bognar, et al., 2024). The agricultural focus of the EGD addresses this by introducing ambitious initiatives to close the agricultural nutrient loop and establish a circular bioeconomy, in support of a transition to a more sustainable and resilient agricultural system: The Farm to Fork strategy (F2F) and Circular Economy Action Plan (CEAP), along with the EU's new Common Agricultural Policy (CAP) will work in conjunction to ensure at least a 20% reduction in synthetic fertilizer use, a 50% reduction in soil nutrient loss, and a 25% increase in organic farmland by 2030 (European Commission, 2020a; European Commission, 2020b; European Commission, 2021).

These agricultural policies, in part, seek to ease the EU's dependence on fertilizer imports, as the past few years of supply chain breakdowns have highlighted the potential threat to EU food security (European Commission, 2022). Therefore, any support towards these policy goals from the CBAM's interactions with demand for imported synthetic fertilizer is particularly interesting. The CBAM will primarily regulate nitrogen fertilizers, alongside precursor products necessary for fertilizer production – like ammonia – and some mixed-nutrient fertilizer products (**Table 1**)[1] (EU, 2023b; EC 2023). These products are a focus of the CBAM due to the fact that the production of ammonia for nitrogen fertilizers through the Haber-Bosch technology is responsible for 1.4% of global carbon emissions and 1% of the world's total energy production (Capdevila-Cortada, 2019; Heinrich-Böll-Stiftung, 2021). In 2022, the EU imported 5.1 million tonnes of nitrogen fertilizers, which accounts for 45% of the EU's total consumption of nitrogen fertilizers (Fertilizers Europe, 2022). This heavy dependence on fertilizer imports underscores the scale of the potential environmental impact of the CBAM in this sector and provides the CBAM with a unique opportunity to support EGD agricultural policies in the pursuit of a sustainable agri-food system.

[1] All tables and figures can be found in Appendix A

Recent discussions have theorized that the CBAM will make "greener", lower-carbon imports more price competitive with domestic fertilizer products in comparison with highly carbon intensive fertilizer imports (Santeramo & Jelliffe, 2024). This shift in the fertilizer market must be quantified in order for the EU to properly harness the opportunity that the CBAM presents to incentivize a movement towards more sustainable and resilient agricultural production inputs. Currently, organic substitutes for synthetic fertilizers are facing a variety of challenges, including logistic issues, nutrient consistency issues, and pricing issues (Kurniawati et al., 2023). A key component to the adoption of organic substitutes is the preferences of the farmers who will use the product. Studies have shown that farmers prefer organic and bio-based fertilizers that contain reliable nutrient concentrations, have been treated to avoid unwanted pests and bacteria, are compatible with their current machinery, and are available at competitive prices compared to synthetic options (Case et al., 2017; Tur-Cardona et al., 2018; Egan et al., 2022). To meet the needs of EU agricultural producers with organic fertilizer products, the logistics of recycling bio-waste to produce farm-ready fertilizers in a circular bio-economy supply chain system must be hammered out with support from government and non-government organizations (Case et al., 2017; Buysse & Cardona, 2020; Kvakkestad et al., 2023). To this end, there are several EU initiatives already underway funding research for nutrient recovery technologies, supporting regional pilot programs for bio-waste collection and processing, and establishing standards for organic fertilizers to ensure consistent quality and safety (Kurniawati, 2023). The CBAM could provide the EU government with an additional opportunity to meet the leftover demand for imported synthetic fertilizers with organic solutions, by investing fertilizer-related CBAM revenue into the development and implementation of bio-based fertilizer production technologies and incentivizing their adoption. In this way, the CBAM's impact on the fertilizer import market could propel the EU agri-food system towards its sustainable future.

Reviewing the literature on EU agriculture, fertilizers, and the recently established EGD agricultural policies demonstrates a gap in the understanding of the CBAM's potential impacts on EU demand for fertilizer imports. As the harms of modern agriculture's dependence on synthetic additives are continually uncovered, the urgency of the transition to a more sustainable agricultural system is at the forefront of new EU climate policy. The EU's CEAP, F2F, and CAP are focused on addressing the negative externalities associated with modern agriculture by reducing nutrient waste and synthetic fertilizer use. While the EU's agricultural policies emphasize reducing the use of synthetic fertilizer, the extent to which the CBAM will contribute to this policy objective remains largely unexplored in existing research. Most existing studies primarily focus on the broader environmental impacts and policy dimensions, neglecting the detailed economic repercussions and the new incentive structures introduced in the fertilizer market by the CBAM. With the EU's CBAM impacting the market for synthetic fertilizer imports, it is important to determine how agricultural stakeholders should expect the synthetic fertilizer market to change, how these policies will incentivize the movement away from synthetic fertilizer use, and how the EU might continue to improve their climate policy to support the sustainable agriculture transition. This creates an opportunity for this study to address these uncertainties by offering a quantitative assessment of how EU import demand will react to the internalization of carbon prices in fertilizer imports.

Estimates of the Social Cost of Carbon

The possible environmental benefits from the impact of the CBAM on the EU's demand for imported fertilizer are many, however, the environmental benefits of any policy can be difficult to quantify in monetary terms. The challenge of monetizing environmental benefits arises due to the fact that environmental goods like clean air and climate stability are non-market goods that lack direct price signals. In the case of the cost of carbon emissions (or the value of a reduction of carbon emissions) this lack of direct price signals, in conjunction with the long-term and global-scale impacts of climate change, have led to an abundance of estimates which vary significantly. Economic theories on the cost of carbon emissions have been hypothesized since the 1920s, however there has been no consensus, academically or politically, about the true cost of carbon emissions or the most appropriate carbon emission pricing structure.

In 1920, renowned economist Arthur Pigou proposed the introduction of a tax on negative externalities as a way to correct a market's failure to find an equilibrium between their marginal private costs and the marginal social costs (Pigou, 1920). In the 1960s, the concept of a market for carbon emission permits was developed, which would allow governments to establish and manage the level of acceptable pollution levels (Crocker, 1968; Dales, 1968). In recent years, it was determined that a globally harmonized carbon pricing system would be the most economically efficient path towards carbon emission reduction, by some estimates reducing the cost of international climate mitigation by up to 32% (Thube, et al., 2021). However, this solution remains out of reach as negotiations for a uniform carbon emission price are regularly stalled by disagreements between developed and developing countries over their respective responsibility for their historical contributions to climate change (Bernstein, 2020; Gupta, 2010; Boroumand et al., 2022).

An alternative method of carbon pricing, called the social cost of carbon (SCC), attempts to quantify the marginal impacts (or damages) of each additional tonne of CO_2 emitted into the atmosphere, by considering health impacts, property damage, agricultural losses, and long-term economic effects (OECD, 2018). As an estimate of the marginal social cost of carbon, it represents a theoretically optimal carbon price at which to set a Pigouvian tax or a carbon market allowance, in order to trigger behavioral change and help mitigate climate change (Pigou, 1920; Nordhaus, 1982; OECD, 2018). Alternatively, the SCC can be considered the benefit to society of reducing carbon emissions by one tonne, which can then be compared with the mitigation cost of reducing carbon emissions as a cost-benefit analysis tool (Rennert, et al., 2021). The SCC is increasingly incorporated in practical risk management decisions from banks and financial institutions, to mitigate potential damages to investments under the threat of climate change, demonstrating its utility as an economic tool (Bolton et al., 2020).

There is a large literature estimating the SCC, with great variation in SCC values, and, in accordance with the increasing damage of each tonne of CO_2 emissions added to the global climate crisis, these SCC estimations are expected to increase over time (Tol, 2023). SCC estimates are typically calculated using integrated assessment models (IAMs) which can combine climate and economic models, in order to aggregate the economic consequences as present-value marginal damages of each added tonne of CO_2 (Rennert, et al., 2021). These projections can be drastically different between research teams due to advancements in climate modeling and economic modeling, or due to differences in the valuation of resources, in accordance with the political economy (NASEM, 2017; Rennert, et al., 2022). However, the variation in estimates is due, in large part, to the discount rate utilized to calculate the present value of future damages.

The choice of discount rate is particularly crucial in SCC estimates because carbon emissions create environmental damages that can persist for centuries, meaning that even small differences in how future damages are discounted can lead to order of magnitude differences in the final estimate of the present value. These differences then translate directly into policy application, as higher SCC values with lower discount values justify more aggressive and immediate climate action. The appropriate discount rate in SCC estimations has been strongly debated, as these discount rates encompass considerations of intergenerational equity, economic growth expectations, time preference, and uncertainty of risk over longer timeframes (Van Den Bergh & Botzen, 2014). Over time, lower discount rates – which place more value on the future – have become more prominent in expert opinion, with discount rates between 1% and 3% being considered most acceptable (Drupp et al., 2018).

Most recent estimations by the DICE-2023 model demonstrate the variability of the SCC value depending on discount rates or preferred scenarios, which could translate into fundamentally different approaches to climate action (Barrage & Nordhaus, 2024). The DICE-2023 results show the optimal SCC values in the year 2025 to be $37, $58, $102, $207, and $571 for discount rates of 5%, 4%, 3%, 2%, and 1% respectively, in 2019 USD. This range of values represents widely different climate policy prescriptions, with the 5% discount rate justifying only modest carbon pricing policies and the 1% discount rate supporting immediate and comprehensive investment into the green industrial revolution across all sectors. Additionally, the Barrage & Nordhaus analysis included scenarios based on global warming temperatures. To ensure that the global temperature does not exceed a 1.5 ºC average increase above pre-industrial levels, they found that an SCC value of $4,185 would be necessary by 2025, in 2019 USD. This scenario is noted as infeasible without an unrealistic reduction in emissions or a "catastrophic reduction in output," however, it demonstrates the potential variability of SCC values given a preferred scenario, even within the same model (Barrage & Nordhaus, 2024).

The evolution of the concept of carbon pricing, from Pigouvian taxes and carbon markets to the SCC, crucially provides the basis for the implementation of the EU's CBAM. As there has been no global consensus about the ideal carbon emission price, individual countries and regions have been left to act unilaterally in order to induce markets to meet environmental goals with economic efficiency. Given this disjointed approach to the global challenge of climate change and the EU's role at the forefront of global climate policy, the possible impacts of the EU's CBAM on individual markets must be understood in order to prepare all relevant stakeholders for the upcoming changes. Additionally, reviewing the literature on SCC estimates, and understanding their variability, provides crucial insight into establishing a balanced cost-benefit analysis of the CBAM.

Building on identified gaps in the literature, this study provides an in-depth assessment of how the CBAM impacts EU demand for imported synthetic fertilizers. Current literature lacks sector-specific economic analyses of the CBAM's effects on the fertilizer market; this research delivers a focused quantitative assessment of the EU import demand response to the internalization of the price of carbon into international trade. The current literature shows a lack of agreement of the effectiveness of BCAs as carbon pricing strategies; this study evaluates the CBAM's effectiveness as a climate policy by weighing the environmental benefits of reduced carbon emissions against the economic costs of higher fertilizer import prices. Limited research exists at the intersection between the CBAM with either fertilizers or sustainable agriculture initiatives; this study fills this gap by considering the unique aspect of the CBAM's impact on the fertilizer import industry, which links international trade and the burgeoning carbon market to the growing movement of sustainable agriculture, providing insights that can inform both policymakers and market actors. By quantifying these relationships, this research provides actionable insights for policymakers designing complementary measures and for market actors preparing for the regulatory transition beginning in 2026.

Section 3: Methodology

Workflow of the Analysis

To perform a cost-benefit analysis of the impact of the CBAM on EU demand for imported fertilizer, the cost was estimated as the loss in importer surplus to the EU due to the CBAM price increase, and the benefit was estimated as the sum of the reduction in CO_2 imported to the EU, valued at the SCC, along with the government revenue generated from the policy. Importer surplus was selected as the measure of cost because it captures the direct economic impact on EU importers and agricultural producers. The SCC was chosen to translate the environmental benefit of the CO_2 reduction into a fiscal measure to fit alongside the government revenue generated from the CBAM, which could be utilized to offset some of the economic costs. This analysis was conducted separately for three general product categories (fertilizer precursor products, nitrogen fertilizer products, and mixed fertilizer products) to capture product-specific impacts of the CBAM. Within each product category, the analysis was focused further, separating by exporting country to display the varying trade relationships and carbon intensities of production among the EU's trading partners. The workflow of this analysis is laid out in **Figure 1** and described in the following paragraphs.

The analysis procedure begins by determining the baseline demand relationship for fertilizer imports to the EU. This relationship, denoted as $Q = f(P, X)$, represents the demand for imported fertilizer (Q) as a function of the price of imported fertilizer (P) and other factors (X), which, after analysis, yields the predicted demand for imported fertilizer ($\hat{Q}$) before the CBAM is implemented. This demand relationship was then evaluated with the CBAM-adjusted price of imported fertilizer (P') to estimate the predicted demand for imported fertilizer ($\widehat{Q'}$) after the CBAM has been implemented. The difference between the predicted demand for imported fertilizer before and after the CBAM price adjustment, $\Delta Q = (\hat{Q}' - \hat{Q})$, given price elasticity of demand (β), was utilized to obtain the bulk of the cost-benefit analysis results.

The price elasticity of demand interacts directly with the CBAM-induced price adjustment to determine the import demand for fertilizers post-CBAM implementation. The price of imported fertilizer after the CBAM, P', is determined by adding the product-specific price of the CBAM (P_0) to the original product price (P), subtracted by any carbon price previously paid at the origin of production (P_r), such that $P' = P + P_0 - P_r$, assuming the full pass-through of CBAM costs to consumers. The product-specific price of the CBAM (tonne CO_2/tonne fertilizer product), P_0, varies significantly across both product categories and exporting countries as the carbon emission intensity of production acts as a multiplier to the EU price of CO_2 .

The EU price of CO_2 (\$/tonne CO_2) is determined by EU ETS weekly auctions, which, for the purposes of this analysis, was evaluated within three possible price scenarios. The baseline CBAM-price scenario was derived by taking the average price of an EU ETS carbon allowance since the beginning of EU ETS regulatory phase 4 in 2021, equal to \$73.5/tonne CO_2. For sensitivity in this analysis, carbon allowance prices 25% below and 25% above this average value were also considered, at \$55.1/tonne CO_2 and \$91.8/tonne CO_2 respectively (**Figure 2**) (The World Bank, 2024). This sensitivity range was selected to capture the recent price volatility in the EU ETS allowance market since 2021 (ICAP, 2024), while providing a reasonable boundary for potential price movements during the CBAM's initial implementation period.

The cost of the CBAM to EU consumers was estimated using the baseline import demand relationship evaluated at each CBAM-price scenario. This cost was estimated as the change in importer surplus (ΔIS), with a constant price elasticity of demand (β), utilizing the quantity demanded before and after the CBAM, $\hat{Q}$ and $\hat{Q}'$, and the price of fertilizer before and after the

CBAM, P and P' (**Figure 3**). This calculation of importer surplus was estimated as the area under the import demand curve, and above a horizontal supply curve equal to the average price per tonne of fertilizer product. By integrating the inverse demand function from 0 to $\hat{Q}$ over the horizontal supply curve, and simplifying by assuming elastic demand, importer surplus is expressed before the CBAM as $\widehat{IS} = \frac{\hat{Q}*P}{\beta-1} - P_{avg} * \hat{Q}$, and after the CBAM as $\widehat{IS'} = \frac{\hat{Q}'*P'}{\beta-1} - P'_{avg} * \hat{Q}'$. The change in importer surplus, and therefore the cost of the CBAM to EU importers, was found by subtracting the two: $\Delta IS = \widehat{IS'} - \widehat{IS}$.

The framework of this importer surplus calculation assumes that the EU is a "price taker" on the international market for fertilizers. This treats the EU as if it were a small open economy for modeling clarity by assuming that the EU's share of global demand is so slight that it cannot influence world prices through any change in EU demand. Under this framework, exporting countries are treated as price takers in the global market, and EU importers face a perfectly elastic supply curve at the world price. This results in the assumption that the full cost of the CBAM is passed-through to EU importers, with producers bearing none of the policy burden. The actual pass-through may vary depending on how much of the policy burden is absorbed by exporters or intermediaries. Further assumptions embedded in the perfectly elastic supply curve include perfect competition on the global market and constant marginal costs for global producers collectively. While this framework introduces some limitations that may affect the applicability of the results, it allows for a straightforward calculation of the importer surplus changes resulting from the CBAM implementation.

Next in this analysis, two components of the environmental benefit were calculated: the reduction of carbon emissions and the government revenue generated. To estimate the environmental benefit due to the reduction in imported carbon emissions, the change in carbon emissions (ΔCO_2) was calculated by multiplying the change in quantity demanded, ΔQ, by the carbon emission content of the fertilizer products foregone, a multiplying factor with units of [tonnes CO_2/tonne fertilizer product]. This reduction in carbon emissions was then multiplied by the social cost of carbon (SCC) found in the 2025 scenario of the DICE-2023 model, for discount rates 3%, 2%, and 1%, inflated to 2024 USD using the Bureau of Labor Statistics Consumer Price Index for All Urban Consumers, and rounded to the nearest dollar (Barrage & Nordhaus, 2024; U.S. Bureau of Labor Statistics, 2024). These values are \$125/tonne CO_2, \$254/tonne CO_2, and \$700/tonne CO_2, respectively, with the central value of \$254/tonne CO_2 – corresponding to a 2% discount rate – used as the baseline for this analysis. Finally, by multiplying the change in carbon emissions with the SCC, a monetary estimation of this portion of the environmental benefit was determined. The DICE-2023 model was selected to estimate the SCC as it is the most recent update to the DICE model which is widely utilized in climate economic literature and international climate policy assessments. The selection of the baseline 2% discount rate is in line with expert opinions about the ideal discount rates for balancing concerns over intergenerational equity while remaining consistent with observed market returns (Drupp et al., 2018).

This calculation of the environmental benefit of a reduction of EU imports of fertilizer assumes that the agricultural producers will be participating in the EU's sustainable agricultural transition by substituting the previously imported fertilizers with bio-based, organic alternatives. Additionally, this environmental benefit calculation assumes that EU trade partners are not diversifying their trade portfolios in response to the CBAM. These assumptions may limit the results by leading to an overestimation of the environmental benefits globally, however these results illuminate the value of the expected reduction in CO_2 imported to the EU.

The government revenue generated from the CBAM's interaction with the import of fertilizers was then simply calculated by multiplying the quantity demanded after the CBAM, $\hat{Q}'$, with the carbon emission intensity of those imported products, and the CBAM price, adjusted for any carbon price paid at the origin of production, $(P_0 - P_r)$. This estimation represents an upper-bound estimate, as it assumes full compliance and comprehensive coverage over all CBAM-regulated fertilizers.

Finally, the cost of the CBAM to consumers, or the change in importer surplus, was subtracted from the social benefit of a carbon emission reduction and the government revenue generated to provide an estimate of the overall impact of the CBAM. This net calculation represents the aggregate societal impact but does not address the distributional consequences across different stakeholders. While government revenue was counted as a benefit in this analysis, the ultimate welfare impact depends on how these revenues are allocated.

Additionally, with the three CBAM price scenarios and the three SCC values, a sensitivity test was performed to demonstrate the impact that the value of carbon emissions has on the overall cost or benefit of this policy. This sensitivity analysis aims to identify how varying valuations of carbon emissions can affect the policy's economic justification by establishing which carbon emission valuations lead to the environmental benefits, offsetting any consumer welfare losses and vice versa. This sensitivity analysis is a crucial aspect of this cost-benefit analysis for the results to be interpreted in the context of various carbon pricing scenarios.

Demand Model for Fertilizers Imported to the EU

The estimation of the price elasticity of demand is the foundation of the cost-benefit analysis framework of this study, as it determines how effectively the implementation of the

CBAM translates into changes of import demand and the subsequent environmental benefits. To quantify these market responses accurately, the core of this empirical analysis relies on estimating the baseline demand for fertilizers imported to the EU, using a partial equilibrium approach with a fixed effects panel model. This partial equilibrium approach was selected over alternatives, such as computable general equilibrium (CGE) models, because it offers greater transparency for sector-specific policy analysis while requiring fewer assumptions about cross-sectoral linkages (McKibbin & Wilcoxen, 1999). Similarly, structural gravity models were not selected given this study's focus on price effects rather than bilateral trade patterns.

To this end, a log-log formulation of the traditional import demand model is used, enabling the prediction of EU import demand after the CBAM price increase. Log-log formulations of import demand have been utilized in international trade literature for their ability to directly estimate elasticities and capture proportional, rather than absolute, changes in demand (Goldstein & Khan, 1985). The traditional import demand model has developed over time as a natural progression from the neoclassical microeconomic demand model which relates quantity demanded to own-price, the price of substitute goods, and income. The demand model in an international trade context relates the quantity of imports demanded to the price of imported products, the price of domestically produced substitute goods, and the importing country's gross domestic product (GDP) (Murray & Ginman, 1976; Khan & Ross, 1977; Warner & Kreinin, 1983; Leamer & Stern, 2006). To this basic import demand model, fertilizer and CBAM context specific variables are added, along with an import quantity lag variable.

This model is further specified to obtain results for the EU's price elasticity of import demand for each category of fertilizer product, from each individual trading partner. Although the EU's individual member countries likely have unique trade relationships with each trading partner, this research studies the EU's import demand as a whole to provide results which focus on trade partner differences. The EU's price elasticity of import demand may vary between trade partners or fertilizer types based on differing production technologies, trade agreements, or specific fertilizer uses. To capture these differences, the trade interactions for CBAM-regulated fertilizer products are separated into three categories based on their functional classification in production and application: Fertilizer Precursor Products, Nitrogen Fertilizers, and Mixed Fertilizers, as shown in **Table 1**. This allows for three separate regression analyses for each specific product category.

Within each product-specific regression analysis, the exporter-specific price elasticity of demand is desired. For this purpose, binary variables indicating the exporting country are included as price-interaction terms. All but one of the relevant exporter-price interaction variables are included in the product-specific regression equations, leaving one as the baseline or reference dummy variable. For each product-specific regression, the excluded exporter-price interaction with the least negative own-price elasticity is utilized as the reference dummy variable, thereby creating the baseline price elasticity of demand. For fertilizer precursor products, Algeria (DZA) is utilized as the reference; for nitrogen fertilizer products, Turkmenistan (TKM) is utilized as the reference; and for mixed fertilizer products, Russia (RUS) is utilized as the reference. This produces an economically intuitive regression output wherein each exporter-price interaction term expresses a price elasticity of demand that is more negative than the baseline.

These specifications yield the following regression model, which is used for each of the three product-specific analyses:

$$ln\,(Q_{ijt}) = \beta_0 + \beta_1 ln\,(P_{it}) + \beta_2 ln\,(P_{jt}) + \beta_3 ln\,(Y_{jt}) + \beta_4 R_{it} + \beta_5 ln\,(G_t) + \beta_6 ln\,(Q_{ij(t-1)}) + \mu_t$$

where $\beta_1 ln\,(P_{it})$ is defined as $\beta_{ref}\, ln(P_{ref,t}) + \sum_{i \neq ref} \beta_i [ln\,(P_{ref,t}) * D_i]$. Here, $ln\,(P_{ref,t})$ is the price from the reference country, *ref*, for fertilizer product under analysis, D_i are dummy variables for each exporting country *i* except the reference country, and β_i captures the additional price elasticity for country *i* relative to the reference.

This model specifies the quantity of fertilizer, Q, imported to EU-27 member[2], j, from exporting country[3], i, for year *t*, (for years within 1995-2021), as determined by the following key economic factors. The price per tonne of imported fertilizer, P_{it}, captures the direct price effect, with its coefficient β_1 representing the own-price elasticity of import demand. The average price per tonne of fertilizer produced in the EU, P_{jt}, measures the substitution effect between imported and domestically produced fertilizers, with β_2 reporting the cross-price elasticity of import demand. The importing country's GDP, Y_{jt}, represents the purchasing power and agricultural sector size of the importing country, with β_3 reflecting the income elasticity of import demand. The presence of a carbon pricing regulation in the exporting country, R_{it} (equal to 1 if yes; 0 otherwise), accounts for existing carbon policies that may already affect trade competitiveness. The average annual price of natural gas, G_t, controls for variation in the principal input cost of fertilizer production which influences domestic and global supply. Finally, a 1-year lag of the quantity of fertilizer imported, $Q_{ij(t-1)}$, is included to account for persistence in

[2] EU-27 members are Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.
[3] Selected trade partners are Algeria (DZA), Belarus (BLR), Canada (CAN), Chile (CHL), Egypt (EGY), Georgia (GEO), Indonesia (IDN), Israel (ISR), Jordan (JOR), Morocco (MAR), Norway (NOR), Russia (RUS), Saudi Arabia (SAU), Serbia (SRB), Turkmenistan (TKM), Trinidad and Tobago (TTO), Tunisia (TUN), Türkiye (TUR), Ukraine (UKR), the United Kingdom (GBR), and the United States of America (USA).

trade relationships and dynamic adjustment in import behavior. This captures inertia due to long-term contracts, habitual sourcing, or adjustment costs, which are common in international fertilizer trade.

Following preliminary model estimation, a series of diagnostic tests were conducted to evaluate the statistical properties of the panel data and to inform the choice of the final estimation strategy. The following tests were selected due to their relevance to panel data in international trade analysis. Fisher-type panel unit root tests indicated price stationarity across all three fertilizer categories ($p < 0.001$), confirming the absence of spurious correlation issues. Within this test, GDP values display persistent dynamics which are consistent with long-term growth trajectories as expected for macroeconomic variables. Pesaran's cross-sectional dependence test showed significant interdependence, particularly in nitrogen fertilizers (CD = 26.22, $p < 0.001$) and mixed nutrient fertilizers (CD = 10.07, $p < 0.001$), reflecting the interconnected nature of global trade patterns and shared input costs to production. The Modified Wald test identified heteroskedasticity across the product panels, (X^2 statistics significant at $p < 0.001$), while Woolridge tests indicated serial correlation, (all F-statistics significant at $p < 0.001$).

The statistical issue of the non-stationarity of the GDP variable was accounted for in the model specification through the use of a log transformation. Although the GDP variable exhibits non-stationarity even after a log transformation, this variable is included in this analysis primarily as a control while focusing on consistent estimation of price elasticities. The issues of heteroskedasticity and serial correlation, which are common with international trade data, were handled in this analysis with a robust fixed effects regression analysis method. This robust regression method ensures accurate coefficient estimates while producing standard errors that account for heteroskedasticity and autocorrelation in the panel data.

Data

After this specification of the import demand model, this section of the methodology describes the sources and characteristics of the data used to estimate the EU's price elasticity of import demand and contribute to the overarching CBAM cost-benefit analysis. For this, a variety of datasets containing the key economic indicators of EU import demand were collected, in accordance with the variables included in the import demand model, alongside data estimating the carbon emissions embedded in fertilizer products. Together, these data sets enable an assessment of how the CBAM might impact EU fertilizer import demand and the resulting economic costs and environmental benefits.

For this analysis, international trade data for EU imports of CBAM-regulated fertilizer products (listed in **Table 1**) from 22 of the EU's top fertilizer trade partners (listed in footnote 3, page 31), was obtained from the CEPII-BACI database, version 202401b, for the years 1995-2021 (CEPII, 2024). This range of years was selected for analysis to coincide with the beginning of the WTO in 1995, and the range deliberately concludes in 2021 to maintain the focus on the EU's fertilizer import market while avoiding any of the significant market disruptions following conflicts in Europe which remain outside the scope of this analysis. The 22 trade partners selected for this analysis represent 96.6% of all EU imports of CBAM-regulated fertilizer products, within the reference year 2019 (JRC, 2023). The selected trade partners are identified as the EU's main trading partners in fertilizers in the 2023 Joint Research Center report on the GHG emission intensities of CBAM-regulated industries (JRC, 2023). The CEPII-BACI database relies on data from the United Nations (UN) Comtrade dataset and provides trade quantity in tonnes, along with the corresponding value in real thousands of 2024 USD (CEPII, 2024). From the given trade value, the per-unit value of each product was calculated for use as a measure of per-unit price in this analysis. The quantity and price per tonne of the traded fertilizer products form the foundation of the import demand relationship for each product category, from each trade partner.

From this database, the quantity and value of each fertilizer product produced and traded within the EU-27 was obtained (CEPII, 2024). This data was used to estimate the average price per tonne for each relevant fertilizer product that had been produced within the EU for each of the years 1995-2021. This average price is used as the approximate value of a domestically produced substitute good. Additionally, the real GDP for each member of the EU-27, in thousands of 2024 USD, was obtained from the CEPII macroeconomic indicators database, for the years 1995-2021 (CEPII, 2024). The GDP for each of the EU-27 member countries provides a measure of economy size as a factor of fertilizer import demand in the regression analysis.

Data indicating the presence of carbon emission pricing-based regulations in EU trade partner countries, for the years 1995-2021, was obtained from The World Bank Carbon Pricing Dashboard, which tracks carbon prices around the world (The World Bank, 2024). Of the 22 EU trade partners within the scope of this analysis, only two began operating a form of carbon pricing regulation before 2021: Norway from 2005 and Canada from 2020. Any trade partner which does not utilize carbon pricing regulations is recorded within the dataset with a carbon price of 0 USD. This carbon pricing data is converted to a binary variable for the regression analysis, indicating the presence of a carbon pricing regulation with a value of 1, and containing a value of 0 otherwise. For the CBAM price adjustment calculations, the real value of the carbon pricing regulation – if present – is utilized as a discount to the CBAM price; consistent with the CBAM regulation.

The price of natural gas, within the years 1995-2021, was obtained from the "Gas Price" database of Our World in Data, as extracted from the Energy Institute's "Statistical Review of World Energy" (Our World in Data, 2024). Data describing the real, annual average price of natural gas imported to Germany was selected as a proxy for global natural gas prices, in 2024 USD per megawatt-hour (MWh). Natural gas is the principal input required to produce ammonia for synthetic fertilizers, therefore by including natural gas prices in the analysis, the relative price of fertilizer production is accounted for in the EU import demand relationship (JRC, 2023). Natural gas imports to Germany serve as an appropriate benchmark for global prices as Germany is a major importing hub connected to diverse supply sources, which results in prices that closely follow international market dynamics.

The price of EU ETS carbon allowances, between 2021-2024, was utilized as a reference to develop three likely CBAM credit pricing scenarios (**Figure 3**) (The World Bank, 2024). The ETS allowance price over these three years was averaged to form the baseline CBAM pricing scenario, with additional pricing scenarios included at 25% above and 25% below this value as reasonable boundaries for potential price movements during the CBAM's initial implementation period given the recent price volatility in the ETS allowance market (ICAP, 2024). The selected years begin in 2021, coinciding with the beginning EU ETS regulatory phase 4, which spans from 2021 to 2030, in order to most accurately represent the possible CBAM prices (EU, 2023a).

Data estimating the product- and exporter-specific carbon emission intensities for synthetic fertilizer imported to the EU was obtained from the EU Joint Research Center (JRC) 2023 Technical Report, which was commissioned by the EU to provide scientific support to the implementation of the CBAM and other EU climate policy. The JRC report provides the single most comprehensive calculation of the carbon emissions due to each fertilizer product, incorporating GHG emissions from energy consumption, fertilizer formulation and finishing processes (JRC, 2023). Within this report, a snapshot of fertilizer trade from 2019 is utilized, along with a variety of data sources regarding fertilizer production from years 2014 to 2023, to complete the complex calculations required to determine the amount of CO_2 (or CO_2 equivalent, CO_{2e}, of other GHGs) emitted per tonne of fertilizer product, by country of origin. **Figures 4** and **5** display the average GHG emission intensity of producing one tonne of a fertilizer product, demonstrating the variability between EU trading partners and fertilizer products. These carbon emission intensities act as the product- and exporter-specific multipliers of the CBAM, contributing to detailed post-estimation results.

The data utilized for the regression analysis of EU import demand is summarized in **Table 2** with sample statistics. This table separately supplies the summary statistics for the three product-specific data set samples which are utilized to capture product-specific and exporter-specific results in the analysis. The table shows that nitrogen fertilizer products are imported in higher quantities than precursor products and mixed fertilizers, but that there are high standard deviations in each category, indicating considerable variation in import demand across countries and years. The table shows that nitrogen fertilizer products are less expensive per unit than precursor products and mixed fertilizers. The table additionally shows that mixed fertilizer products are on average imported to EU members with smaller GDPs in comparison to precursor products and nitrogen fertilizers, suggesting that less affluent member countries demand fertilizer products with more general nutrient composition. A final key characteristic of the data summary shown in this table is that only between 4% and 9% of trade involves exporters with carbon pricing regulations, reflecting the limited global carbon policy adoption during the study period.

Section 4: Results

This results section presents the findings on how the CBAM impacts EU import demand for fertilizers within three product categories and across the EU's major trading partners, followed by the cost-benefit implications of these impacts. This section begins with an overview of key regression findings which illustrate how price elasticities vary by exporting country and fertilizer product. Next, the details of the product-specific regression results are presented to more closely examine the exporter-specific differences within trade of each fertilizer product. Following this, the estimation of the costs and benefits of the CBAM are presented, culminating in the overall cost-benefit analysis of the policy, and a sensitivity analysis which explores the implications of varying carbon valuation assumptions. Finally, the methodological limitations of this analysis are discussed to provide the appropriate context for the application and interpretation of these results.

Overview of Key Regression Findings

The analysis of EU demand for imported fertilizer products was conducted using a panel data linear regression model with fixed effects to account for unobserved heterogeneity across countries over time. These regressions explain 54.7% to 61.3% of variation in import demand, with R^2 values of 0.613, 0.547, and 0.600, for precursor products, nitrogen products, and mixed fertilizer products, respectively. The full regression results, presented in **Table 3**, demonstrate the significant differences in the elasticity of demand across product categories and trading partners which are central to understanding how the CBAM will reshape trade flows and contribute to environmental outcomes when implemented.

The regression results reveal that the EU price elasticity of demand for imported fertilizer products is negative and elastic across all exporting countries within all three product categories.

Comparing the average price elasticity of demand for each product category provides some insight into which sectors might be most vulnerable to a CBAM price increase. Fertilizer precursor products show the highest average elasticity (-2.466), with demand decreasing by approximately 24.7% for every 10% increase in price. This high price elasticity is likely reflective of the nature of these products being an input to fertilizer production rather than a consumer-oriented product. Nitrogen fertilizer products demonstrate the lowest average price elasticity (-1.999), indicating that demand is expected to decrease by approximately 19.9% for every 10% increase in price. This is indicative of the importance of nitrogen fertilizers in agricultural production and the low substitutability of nitrogen fertilizer products within the EU market. Mixed fertilizer products exhibit strong price elasticity (-2.393), meaning demand decreases by approximately 23.9% for every 10% increase in price. This is likely reflective of the variability between mixed fertilizer products, providing a wider range of substitutes for consumers in the face of a price increase.

Additionally, the regression results show that the country of origin significantly influences the elasticity of demand across all product categories, demonstrating patterns in country-specific trade relationships which will influence the magnitude of the CBAM's impact. Trade partners which supply the majority of the EU's fertilizer imports across each category maintain price elasticities below the average of the sample set, suggesting the presence of strategic trade partnerships with more resilient trade relationships. Algeria, Russia and Trinidad and Tobago supply the highest volumes of precursor fertilizer products; Egypt, Russia, and Trinidad and Tobago supply the highest volumes of nitrogen fertilizers; and Morocco and Russia supply the highest volumes of mixed fertilizer products to the EU. All of these countries face price elasticities of import demand which are below the product-category average, with most in the lower 25th percentile of the price elasticities of the sample set within each product category. The resilience of these trade partnerships will contribute to these countries experiencing smaller proportional reductions in export volumes, despite the CBAM price increase. Consequently, a larger portion of the total CBAM cost burden for EU importers will be associated with fertilizers from these major trade partners.

Furthermore, the regression results showed that the relationship between imported fertilizers and domestic substitutes varies significantly across product categories. Precursor and mixed fertilizer products show positive cross-price elasticities, which is consistent with economic theory where domestic products and imported products are expected to be substitutes. This indicates that when the price of these domestic fertilizer products increases, demand for imports will increase while demand for domestically produced fertilizer products will decrease. However, nitrogen fertilizers demonstrate a negative cross-price elasticity, suggesting that imported and domestic nitrogen fertilizers are complements, defying conventional expectations. This means that when the price of domestic nitrogen fertilizers increases, demand for both imported and domestically produced nitrogen fertilizers will decrease. This counterintuitive finding could be due to the presence of vertical supply chain integration in the EU fertilizer manufacturing sector wherein some domestic producers also act as importers of nitrogen intermediates, creating a complementary relationship between domestic and imported products.

Finally, the regression revealed heterogeneous impacts of exporter carbon pricing regulations and natural gas prices, and consistent effects of income and lagged demand. Exporter carbon pricing effects were negative for precursor products, non-significant for nitrogen fertilizers, and positive for mixed fertilizers, suggesting complex interactions between environmental regulations and trade competitiveness, likely reflecting differences in carbon emission intensities of production and production technologies. Natural gas prices significantly and positively affect precursor and nitrogen products, but are insignificant for mixed fertilizers. This is consistent with the relative importance of natural gas as a production input for ammonia and nitrogen products as opposed to mixed fertilizers. Income effects, measured through GDP elasticities, and market persistence, measured by a year lagged import quantity, were positive and significant across all categories, confirming that fertilizer imports are normal goods and demonstrating stability in EU fertilizer import relationships. Detailed descriptions of the product-specific regression results are presented in the following subsections.

Results of Regression 1: Fertilizer Precursor Products

EU import demand for fertilizer precursor products can be predicted by the price of the imported good, the average price of a domestically produced substitute good, the importing country's GDP, the presence of a carbon pricing regulation in the exporting country, the average price of natural gas, and the previous year's demand, all within a 5% significance level.

The EU elasticity of import demand varies substantially by country of origin. The price elasticity of the baseline country, Algeria (DZA), captured by the main coefficient, shows the lowest price elasticity, with imports decreasing by about 2.2% for every 1% price increase. The non-significant interaction terms for Egypt (EGY), Georgia (GEO), and Saudi Arabia (SAU) indicate no difference in price elasticity from the baseline country. The remaining significant price interaction terms reflect stronger or weaker demand responses relative to the baseline. Canadian (CAN) fertilizer precursor products induced the greatest response from EU importers, with demand decreasing by nearly 3% for every 1% increase in price, indicating that a 10% increase in price would decrease EU demand for Canadian precursor products by almost 30%. The EU maintains relatively low price elasticities of demand with their top trade partners, including Trinidad and Tobago (TTO), with nearly a 2.3% percent decrease in demand for every 1% increase in price, and Russia (RUS), with around a 2.4% percent decrease in demand for every 1% increase in price, along with Algeria, as previously mentioned. These variations in price elasticity across trading partners likely reflect structural factors in the EU import market, including established supply chain dependencies, historical trade agreements with certain countries, and differences in production costs that affect the availability of alternative suppliers.

The remaining regression variables contribute to predicting EU import demand for fertilizer precursor products in the following ways: The cross-price elasticity with EU-produced substitutes is positive and significant, with an elasticity of 0.379, confirming that domestically produced precursor products can act as economic substitutes with imports. Higher importer GDP is associated with increased demand for imports, with an income elasticity of 0.751, indicating precursor fertilizer products are normal goods. The presence of a carbon pricing regulation in the exporting country slightly dampens import demand, with an elasticity of -0.516, likely reflecting the lack of competitiveness of producers of such a highly carbon emitting product in a country with carbon regulations. Increased natural gas prices are associated with increased import demand, with an elasticity of 0.639, potentially demonstrating reduced domestic production capacity when energy costs rise. Finally, the effect of the previous year's demand indicates market persistence, with an elasticity of 0.355, demonstrating stability in the EU import market.

Results of Regression 2: Nitrogen Fertilizer Products

EU import demand for nitrogen fertilizer products can be predicted by the price of the imported good, the average price of a domestically produced substitute good, the importing country's GDP, the average price of natural gas, and the previous year's demand, all within a 5% significance level.

EU importers were least sensitive to the price changes of products from Turkmenistan (TKM), with demand decreasing by about 1.6% for every 1% in price. Import demand for nitrogen fertilizer products from top trade partners Algeria, Egypt, Russia, and Trinidad and Tobago maintain similar price elasticities, as their price-country interaction terms were not significantly different than that of the baseline, Turkmenistan. This pattern likely reflects the importance of these established suppliers and similarities in their production costs. Similarly to precursor products, a change in the price of Canadian fertilizer precursor products induced the greatest response from EU importers, with demand decreasing by around 2.4% percent for each 1% increase in price, potentially due to higher transportation costs paired with the availability of substitutes from closer sources.

The remaining regression variables contribute to predicting EU import demand for fertilizer precursor products in the following ways: The cross-price elasticity with EU-produced nitrogen fertilizers is negative and significant, with an elasticity of -0.618, suggesting a complementary relationship between domestic products and imports. GDP maintains a positive and significant effect, with an income elasticity of 0.558, indicating nitrogen fertilizers are normal goods. Notably, the presence of carbon pricing regulations in exporting countries does not significantly affect nitrogen fertilizer imports, unlike precursor products. Natural gas prices show a strong, positive relationship with import demand, with an elasticity of 1.299, reflecting the importance of natural gas as a production input. Finally, the impact of the previous year's demand suggests persisting import market patterns, with an elasticity of 0.200.

Results of Regression 3: Mixed Fertilizer Products

EU import demand for mixed fertilizer products can be predicted by the price of the imported good, the average price of a domestically produced substitute good, the importing country's GDP, the presence of a carbon pricing regulation in the exporting country, and the previous year's demand, all within a 5% significance level.

EU importers were least sensitive to the price changes of products from Russia, with imports decreasing by almost 2.2% percent for every 1% increase in the price of mixed fertilizer products from Russia. Imports from Algeria, Morocco (MAR), and Tunisia (TUN) face similar relationships with EU import demand, as their price-country interaction terms were not significantly different than that of Russia. This lower price elasticity likely stems from persistence in established trade relationships, geographic proximity to the EU, and the specific mixed fertilizer formulations from these producers which might be less easily substituted. EU importers are most sensitive to the price changes of mixed fertilizer imports from Saudi Arabia, with demand for imports decreasing by almost 2.6% percent for each 1% increase in price, possibly reflecting greater competition in this fertilizer product category for Saudi Arabia, or the availability of closer domestic or regional alternatives for similar products.

The remaining regression variables contribute to predicting EU import demand for mixed fertilizer products in the following ways: The cross-price elasticity with EU-produced mixed fertilizers is positive and significant, with a value of 1.121, indicating a clear substitution effect. GDP shows a positive but more moderate relationship with import demand compared to other categories, with an income elasticity of 0.405. Unlike other product categories, the presence of a carbon pricing regulation in exporting countries has a positive and significant effect on imports, with an elasticity of 0.476, suggesting that countries with carbon regulations may produce more competitive or higher-quality mixed fertilizers. For mixed fertilizer products, the annual average price of natural gas does not significantly affect EU import demand, likely due to their inclusion of significant proportions of potassium and phosphate nutrients for which natural gas is not a primary production input. Finally, the previous year's demand has a positive and significant impact on imports, with an elasticity of 0.298, further demonstrating the stability of the EU import market for fertilizer products.

Results of CBAM Cost Calculations

The impact of the CBAM on the welfare of EU importers varies significantly across the three fertilizer categories, with precursor products experiencing the most substantial economic effects followed by nitrogen fertilizers and mixed fertilizers. **Tables 4, 5, and 6** provide the detailed results of the CBAM cost calculations for each product-country combination, revealing important patterns in how the CBAM's burden is distributed across the market. Across all fertilizer categories, the CBAM reduces total importer surplus by approximately $4.04 billion annually, representing a 31.5% reduction from pre-CBAM levels. However, this impact is unevenly distributed across the product categories, with importers of precursor products losing the most, closely followed by importers of nitrogen products, and trailed by importers of mixed fertilizers losing the least.

EU importers of fertilizer precursor products bear the largest economic burden, with importer surplus decreasing by $1.92 billion, representing a 39.3% reduction. This is underpinned by these products experiencing the highest average price increase of $149 per tonne of fertilizer, or a 27.5% increase, due to the CBAM; and an average decrease in import demand by 48,000 tonnes of fertilizer precursor products from each trade partner. These findings indicate that fertilizer precursor products face the largest relative impact from CBAM-driven price increases, suggesting a particularly sensitive market position for these foundational agricultural inputs due to their high carbon emission intensity of production and status as an input to fertilizer production.

For EU importers of nitrogen fertilizer products, the total annual decrease in importer surplus after the CBAM is $1.5 billion, or a 27.8% reduction from before the CBAM. This decrease in importer surplus is driven by an average price increase of $121 per tonne, representing a 32% rise; and an average decrease in import demand by 45,000 tonnes of nitrogen fertilizers from each trade partner. The substantial decrease in importer surplus for nitrogen fertilizers, despite being lower than precursor products, reflects the importance of these products in EU agri-food systems and draws attention to potential challenges for maintaining the affordability of food production inputs without technological adaptations or government support structures.

For EU importers of mixed fertilizer products, the total annual decrease in importer surplus after the CBAM is $571 million, or an 18.7% reduction from EU importers' importer surplus before the CBAM. This decrease is formed by an average price increase of $62.1 per tonne of fertilizer, representing an 11.1% price increase; and an average decrease in import demand by 33,000 tonnes of mixed fertilizers from each trade partner. The relatively lower impact on mixed fertilizers suggests greater resilience in this section of the market, likely due to the lower carbon emission intensity of production and higher product differentiation.

These differential impacts across product categories display the complex interaction between carbon emission intensity, price elasticity, and market structure with the CBAM price increase. The higher burden on precursor products and nitrogen fertilizers provide motivation for complementary policies to support the agricultural sector during this transition. While the

CBAM imposes significant costs on EU importers, these costs are in pursuit of environmental benefits which must be weighed against the environmental benefits in order to assess the overall impact of the policy.

Results of CBAM Benefit Calculations

The environmental benefits of the CBAM for which the economic costs are sustained are primarily found through reducing carbon emissions and generating government revenue **Tables 4, 5, and 6**. These benefits vary across the three fertilizer categories, but together the CBAM is projected to generate an estimated $1.49 billion in government revenue, while reducing virtual CO_2 imports by approximately 4.3 million tonnes annually, with the value to society and the environment equal to approximately $1.09 billion in the baseline scenario. The distribution of these benefits across the three fertilizer categories demonstrates where the CBAM is most effective environmentally.

Due to the CBAM's impact on import demand for fertilizer precursor products, 2 million less tonnes of CO_2 is projected to be virtually imported into the EU. The value of the environmental benefit of this emissions reduction is $532 million, and the government revenue generated from the remaining imports within this product category is estimated to total $457 million. This category demonstrates the highest emissions reduction among the three fertilizer types, though it generates less government revenue than nitrogen fertilizers, likely due to this category retaining the highest average price elasticity of demand.

Due to the CBAM's impact on import demand for nitrogen fertilizer products, 1.66 million less tonnes of CO_2 is projected to be virtually imported into the EU. The value of the environmental benefit of this emissions reduction is $422 million, and the government revenue generated from the remaining imports within this product category is estimated to total $624 million. Nitrogen fertilizers, with the lowest average price elasticity of demand, generate the highest government revenue out of all three categories, resulting from the larger volume of imports retained after the CBAM is implemented.

Due to the CBAM's impact on import demand for mixed fertilizer products, 535 thousand less tonnes of CO_2 is projected to be virtually imported into the EU. The value of the environmental benefit of this emissions reduction is $136 million, and the government revenue generated from the remaining imports within this product category is estimated to total $405 million. Mixed fertilizer products show both the lowest emissions reduction and government revenue generation of the three categories, reflecting their relatively lower carbon emission intensity and the moderate impact of the CBAM on trade flows within this category.

These benefit calculations demonstrate that the CBAM creates significant positive externalities through emissions reduction, while generating substantial government revenue and providing an opportunity for the EU to reinvest into the sustainable agricultural transition. The variation across market categories highlights how the CBAM is projected to impact different market segments based on the underlying patterns of demand and carbon emissions elasticities of production. The benefit calculations show that precursor products yield the highest carbon emission reductions, nitrogen fertilizers generate the most revenue, and mixed fertilizers produce the lowest impact on both fronts. These findings are a crucial component to the comprehensive cost-benefit analysis in the following section, where the net welfare implications of the CBAM is assessed across multiple carbon valuation scenarios.

Results of Cost-Benefit Analysis, with Sensitivity

When the costs and benefits of the CBAM's impact on each of the three fertilizer categories are combined, the total cost amounts to \$4.04 billion, stemming from losses of importer surplus for EU importers. The combined total benefit, \$1.09 billion derived from emissions reductions and \$1.49 billion derived from government revenue, amounts to \$2.58 billion in the baseline scenario. The baseline scenario values a CBAM certificate price at \$73.5/tonne CO_2 and the SCC at \$254/tonne CO_2. When the costs and benefits are compared in this scenario, the estimated overall cost of the CBAM is \$1.46 billion.

The cost-benefit balance shifts considerably in scenarios that value CBAM certificates and the SCC differently. At the lower SCC estimate of \$125/tonne CO_2, the cost of the CBAM exceeds its benefits by approximately \$2.01billion, leaning towards a more unfavorable policy outcome. Conversely, at an SCC of \$700/tonne CO_2, the policy generates a net benefit of approximately \$453 million, as the higher valuation of emissions reductions as social and environmental welfare increases the calculated environmental benefits. Similarly, when CBAM certificate prices are increased to \$91.8/tonne CO_2, government revenue rises sufficiently to create a net beneficial outcome, even if all other parameters remain unchanged.

Table 7 shows a sensitivity analysis of these cost-benefit results, based on SCC values of \$125, \$254, and \$700, and CBAM certificate prices of \$55.1, \$73.5, and \$91.8. From this sensitivity analysis, we can see that the CBAM has a net beneficial impact when the SCC is valued at \$700 or a CBAM certificate costs \$91.8; otherwise, the cost of the CBAM outweighs the benefits. This result indicates that the CBAM only yields a net benefit under two conditions: (1) when the SCC is valued enough to justify emissions reductions, or (2) when CBAM certificate prices are sufficiently elevated to offset importer surplus losses.

The findings of this sensitivity analysis demonstrate the importance of fine tuning the CBAM policy as it is implemented to ensure a balanced outcome. The results suggest that the CBAM's economic justification is contingent on how climate damages are valued, with higher SCC estimates supporting the policy's implementation. Additionally, these results indicate that policymakers face a tradeoff between higher CBAM prices for cost-effectiveness but greater importer surplus losses. Furthermore, the sensitivity analysis highlights the importance of complementary policies and revenue recycling initiatives which might mitigate importer surplus losses while maintaining the integrity of the EU's overarching carbon neutrality goals. Finally, these results reinforce the fact that the CBAM's effectiveness should not only be evaluated on economic grounds, but also on its broader objectives of preventing carbon leakage and incentivizing global decarbonization, while contributing to the sustainable agricultural transition with its interactions with the fertilizer sector; as these indirect effects may justify the implementation of the policy even if the direct economic costs exceed benefits.

Limitations of the Results

The conclusion of the results section of this study warrants an acknowledgement of several methodological limitations in the analysis. First, the approach of this analysis assumes that the EU is a "price taker" in the global fertilizer market, treating the EU as if it were a small open economy for modeling clarity, despite the EU accounting for approximately 20% of global nitrogenous fertilizer imports by value (CEPII, 2024). This assumption potentially overlooks a price feedback loop where decreased EU demand could decrease global prices, thereby limiting the economic costs of the CBAM to EU consumers. This "price taker" assumption additionally may result in slightly inflated estimates of price elasticities of demand, implying that there could be a smaller change in importer surplus and a lower negative economic effect of the CBAM, leading to a more positive net policy outcome. Future research could address these limitations by employing a partial equilibrium model with endogenous price responses, which would allow for a more nuanced analysis of how the burden of the CBAM is distributed between EU importers and their international suppliers. Additionally, this analysis does not account for any strategic price absorption by exporters seeking to maintain their market share. This assumption could lead to an overstatement of the economic costs, as exporters voluntarily taking on part of the policy burden could reduce economic costs to EU importers.

Another limitation is that the environmental benefit calculations cannot account for carbon leakage due to the CBAM if exporters shift their focus to markets with lower environmental standards. This could reduce the scope of the environmental benefits to only be beneficial for the EU's carbon accounting ledger rather than a true global environmental benefit. Conversely, the environmental benefit calculations are primarily limited to the value of carbon emissions, and do not account for the value of environmental benefits due to the reduction of synthetic fertilizer usage, the potential benefits of induced innovation in low-carbon technology, or the ripple effects of the CBAM on global climate policy. Therefore, the environmental benefits could be greater than what has been calculated in this analysis, given these alternative environmental benefits are effectively not valued.

Section 5: Discussion

The implementation of the CBAM represents a significant transformation in international trade dynamics within EITE industries as it increases the price of goods for EU importers and consequently decreases EU import demand. The results of the regression analysis suggest that EU import demand for CBAM-regulated fertilizer products is elastic and negatively related to price increases, regardless of the origin of the product, and that there is significant variation in price elasticity between trade partners and among fertilizer product categories. Additionally, the results of the cost benefit analysis, with sensitivity, provide key insight into the role of the SCC and CBAM pricing in the overall impact of the policy. These results open an important discussion about how the CBAM will directly impact EU trade partners, EU consumers, and the EU fertilizer market. Within these discussions, the implications of the CBAM's impact on the global green industrial revolution, the EU's climate and agricultural goals, and the value of carbon emissions in climate policy are examined. The discussion of the results lends itself to some crucial policy recommendations, which could act alongside the CBAM to maximize the environmental benefit of the policy and improve the cost-benefit ratio, while ensuring the CBAM aligns with the EU's goal of transitioning towards a climate-neutral economy in an equitable way.

Following the empirical findings of this study, EU trade partners seeking to maintain their trade relationship with the EU must face critical strategic decisions, as the implementation of the CBAM significantly decreases demand due to price increases which are proportional to their carbon emission intensities of production. Their principle policy considerations must be in recognition that the impact of the CBAM on exporters is lessened when trade partners implement their own domestic carbon pricing regulation or utilize low-carbon production technology, as these adaptations reduce the price of the CBAM to importers. Additionally, these governments must weigh the costs of inaction: continued government revenue transfers to the EU and a declining market share versus the complexities of implementing a domestic carbon pricing regulation or investing in low-carbon technologies. Recent policy briefs and recommendations for EU trade partners are largely in support of more ambitious domestic carbon emission regulations, largely due to the financial incentive for trade partners to capture carbon pricing revenue domestically rather than transferring it to the EU (Chaivanich & Singyoocharoen, 2024; Elder et al., 2025; Kashbrasiev, 2024). In this way, the CBAM is harkening a global green industrial revolution – at least within EU trade partners that are willing and able to utilize the opportunity that the CBAM presents.

The CBAM's opportunity to bring about a global green industrial revolution is hampered by concerns of disparities between developed and developing trade partners. Unlike other recent tariff-based trade measures criticized as protectionist or driven by economic nationalism, the CBAM is framed as an environmental tool aligned with WTO principles – though amid ongoing global trade tensions, it may still raise concerns among trade partners as protectionism in disguise. From the results of this study, it is clear that major fertilizer trading partners like Algeria, Russia, and Trinidad and Tobago in precursor products; Egypt, Russia, and Trinidad and Tobago in nitrogen fertilizers; and Morocco and Russia in mixed fertilizers, will see the largest decreases in demand from the EU for their fertilizer products, by volume. Of these most affected, economically powerful nations that resist cooperation with the CBAM are applying to challenge the CBAM through WTO legal channels, seeking WTO-sanctioned retaliation measures (Mehling et al, 2019; Overland & Sabyrbekov, 2022). Meanwhile, the developing countries most impacted – particularly those most dependent on trade with the EU in CBAM-regulated industries – face more fundamental barriers to participation in any CBAM-motivated green industry adaptations due to limited capital resources and technological capacity (Mehling et al., 2019; Overland & Sabyrbekov, 2022; Smith, Overland, & Szulecki, 2023). Recent research emphasized that effective CBAM implementation requires the EU to actively participate in facilitating the global decarbonization movement by providing targeted financial, technological and knowledge-based transfer programs for the developing countries most impacted by the CBAM (Weko & Goldthau, 2022; Pan & Liu, 2024; Erdogu, 2025).

Ultimately, EU consumers of imported fertilizer products are participants in the agri-food system value chain, and the CBAM's impact on the EU's fertilizer imports will create an immediate need for complementary policies that maximize the environmental benefits while minimizing economic disruption and maintaining food security. In terms of the environment, the CBAM's impact on demand for imported synthetic fertilizers offers dual benefits at the intersection of the climate change mitigation and the EU agri-food system transition when coordinated with the broader EGD sustainable agriculture policies. In this context, increasing the price of imported synthetic fertilizers by an average of 23.5% becomes an incentive for EU consumers to find substitute products, rather than a simple economic cost. This moment could be capitalized upon if bio-based organic fertilizers are made available at competitive prices, supported by sufficient production capacity and distribution networks to meet agricultural demand. The current challenges facing bio-based fertilizers are solvable with the appropriate investment and policy support in logistics, product consistency, and production capacity. Strategic allocation of CBAM revenue toward research, development, and scaling of bio-based fertilizer alternatives would both strengthen EU agri-food supply chain resilience and decarbonization efforts. These reinvestment efforts would align the CBAM's revenue generation with its environmental goals, while supporting the sustainable agricultural transition by addressing the immediate market disruptions that EU consumers in the agricultural industry will face.

A further demonstration of the variability of the overall consequences of the CBAM is evident in the sensitivity analysis of the cost-benefit analysis in this study. The results of the cost-benefit analysis in the baseline scenario show the overall cost of the CBAM to consumers to be nearly $1.5 billion USD beyond the value of the potential carbon emission reduction. However, the sensitivity analysis reveals that the overall cost or benefit of the CBAM largely depends on the cost of a CBAM certificate and the estimation of the social cost of carbon. More simply: the overall cost or benefit of the CBAM is largely dependent on how clean air and the environment are valued. The estimation of the SCC, which contains variation across a number of assumptions about future scenarios – and the value of the future itself – is beyond the scope of policy power; however the questions of intergenerational and geographical equity that its estimation presents should be a guiding force for policy decisions. As previously discussed, a CBAM certificate is set at the price of an ETS allowance. The EU peripherally controls the environment in which the price of carbon emissions is determined through the overall 'cap' placed on ETS allowances, however the ETS price itself is obtained each week at auction by those who buy the allowances. The ETS allowance 'cap' is linearly decreased yearly according to each phase of the policy, and this remains the main lever through which the EU can drive the price of carbon emissions. Through this means, the EU can ensure that the CBAM certificate price is appropriately valued to balance the costs and benefits of the policy.

These discussion points together bring to light the fact that the CBAM, in the right policy landscape, offers an opportunity for a global shift in how environmental costs are integrated into trade systems. While the cost-benefit results suggest the policy's economic impact depends heavily on carbon valuation parameters, the broader implications extend far beyond quantifiable metrics. The CBAM's interaction with fertilizer markets creates strategic decision points for trade partners, opens opportunities for a sustainable agricultural transition, and highlights global inequities that require thoughtful policy responses. These far reaching consequences reflect the fundamental challenge of environmental policy: balancing immediate economic costs with long-term ecological imperatives. As the EU moves toward implementing this policy in 2026, complementary policies addressing distributional impacts, supporting vulnerable trade partners, and investing in sustainable alternatives will ultimately determine whether the CBAM fulfills its transformative potential. The following conclusion will draw together these findings into actionable recommendations and policy implications that can help maximize the benefits of the CBAM in an economically balanced manner.

Section 6: Conclusion

The EU CBAM has the potential to radically change the status quo of environmental policy around the world through its interaction with international trade, requiring EU trade partners to confront the opportunity cost of environmental policy inaction. This coming change is a vital step toward internalizing the environmental damage embedded within market transactions. However, effective implementation will require an adaptive approach that identifies and addresses unintended consequences as they emerge, particularly regarding shifting market conditions, carbon leakage, and distributional impacts. The potential costs of the CBAM can range from increasing expenses for EU importers and agricultural producers, to creating additional barriers for less developed EU trade partners. However, by reframing these challenges as opportunities, the EU can grow in their leadership role within the international environmental policy sphere, by leading the transition to sustainable agricultural systems and by assisting trade partners within their realm of influence.

The cost of the CBAM to EU consumers can be utilized as an opportunity to expand the market share of organic bio-based fertilizers and convert more EU farmland to organic farmland in support of the EU's broader climate neutrality goals. As demand for imported synthetic fertilizer reduces following the CBAM, the EU has an opportunity to support the transition to bio-based fertilizers. The EU should consider allocating a significant portion of the fertilizer-related CBAM revenue toward research, development, and scaling of bio-based fertilizer alternatives in order to provide bio-based fertilizers at a quality and price comparable to that of synthetics. In the short term, this funding could alleviate the immediate needs of agricultural producers by scaling production and distribution infrastructure, and by providing farmers with incentives to adopt organic fertilizer alternatives. In the long term, investments could focus toward the continued research and development of solutions for the technical challenges of bio-based fertilizers, like nutrient consistency, application efficiency, and production technologies that fit into a circular bio-economy. Additionally, encouraging the development of agricultural cooperatives on a local level could empower farmers to collectively invest in organic fertilization methods, like facilitating regional biomass collection networks or creating shared composting facilities, ultimately fostering collaboration to provide local solutions to local problems. By connecting revenue generation to supporting the sustainable transition, the EU can demonstrate how carbon border adjustments can serve as catalysts for progress toward climate neutrality goals.

The barriers to trade partners can be utilized as an opportunity to assist less developed countries in the green energy and industry transition with targeted technological support. Tiered assistance programs should be established to provide support for less developed trade partners based on their economic development level and export dependency on the EU market to ensure a just transition for all those within the EU's realm of influence. These assistance programs should include: (1) extended transition periods with gradually increasing CBAM certificate requirements for least developed countries, similar to the EU's successful Special Arrangement for Sustainable and Good Governance; (2) technical assistance on low-carbon production technologies and carbon accounting methodologies through initiatives like the EU Technical Assistance and Information Exchange Program; and (3) financial assistance for capital-intensive clean energy infrastructure that supports fertilizer production with the European Investment Bank's Climate Action initiative. Furthermore, technical knowledge should be provided specifically regarding the environmental benefit and practical implementation of bio-based organic fertilizers. Building capacity for both carbon-efficient conventional fertilizer production and bio-based fertilizer alternatives would help vulnerable trade partners develop more self-sustaining and environmentally responsible agricultural systems, leading to stronger trade partners for the EU. CBAM-generated revenue could be explicitly allocated to fund these assistance programs, reinforcing their feasibility and alignment with the policy's environmental goals. These concrete measures could bolster the EU's broader environmental goals by providing targeted assistance in environmental protection and economic development abroad, further cementing the EU as an innovative leader in environmental policy.

With appropriately valued ETS allowances and CBAM certificates, the CBAM has the potential to create environmental benefits through government revenue and carbon emission reductions which would outweigh any economic costs to consumers. The CBAM creates a positive impact through three avenues: First, given that trade partners do not divert trade, the reduction in carbon emissions due to the reduction in EU import demand could meaningfully contribute to solving the global issue of climate change. Second, it generates significant government revenue that could create a virtuous cycle of environmental improvement and economic adaptation by reinvesting in bio-based alternatives and assisting developing trading partners in the green industrial transition. Third, the CBAM incentivizes trade partners to develop their own carbon emission regulation structures, generating global environmental benefits beyond EU borders. By reframing the challenges of the CBAM as opportunities, the EU can firmly establish itself as a role model for using environmental policy as a tool to drive systemic change while ensuring a just transition.

This study suggests that carbon pricing mechanisms have the opportunity to be catalysts for reimagining economic systems that reflect ecological realities. The high price elasticity of EU import demand across all CBAM-regulated fertilizer products and trade partners demonstrates that markets respond decisively to environmental price signals when properly implemented. Yet the sensitivity analysis shows that the net benefit hinges almost entirely on how carbon emissions are valued. This quantitative finding reflects a practical challenge for policymakers to reckon with: the success of nature lies in reciprocal support systems that ensure mutual flourishing growth, systems that traditional economic metrics struggle to value. How can we ensure that environmental preservation is appropriately valued within the current economic system? By establishing the principle that environmental costs must be integrated into market transactions, the CBAM creates space for more profound innovations in how we produce, trade, and consume. The challenge for policymakers now is to build upon this foundation to reinvest in the green transition to support trade partners and agricultural consumers, ensuring that the costs of the CBAM are effectively utilized to maximize the environmental benefits.

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Appendix

Appendix A – Tables and Figures

Table 1 – CBAM-Regulated Fertilizer Products and Their Analysis Categories

HS Code	Fertilizer Product Description	Analysis Category
2808 00 00	Nitric Acid; Sulphonitric Acids	Fertilizer Precursor Products
3102 10	Urea, whether or not in aqueous solution	
2814	Ammonia, anhydrous or in aqueous solution	
2834 21 00	Nitrates of potassium	
3102	Mineral or chemical fertilizers, nitrogenous	Nitrogen Fertilizer Products
3105*	Mineral or chemical fertilizers containing two or three of the fertilizing elements nitrogen, phosphorous, and potassium; other fertilizers	Mixed Fertilizer Products
*3105 60 00 – not included under CBAM regulation		

Data: (European Commission, 2023b)

Fertilizer products under harmonized system (HS) code 3105 60 00 (Mineral or chemical fertilizers containing the two fertilizing elements phosphorus and potassium) are excluded under the current scope of the CBAM regulation. This is because the CBAM is primarily focused on regulating nitrogen fertilizers and precursor products to nitrogen fertilizers. Products under HS code 3105 60 00 do not include mixed fertilizers with nitrogen.

Table 2 – Descriptive Statistics for Fertilizer Import Quantities and Associated Variables by Product Type

Variable [Units]	Variable Notation	Definition	Precursor Products	Nitrogen Fertilizers	Mixed Fertilizers
			Mean (Std. Dev)	Mean (Std. Dev)	Mean (Std. Dev)
Dependent Variable					
Import Quantity of Fertilizer [Tonnes]	Q_{ijt}	The quantity of a fertilizer product imported to an EU-27 member, i, from one of 22 trading partners*, j, in one of the years, t, included in 1997 - 2021	22,479.22 (63,740.26)	25,879.46 (78,373.62)	22,497.45 (65,736.38)
Independent Variables					
Price per Tonne of Imported Fertilizer [USD]	P_{it}	The price per tonne of a fertilizer product imported to an EU-27 member from one of 22 trading partners* in one of the years included in 1997 - 2021	648.13 (465.52)	448.99 (417.44)	711.43 (517.60)
Average Price per Tonne of EU-Produced Fertilizer [USD]	P_{jt}	The average price per tonne of a fertilizer product which was produced and sold in the EU-27 in one of the years included in 1997 - 2021	536.55 (274.42)	276.30 (96.70)	389.28 (152.38)
Importing Country GDP [Million USD]	Y_{jt}	The GDP (Gross Domestic Product) of an EU-27 member country importing fertilizer products in one of the years included in 1997 - 2021	861.18 (1,033.88)	810.01 (1,026.21)	669.41 (920.33)
Exporting Country Carbon Pricing Regulation Indicator [Binary]	R_{it}	Indication of a carbon pricing regulation within an exporting country in one of the years included in 1997 - 2021. If present, indicate 1; otherwise, indicate 0.	0.04 (0.19)	0.09 (0.29)	0.06 (0.24)
Annual Average Price of Natural Gas [USD/MWh]	G_t	The annual average price per megawatt-hour of natural gas imported to the EU-27** in one of the years included in 1997 - 2021	22.38 (9.65)	23.97 (9.25)	22.44 (9.73)
1-Year Lag of Import Quantity of Fertilizer [Tonnes]	$Q_{ij(t-1)}$	The total quantity of a fertilizer product imported to an EU-27 member from one of 22 trading partners* in the previous year, t-1	270,439.20 (392,842.40)	427,033.40 (654,313.30)	447,400.70 (869,237.20)

*Each of the 22 trading partners are assigned a binary variable which indicates when they are acting within a trade interaction with an EU-27 member. Within the regression analysis, all but one of these binary country indicator variables interact with the price variable to obtain country-specific price effects, excluding one country indicator as the baseline price effect.

**The average price per megawatt-hour of natural gas to EU-27 member country Germany is used as a proxy for the average price per megawatt-hour of natural gas to the EU-27.

Table 3 - Regression Results for Fertilizer Products (Precursor, Nitrogen, and Mixed Fertilizers)

Variable Name	[Variable Notation]	(1) Precursor Products	(2) Nitrogen Fertilizers	(3) Mixed Fertilizers
		Dependent Variable: ln(Import Quantity)	Dependent Variable: ln(Import Quantity)	Dependent Variable: ln(Import Quantity)
ln(Price per Tonne of Imported Fertilizer)	[ln(P)]	-2.177* (0.102)	-1.594* (0.120)	-2.174* (0.0870)
ln(Price) x Algeria Dummy Interaction	[ln(P)_DZA]	Reference Dummy^	-0.122 (0.0955)	-0.111 (0.176)
ln(Price) x Belarus Dummy Interaction	[ln(P)_BLR]	-0.223* (0.0620)	-0.374* (0.0903)	-0.276* (0.0400)
ln(Price) x Canada Dummy Interaction	[ln(P)_CAN]	-0.775* (0.0874)	-0.794* (0.0941)	-0.245* (0.0393)
ln(Price) x Chile Dummy Interaction	[ln(P)_CHL]	-0.245* (0.0394)	-0.441* (0.0883)	-0.321* (0.0735)
ln(Price) x China Dummy Interaction	[ln(P)_CHN]	-0.400* (0.0588)	-0.659* (0.0861)	-0.321* (0.0324)
ln(Price) x Egypt Dummy Interaction	[ln(P)_EGY]	-0.0537 (0.0451)	-0.0935 (0.0914)	-0.217* (0.0468)
ln(Price) x Georgia Dummy Interaction	[ln(P)_GEO]	-0.377 (0.320)	-0.223* (0.0943)	---
ln(Price) x Indonesia Dummy Interaction	[ln(P)_IDN]	-0.428* (0.159)	-0.384* (0.120)	-0.329* (0.0803)
ln(Price) x Israel Dummy Interaction	[ln(P)_ISR]	-0.243* (0.0354)	-0.685* (0.0906)	-0.204* (0.0274)
ln(Price) x Jordan Dummy Interaction	[ln(P)_JOR]	-0.169* (0.0420)	-0.505* (0.0960)	-0.277* (0.0394)
ln(Price) x Morocco Dummy Interaction	[ln(P)_MAR]	-0.525* (0.174)	-0.704* (0.137)	-0.0159 (0.0237)
ln(Price) x Norway Dummy Interaction	[ln(P)_NOR]	-0.410* (0.0586)	-0.426* (0.0922)	-0.299* (0.0385)

Table 3 continued

ln(Price) x Russia Dummy Interaction	[ln(P)_RUS]	-0.208* (0.0334)	-0.116 (0.0899)	Reference Dummy^
ln(Price) x Saudi Arabia Dummy Interaction	[ln(P)_SAU]	-0.0630 (0.164)	-0.465* (0.0983)	-0.376* (0.129)
ln(Price) x Serbia Dummy Interaction	[ln(P)_SRB]	-0.254* (0.0700)	-0.536* (0.0926)	-0.280* (0.0371)
ln(Price) x Turkmenistan Dummy Interaction	[ln(P)_TKM]	---	Reference Dummy^	---
ln(Price) x Trinidad and Tobago Dummy Interaction	[ln(P)_TTO]	-0.0872* (0.0398)	-0.0764 (0.0894)	---
ln(Price) x Tunisia Dummy Interaction	[ln(P)_TUN]	---	-0.466* (0.107)	-0.0370 (0.0268)
ln(Price) x Türkiye Dummy Interaction	[ln(P)_TUR]	-0.276* (0.0540)	-0.479* (0.0913)	-0.259* (0.0329)
ln(Price) x Ukraine Dummy Interaction	[ln(P)_UKR]	-0.218* (0.0342)	-0.375* (0.0907)	-0.252* (0.0337)
ln(Price) x United Kingdom Dummy Interaction	[ln(P)_GBR]	-0.430* (0.0357)	-0.466* (0.0877)	-0.197* (0.0266)
ln(Price) x United States of America Dummy Interaction	[ln(P)_USA]	-0.400* (0.0551)	-0.552* (0.0884)	-0.146* (0.0311)
ln(Average Price per Tonne of EU-Produced Fertilizer)	[ln(P)_EU]	0.379* (0.135)	-0.618* (0.210)	1.121* (0.149)
ln(Importing Country GDP)	[ln(Y)]	0.751* (0.0268)	0.558* (0.0254)	0.405* (0.0201)
Exporting Country Carbon Pricing Regulation Indicator	[R]	-0.516* (0.237)	-0.255 (0.216)	0.476* (0.241)
ln(Average Natural Gas Price)	[ln(G)]	0.639* (0.116)	1.299* (0.160)	0.199 (0.118)
ln(1-Year Lag of Import Quantity of Fertilizer)	[ln(Q_{t-1})]	0.355* (0.0384)	0.200* (0.0268)	0.298* (0.0259)

Table 3 continued

Constant Term	-0.917 (0.927)	4.991* (1.029)	3.467* (0.765)
Observations	2,867	3,810	4,547
R-squared	0.613	0.547	0.600
Robust standard errors in parentheses * p<0.05			
^Indicates the country used as the regression baseline reference Ln(Price) x Dummy Variable. For precursor products, Algeria is the reference dummy; for nitrogen fertilizers, Turkmenistan is the reference dummy; and for mixed fertilizer products, Russia is the reference dummy. --- Indicates zero trade between the exporting country and EU-27 within the product category. For precursor products, Turkmenistan and Tunisia do not export to the EU-27; for mixed fertilizer products, Georgia, Trinidad and Tobago, and Turkmenistan do not export to the EU-27.			

Table 4 - Cost-Benefit Analysis for Fertilizer Precursor Products

Fertilizer Precursor Products (HS Code: 2808, 2814, 2834) / Country Code+	Cost Calculation Results				Benefit Calculation Results				Net Cost [USD]
	Price Elasticity of Demand	Change in Demand [Tonnes Fertilizer]	Change in Average Price [USD]	Change in Importer Surplus [USD]	Carbon Emission Intensity^	Carbon Emission Reduction * [Tonnes CO2]	Environmental Benefit** [USD]	EU Government Revenue*** [USD]	
BLR	-2.400	-5,895.6 -54.2%	137.97 28.8%	-13,689,538 -41.1%	1.877	-11,066.7	2,810,946	3,430,531	-7,448,061
CAN	-2.952	-31.5 -53.6%	123.21 25.4%	-76,367 -41.8%	1.871	-59.0	14,993	18,771	-42,603
CHL	-2.422	-3,907.2 -29.9%	127.67 16.1%	-12,353,325 -18.6%	1.864	-7,282.0	1,849,635	6,283,178	-4,220,512
CHN	-2.577	-1,391.7 -44.8%	205.56 27.4%	-4,434,490 -29.7%	2.797	-3,892.3	988,641	1,761,995	-1,683,853
DZA	-2.177	-415,921.8 -60.2%	152.88 43.5%	-668,172,480 -42.9%	2.080	-865,117.4	219,739,808	210,012,056	-238,420,616
EGY	-2.231	-51,938.7 -61.0%	152.16 38.3%	-99,789,736 -46.1%	2.070	-107,523.9	27,311,058	25,226,926	-47,251,752
GBR	-2.607	-21,982.0 -55.6%	119.31 14.8%	-100,034,664 -49.0%	1.623	-35,684.1	9,063,756	10,472,366	-80,498,542
GEO	-2.554	-1.6 -31.2%	163.17 18.7%	-5,101 -18.3%	2.220	-3.5	879	2,805	-1,416
IDN	-2.605	-1.0 -31.1%	135.24 18.7%	-2,647 -18.2%	1.840	-1.8	455	1,457	-736
ISR	-2.420	-5,050.8 -34.7%	169.52 20.8%	-16,005,811 -21.1%	2.306	-11,649.1	2,958,877	8,044,419	-5,002,515
JOR	-2.346	-6,394.8 -34.0%	158.76 20.5%	-19,106,956 -20.5%	2.160	-13,812.7	3,508,435	9,863,339	-5,735,182

Table 4 continued

MAR	-2.702	-29.1 -69.5%	158.76 31.5%	-80,844 -59.8%	2.160	-62.8	15,957	10,151	-54,736
NOR	-2.587	-259.5 -39.0%	62.17 6.8%	-1,368,015 -34.8%	1.535	-398.4	101,182	229,425	-1,037,408
RUS	-2.385	-186,340.7 -62.1%	164.14 30.4%	-524,817,984 -50.6%	2.233	-416,125.9	105,695,984	93,234,647	-325,887,353
SAU	-2.240	-104.2 -56.3%	155.08 46.3%	-143,351 -36.1%	2.110	-219.8	55,837	62,718	-24,796
SRB	-2.431	-815.8 -59.3%	161.90 32.5%	-2,022,161 -46.1%	2.203	-1,796.9	456,422	453,484	-1,112,255
TKM	--	--	--	--	--	--	--	--	--
TTO	-2.264	-241,841.8 -72.7%	178.60 54.6%	-403,172,288 -57.8%	2.430	-587,675.7	149,269,622	81,060,980	-172,841,686
TUN	--	--	--	--	--	--	--	--	--
TUR	-2.453	-7,320.9 -61.2%	157.30 22.5%	-28,083,994 -52.5%	2.140	-15,667.8	3,979,617	3,645,842	-20,458,535
UKR	-2.395	-5,584.7 -66.1%	165.38 42.4%	-10,915,868 -51.8%	2.250	-12,565.5	3,191,649	2,364,917	-5,359,301
USA	-2.577	-2,138.6 -55.0%	130.36 11.0%	-14,729,531 -50.0%	1.774	-3,793.1	963,442	1,142,458	-12,623,631

[+]BLR, Belarus; CAN, Canada; CHL, Chile; DZA, Algeria; EGY, Egypt; GBR, United Kingdom; GEO, Georgia; IDN, Indonesia; ISR, Israel; JOR, Jordan; MAR, Morocco; NOR, Norway; RUS, Russia; SAU, Saudi Arabia; SRB, Serbia; TKM, Turkmenistan; TTO, Trinidad and Tobago; TUN, Tunisia; TUR, Türkiye; UKR, Ukraine; USA, United States of America.

^Units of Carbon Emission Intensity: [Tonnes CO2/Tonne Fertilizer]

*Carbon Emission Reduction = Change in Demand [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer]

**Environmental Benefit = Carbon Emission Reduction [Tonnes CO2] * Social Cost of Carbon [254 USD/Tonne CO2]

***Government Revenue = Demand Post-CBAM [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer] * CBAM Price Adjustment [73.5 USD/Tonne CO2]

Table 5 - Cost-Benefit Analysis for Nitrogen Fertilizer Products

Nitrogen Fertilizer Products (HS Code: 3102) / Country Code+	Cost Calculation Results				Benefit Calculation Results				Net Cost [USD]
	Price Elasticity of Demand	Change in Demand [Tonnes Fertilizer]	Change in Average Price [USD]	Change in Importer Surplus [USD]	Carbon Emission Intensity^	Carbon Emission Reduction* [Tonnes CO2]	Environmental Benefit** [USD]	EU Government Revenue*** [USD]	
BLR	-1.968	-31,766.4 -47.8%	101.00 41.0%	-44,680,600 -26.4%	1.374	-43,651.8	11,087,548	17,530,768	-16,062,284
CAN	-2.388	-636.4 -50.4%	96.84 15.2%	-3,578,767 -42.9%	1.480	-941.9	239,245	340,179	-2,999,343
CHL	-2.005	-975.5 -39.7%	208.68 35.9%	-2,675,071 -18.1%	3.046	-2,971.9	754,861	1,658,933	-261,277
CHN	-2.253	-6,739.7 -57.9%	169.98 36.7%	-23,677,658 -42.4%	2.313	-15,587.0	3,959,090	4,171,232	-15,547,336
DZA	-1.716	-87,818.9 -41.2%	103.43 36.4%	-124,098,200 -19.8%	1.407	-123,582.0	31,389,830	64,742,191	-27,966,179
EGY	-1.688	-150,265.5 -39.7%	102.56 32.6%	-246,730,656 -20.1%	1.395	-209,674.4	53,257,303	116,902,471	-76,570,882
GBR	-2.060	-11,511.5 -32.9%	72.00 10.6%	-63,063,784 -25.7%	0.980	-11,276.4	2,864,204	8,469,442	-51,730,138
GEO	-1.817	-57,332.0 -62.8%	167.34 59.5%	-108,102,448 -40.7%	2.277	-130,530.5	33,154,754	28,411,947	-46,535,747
IDN	-1.978	-14.2 -29.7%	112.46 24.8%	-27,678 -12.3%	1.530	-21.8	5,528	18,906	-3,244
ISR	-2.279	-500.2 -49.1%	131.45 24.2%	-2,111,293 -36.8%	1.788	-894.5	227,206	340,501	-1,543,586
JOR	-2.099	-3.6 -22.1%	117.32 13.2%	-17,701 -11.8%	1.596	-5.8	1,462	7,471	-8,769

Table 5 continued

MAR	-2.298	-104.2 -39.4%	107.22 28.0%	-235,351 -22.4%	1.459	-152.0	38,619	86,030	-110,702
NOR	-2.020	-10,521.7 -26.7%	56.96 16.3%	-20,888,308 -14.7%	1.136	-11,955.5	3,036,705	12,084,700	-5,766,903
RUS	-1.710	-366,506.2 -51.7%	130.23 50.5%	-516,982,880 -27.3%	1.772	-649,392.1	164,945,587	223,230,376	-128,806,917
SAU	-2.059	-1,383.7 -38.0%	114.08 29.0%	-2,973,681 -20.1%	1.552	-2,147.8	545,529	1,286,698	-1,141,454
SRB	-2.130	-5,562.5 -39.4%	96.66 29.0%	-10,644,915 -21.8%	1.315	-7,315.7	1,858,182	4,133,702	-4,653,031
TKM	-1.594	-41,805.9 -47.0%	116.130 44.6%	-56,139,956 -23.4%	1.580	-66,053.2	16,777,525	27,319,881	-12,042,550
TTO	-1.670	-171,369.1 -56.8%	131.16 65.1%	-180,791,552 -28.8%	1.784	-305,798.7	77,672,861	85,307,388	-17,811,303
TUN	-2.060	-563.7 -59.7%	155.526 26.0%	-2,873,051 -49.2%	2.116	-1,192.8	302972.503	295,859	-2,274,220
TUR	-2.073	-16,364.7 -53.8%	130.22 26.1%	-65,715,116 -41.7%	1.772	-28,993.1	7,364,255	9,155,083	-49,195,778
UKR	-1.969	-23,107.5 -51.1%	137.84 46.7%	-39,088,808 -28.3%	1.875	-43,336.1	11,007,372	15,242,408	-12,839,028
USA	-2.146	-4,589.3 -44.5%	99.71 12.7%	-31,521,818 -37.5%	1.357	-6,225.6	1,581,294	2,847,941	-27,092,583

+BLR, Belarus; CAN, Canada; CHL, Chile; DZA, Algeria; EGY, Egypt; GBR, United Kingdom; GEO, Georgia; IDN, Indonesia; ISR, Israel; JOR, Jordan; MAR, Morocco; NOR, Norway; RUS, Russia; SAU, Saudi Arabia; SRB, Serbia; TKM, Turkmenistan; TTO, Trinidad and Tobago; TUN, Tunisia; TUR, Türkiye; UKR, Ukraine; USA, United States of America.

^Units of Carbon Emission Intensity: [Tonnes CO2/Tonne Fertilizer]

*Carbon Emission Reduction = Change in Demand [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer]

**Environmental Benefit = Carbon Emission Reduction [Tonnes CO2] * Social Cost of Carbon [254 USD/Tonne CO2]

***Government Revenue = Demand Post-CBAM [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer] * CBAM Price Adjustment [73.5 USD/Tonne CO2]

Table 6 - Cost-Benefit Analysis for Mixed Fertilizer Products

Mixed Fertilizer Products (HS Code: 3105)	Cost Calculation Results				Benefit Calculation Results				Net Cost [USD]
Country Code+	Price Elasticity of Demand	Change in Demand [Tonnes Fertilizer]	Change in Average Price [USD]	Change in Importer Surplus [USD]	Carbon Emission Intensity^	Carbon Emission Reduction* [Tonnes CO2]	Environmental Benefit** [USD]	Government Revenue*** [USD]	
BLR	-2.450	-20,525.6 -36.2%	63.67 19.6%	-15,049,210 -23.7%	0.866	-17,779.3	4,515,950	11,519,705	986,445
CAN	-2.419	-243.3 -15.8%	51.12 4.2%	-791,157 -12.2%	0.774	-188.2	47,795	369,226	-374,136
CHL	-2.495	-166.3 -27.5%	59.27 8.8%	-298,889 -21.1%	0.865	-143.9	36,541	139,410	-122,938
CHN	-2.495	-1,505.2 -23.3%	79.40 9.3%	-3,062,605 -16.2%	1.080	-1,626.0	413,001	1,965,142	-684,462
DZA	-2.285	-4.1 -13.5%	38.22 6.9%	-4,399 -7.6%	0.520	-2.2	547	5,047	1,195
EGY	-2.391	-3,038.6 -18.3%	42.77 8.6%	-3,225,250 -11.3%	0.582	-1,768.1	449,105	2,892,478	116,333
GBR	-2.371	-1,576.1 -13.2%	39.73 3.3%	-5,182,231 -10.4%	0.541	-852.1	216,426	2,059,352	-2,906,452
GEO	--	--	--	--	--	--	--	--	--
IDN	-2.503	-221.6 -30.3%	78.64 15.2%	-257,073 -19.7%	1.070	-237.1	60,215	200,693	3,835
ISR	-2.378	-1,158.8 -17.4%	74.30 8.2%	-2,223,266 -10.6%	1.011	-1,171.3	297,514	2,044,005	118,254
JOR	-2.451	-2,459.9 -26.2%	71.58 10.1%	-4,330,611 -18.8%	0.974	-2,395.8	608,537	2,479,170	-1,242,904

Table 6 continued

MAR	-2.190	-127,437.8 -28.3%	55.10 14.3%	-107,966,360 -18.0%	0.750	-95,534.1	24,265,658	89,135,046	5,434,344
NOR	-2.473	-16,848.3 -19.1%	31.05 7.5%	-16,292,544 -13.0%	0.620	-10,441.4	2,652,106	16,226,850	2,586,413
RUS	-2.174	-389,777.8 -35.0%	65.13 17.7%	-331,482,816 -23.5%	0.886	-345,373.2	87,724,784	235,785,162	-7,972,870
SAU	-2.550	-3.3 -40.4%	80.85 26.9%	-2,038 -24.4%	1.100	-3.6	909	1,940	811
SRB	-2.454	-7,675.2 -32.3%	83.44 14.3%	-10,846,768 -22.6%	1.135	-8,713.1	2,213,127	6,710,059	-1,923,582
TKM	--	--	--	--	--	--	--	--	--
TTO	--	--	--	--	--	--	--	--	--
TUN	-2.211	-44,263.7 -36.0%	65.201 16.7%	-41,896,256 -25.3%	0.887	-39,266.1	9973594.306	25,653,588	-6,269,074
TUR	-2.433	-8,270.2 -33.7%	70.90 8.1%	-21,113,180 -28.4%	0.965	-7,978.1	2,026,428	5,765,635	-13,321,117
UKR	-2.426	-582.1 -36.4%	76.10 6.4%	-2,135,361 -32.4%	1.035	-602.7	153,083	386,736	-1,595,542
USA	-2.320	-1,235.8 -18.6%	54.33 3.9%	-4,864,472 -15.4%	0.739	-913.5	232,033	1,470,966	-3,161,473

+BLR, Belarus; CAN, Canada; CHL, Chile; DZA, Algeria; EGY, Egypt; GBR, United Kingdom; GEO, Georgia; IDN, Indonesia; ISR, Israel; JOR, Jordan; MAR, Morocco; NOR, Norway; RUS, Russia; SAU, Saudi Arabia; SRB, Serbia; TKM, Turkmenistan; TTO, Trinidad and Tobago; TUN, Tunisia; TUR, Türkiye; UKR, Ukraine; USA, United States of America.

^Units of Carbon Emission Intensity: [Tonnes CO2/Tonne Fertilizer]

*Carbon Emission Reduction = Change in Demand [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer]

**Environmental Benefit = Carbon Emission Reduction [Tonnes CO2] * Social Cost of Carbon [254 USD/Tonne CO2]

***Government Revenue = Demand Post-CBAM [Tonnes Fertilizer] * Carbon Emission Intensity [Tonnes CO2/Tonne Fertilizer] * CBAM Price Adjustment [73.5 USD/Tonne CO2]

Table 7 - Net Cost/Benefit by CBAM and SCC Scenario

Net Cost/Benefit by CBAM and SCC Scenario		Cost per CBAM Certificate* [USD/Tonne CO2]		
		$55.10	$73.50	$91.80
Value of the Social Cost of Carbon^ [USD/Tonne CO2]	$125	-$1.61 billion	-$2.01 billion	$21 million
	$254	-$1.14 billion	-$1.46 billion	$3.11 billion
	$700	$491 million	$453 million	$13.8 billion

^Social Cost of Carbon as estimated in Barrage & Nordhaus, 2024. Utilizing the 2025 estimates in 2019 USD corresponding to 3%, 2%, and 1% discount values. Converted to 2024 USD using the Bureau of Labor Statistics CPI Inflation Calculator and rounded to the nearest dollar.

*Cost per CBAM credit estimated using the average value of an EU Emission Trading System carbon allowance between the years 2021-2024, in 2024 USD. The values utilized include 25% below the average value, the average value, and 25% above the average value.

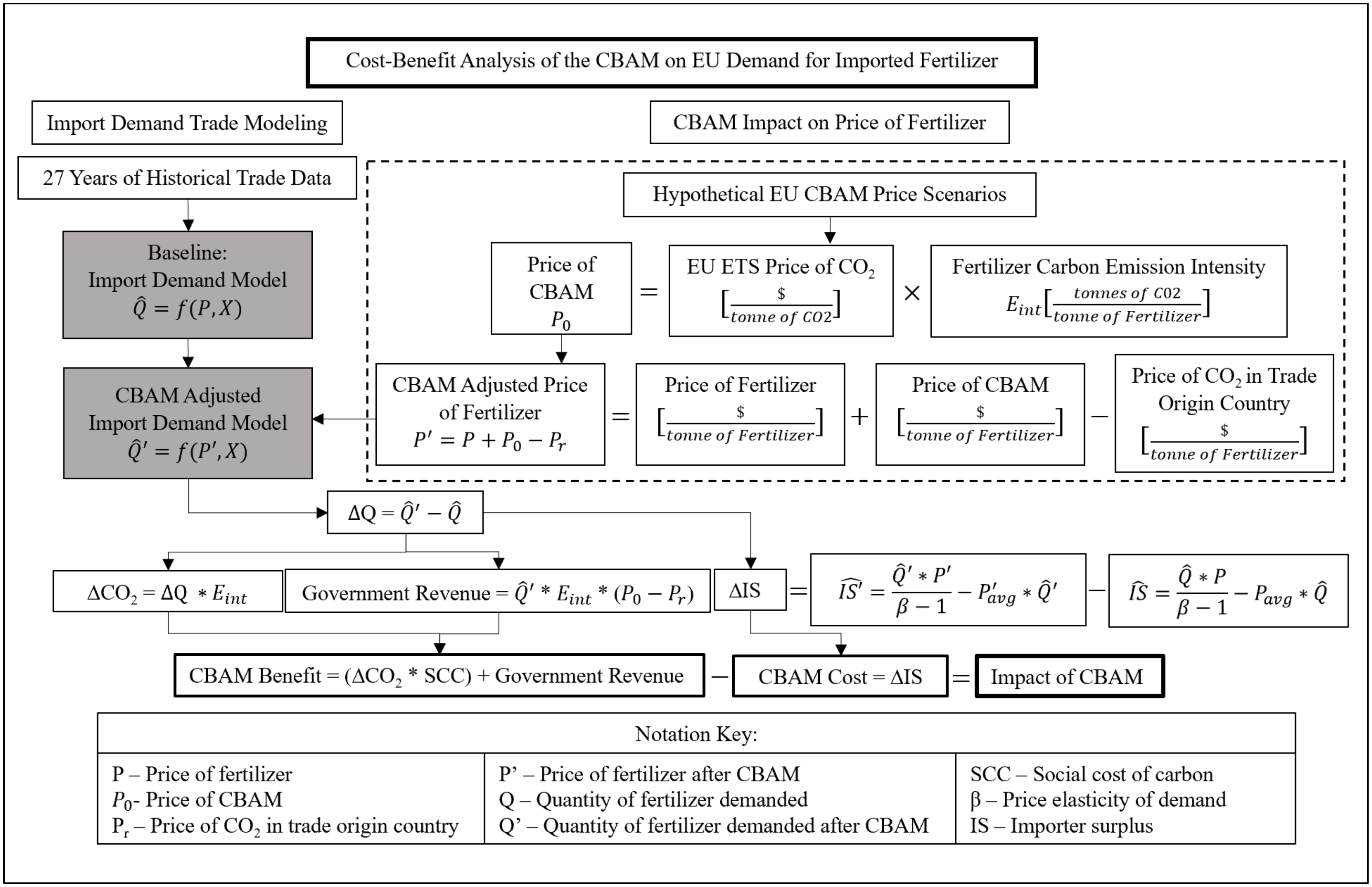

Figure 1 - Workflow of the Analysis

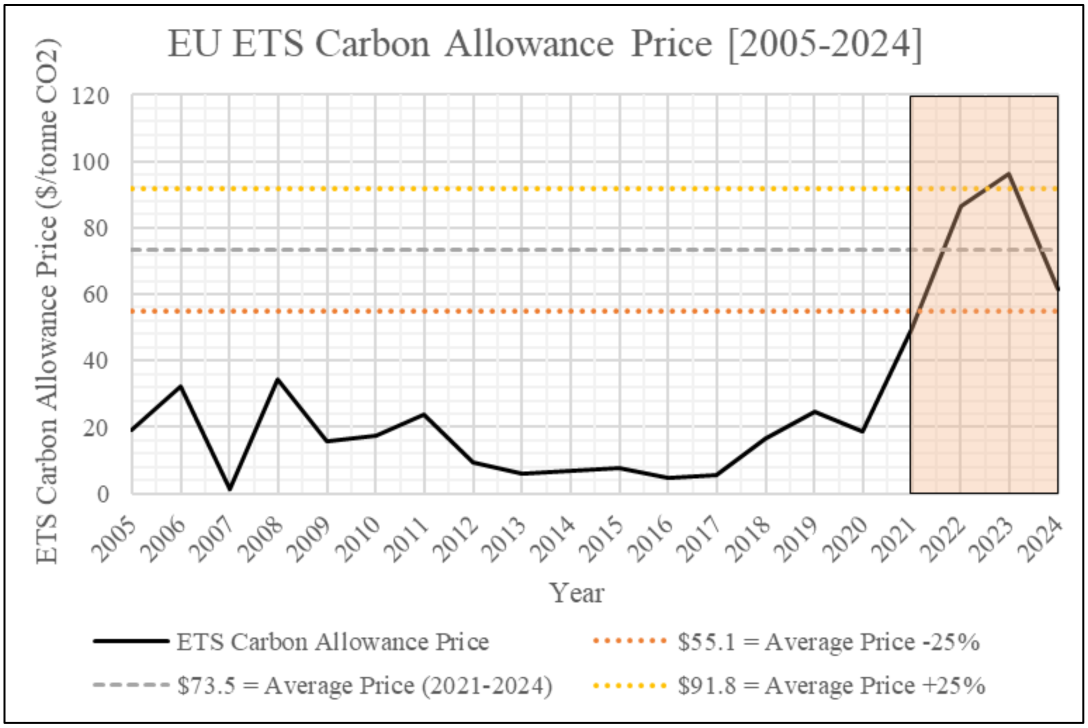

Figure 2 - Historical and Projected EU ETS Carbon Allowance Prices (2005-2024)
Data: (The World Bank, 2024)

The area highlighted in orange shows the ETS carbon prices between the years 2021-2024, which were used to calculate the CBAM pricing scenarios for this study.

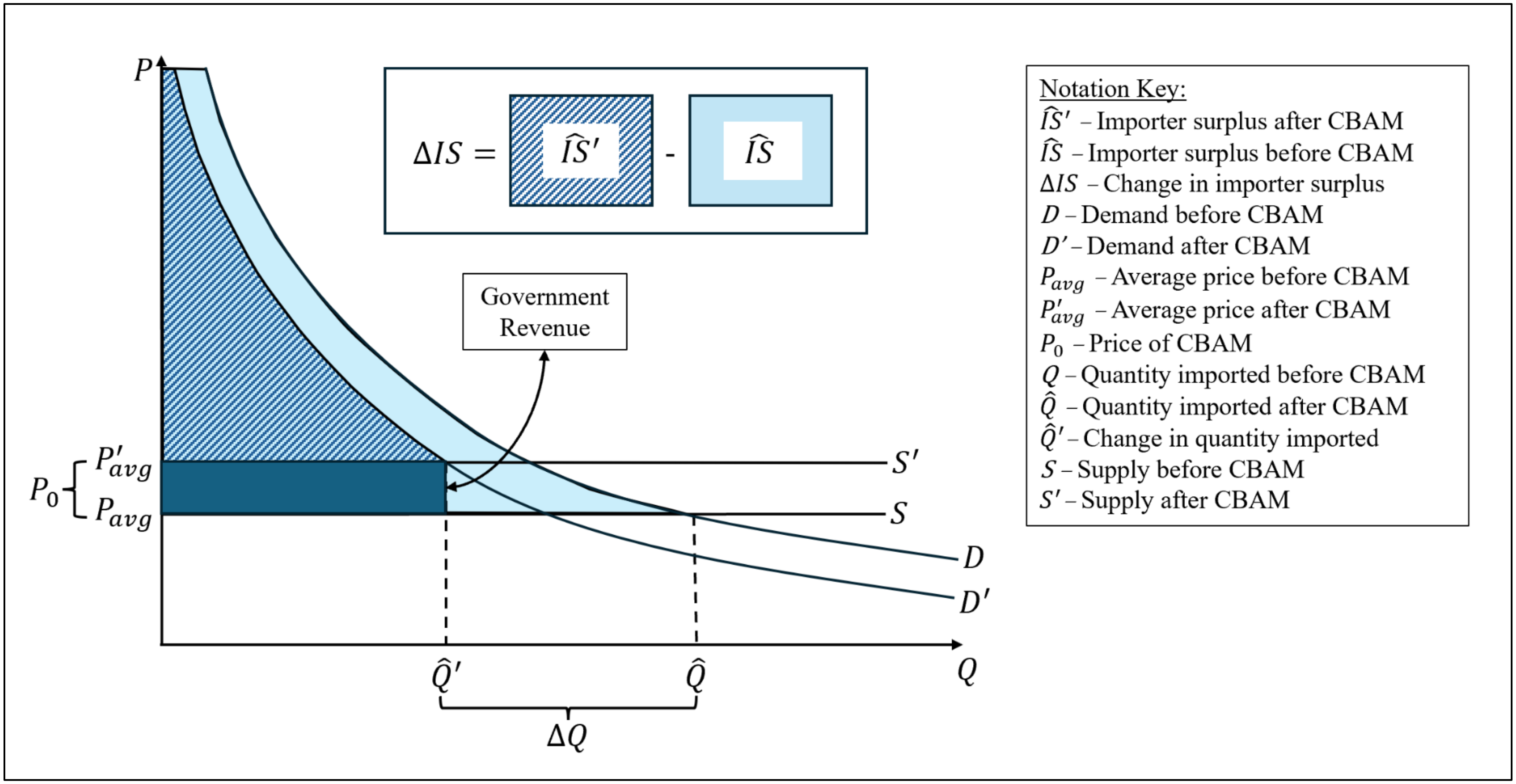

Figure 3 - Diagram of Importer Surplus and Government Revenue Impact under CBAM

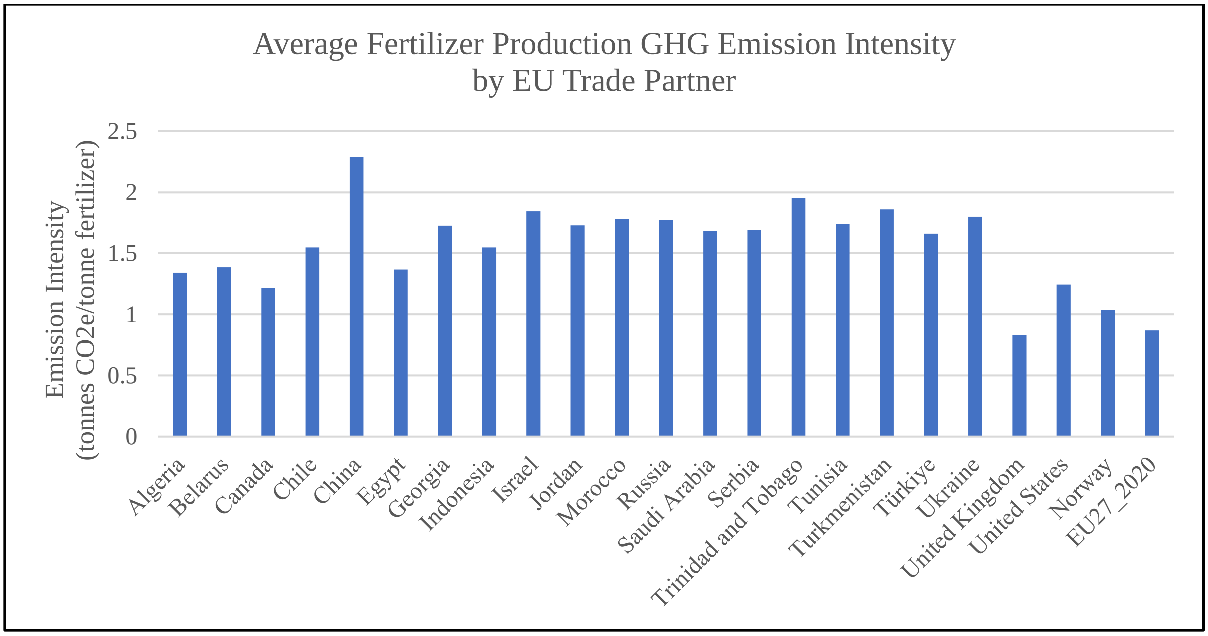

Figure 4 - Average Fertilizer Production GHG Emission Intensity of Fertilizer Production by EU Trade Partner
Data: (JRC, 2023)

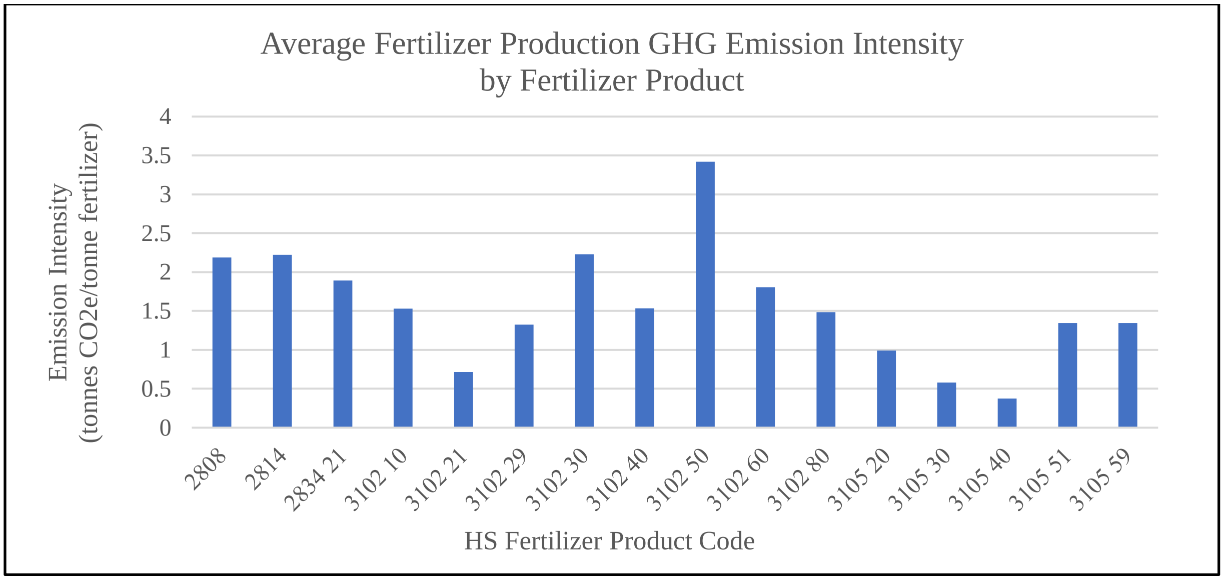

Figure 5 - Average Fertilizer Production GHG Emission Intensity of Production by Fertilizer Product
Data: (JRC, 2023)

Vita

Originally from Arizona, Natalie Crisci grew up in Chandler Arizona. After completing high school, she attended the University of Alabama and received a Bachelor of Science degree in Civil Engineering, with minor studies in Italian: Language and Culture and the Randall Research Scholars Program. In her final year of study, as an undergraduate research intern with the Alabama Water Institute, she became interested in the intersection between agriculture and water resources issues and the incentive structures that drive these systemic issues. This prompted her to take the opportunity to pursue a Master of Science degree in Natural Resource Economics at the University of Tennessee as a part of the USDA Food and Agricultural Sciences National Needs Fellowship. Her research interests include sustainable agriculture, ecological economics, water resources, and ecological engineering. After graduation, she seeks to combine her engineering and economics backgrounds at the Tennessee Department of Environment and Conservation as a part of the Division of Water Resources.