Configuration selection in a decarbonizing world. How ISO 14083 can influence supply chain operations design

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Abstract
As decarbonization is increasingly prioritized, new measures are being introduced to impose financial penalties on Green House Gas (GHG) emissions in supply chains. Carbon Border Adjustments (CBA) are trade policies that apply tariffs on imports based on their GHG emissions. The European Union implemented a CBA mechanism in 2023 and strong cross-party support has been expressed in the United States. CBA are expected to feature as part of financial instruments used to encourage decarbonization of international supply chains.

The GHG implications of route and mode selection by supply chain designers and operators will have to be quantified and reported. ISO 14083:2023 provides a framework for quantifying GHG emissions for a supply chain. International calculators are available to support quantification, like the EcoTransIT calculator. Since the GHG implications of supply chain design choices will increasingly have a financial impact, emphasizing the Well to Wheel (WTW) concepts within a supply chain could provide an additional approach of explaining proven and well-known advantages of more productive vehicle configurations.

This paper provides an example on how the impact of selecting different truck/trailer configurations on potential CBA charges is quantified, by analysing the freight transport of a lithium supply chain delivering 50,000 tonnes annually, from La Puna Argentina to the EU and the United States using ISO 14083:2023. Our results show that the use of 75 tonne B-Doubles reduces road transport emissions by almost 39%, in comparison to the standard configuration of 45 tonne, a result mostly known. However, this 39% translates to a 19% reduction in GHG emissions for the freight transport across the whole analysed supply chain.

A United States CBA would add approximately $52 to the cost of a tonne of Lithium Carbonate in 2026 rising to US$71 per tonne in 2030. The EU's CBA mechanism is likely to add US$100 to the cost of a tonne of Lithium Carbonate in 2026 rising to US$121 in 2030. While the financial impact on an individual supply chain may be relatively small, it can translate into significant costs depending on the commodity being transported. For example, commodities with lower trading value, such as iron ore, would be more impacted by the CBA and mode selection would become more financially meaningful. Quantification and financialization of GHG emissions act as an additional argument in favour of HPVs.

Keywords: Greenhouse gas emissions, ISO14083, configuration selection, decarbonization

1. Introducing the Context

Achieving the authorization of High-Performance Vehicles (HPV) such as B-doubles on national roads has been a challenge for road heavy vehicle practitioners, regardless of HPV's well proven benefits in safety, productivity and fuel use compared to conventional and even less safe authorised configurations. (Efron, and Corvalan 2016).

This paper brings an additional approach to explaining those benefits, to support argument in favour of HPVs regulation: a methodology to quantify the potential financial impact of Greenhouse Gas (GHG) emissions on the costs of the supply chain of a particular product or commodity.

As decarbonization increasingly becomes a higher priority in the public and private sectors, new measures and mechanisms are being introduced to impose financial penalties on GHG emissions in supply chains. Such measures include:

- Local carbon taxes which are levied on fuels, currently applied in 38 jurisdictions (World Bank Group 2024)
- Carbon trading schemes, which are used in the European Union and the United States of America, which received a significant boost at COP29. (Seth Kerschner, Ingrid York, and William De Catelle 2024)

As GHG emissions will have financial implications for supply chain operators, efforts to quantify them in an accurate and consistent manner are continuing to be made. One such initiative is ISO 14083:2023 *Greenhouse gases — Quantification and reporting of GHG emissions arising from transport chain operations*. (International Organization for Standardization 2023, 14083) This standard has been adopted as the basis of a common framework for quantifying the GHG emissions of transport services across different modes. (ALICE 2024).

Intertwined with these mechanisms are the Carbon Border Adjustments (CBA) trade policies, which apply tariffs on imports based on their carbon emissions. Such policies can have multiple objectives including:

- preventing carbon leakage, i.e. where goods produced in countries with no carbon regulation or taxes are at a competitive advantage
- encouraging decarbonisation in 3rd party countries
- onshoring manufacturing jobs

The European Union's Carbon Border Adjustment Mechanism (CBAM) started on a transitional basis on 1st October 2023 and will be definitively applied from 2026. CBAM puts a "*price on the carbon emitted during the production of carbon intensive goods that are entering the EU… to encourage cleaner industrial production in non-EU countries.*" ("Carbon Border Adjustment Mechanism" 2023)

CBAM currently addresses 6 sectors (cement, fertilizers, iron & steel, electricity, aluminium, and hydrogen) however consultants such as KPMG anticipate that, as a refined chemical, CBAM will be applied to Lithium Carbonate. (Freismuth 2024)

CBAM will apply adjustments based on the "*weekly average auction price of EU ETS allowances*." As of April 2024, the auction price was typically €90 - €100 per tCO_2e. Prices are anticipated to increase to approximately €150 per tCO_2e by 2030. (Görlach et al. 2022)

Strong bipartisan support for a CBA has been expressed in the United States Congress. Between June and December 2023, four separate bills have been introduced introducing a price on GHG emissions of imported goods. (Gangotra, Carlsen, and Kennedy 2023) Lithium-Ion batteries and Critical Minerals are both included on the list of applicable goods. Prices vary between proposals; however, the *Clean Competition Act* suggest carbon price starting at USUS$ 55 per tCO_2e rising to roughly USUS$88 per tCO_2 by 2030. (Görlach et al. 2022).

This paper provides a methodology and an example that quantifies the potential financial impact on the costs of the Carbon Border Adjustment on a Lithium Carbonate supply chain to 2030. The analysis uses, where possible, complementary calculators according to the mode, route and road configuration used, such as the EcoTransitWorld Calculator and the inhouse BrAle Truck Transport Calculator. Three types of truck semitrailer configurations were tested to provide differences in the total Well to Wheel (WTW) GHG emissions.

2. Freight transport supply chain GHG emissions quantification methodology

ISO 14083:2023 includes the quantification of GHG emissions for the direct consumption (Tank to Wheel or TTW) of fuel by transport equipment and hub operations (e.g. materials handling equipment, as well as the upstream emissions associated the production of the fuel (Well to Tank or WTT). Combining these values produces a "Well to Wheel" (WTW) quantification of GHG emissions of fuel consumption. Figure 1 illustrates the different GHG emission scopes throughout the value chain.

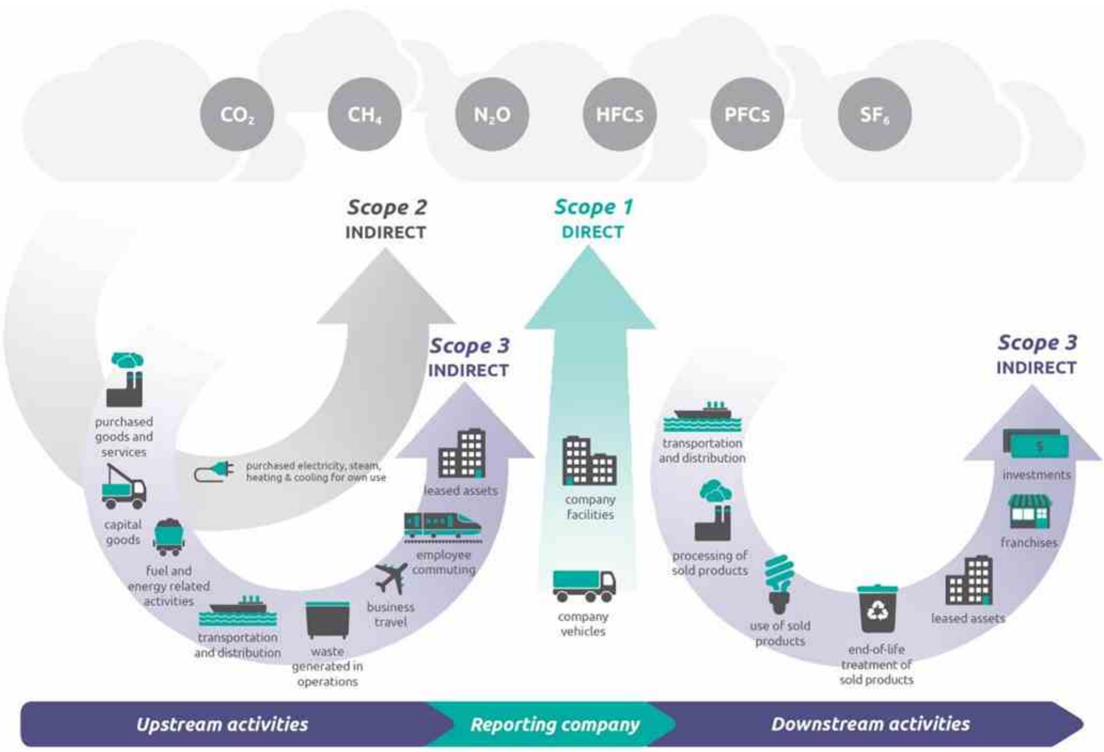


Figure 1 – GHG emission scopes (GHG Protocol 2013)

ISO 14083:2023 excludes several Scope 3 categories in the quantification of GHG emissions that would typically be considered in a GHG inventory to standards, such as Greenhouse Gas Protocol's Corporate Value Chain (Scope 3) Accounting & Reporting Standard. (GHG Protocol 2013, 3).

Scope 3 categories not addressed by ISO 14083:2023 include the GHG emissions associated with the material being transported, manufacture of transport equipment, waste generated by operations and end of life treatment for vehicles and consumables.

Figure 2 illustrates the boundary that would apply to a freight supply chain consisting of a number of Transport Chain Elements (TCEs) of different modes.

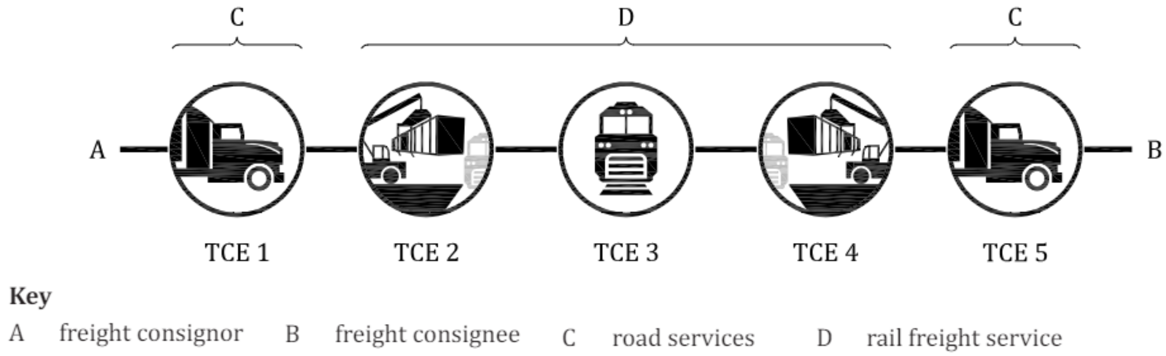


Figure 2- Illustrative example of a multi-element freight transport supply chain (ISO 14083:2023)

In addition to providing methodologies for GHG emissions, ISO 14083 also provides methodologies and emission factors for Nitrogen oxides (NOx), Sulphur Oxides (SOx), Non-Methane Hydrocarbons (NMHC) and Particulate matter (PM).

2.1. Applying the Methodology in a Supply chain

A supply chain delivering 50,000 tonnes of Lithium Carbonate annually following the most probable modes of transport from La Puna Argentina to the EU and the United States. The challenging road conditions of La Puna have been described by the authors in HVTT17. (Efron, Guivant, and Dwyer 2023).

The different commodities and reagents were considered and are defined as follows:

- The transportation of Sodium carbonate from a US supplier to la Puna in Argentina. The US leg was to be by rail. From the port in Argentina to La Puna is by truck.
- Transportation of all acids used in the process from points of production to La Puna. These reagents were considered to be transported by truck.
- Transportation of Sodium Hydroxide from origin port to la Puna is by truck
- The transportation of all Lithium Carbonate from la Puna to the port is by truck

A map showing the supply chain routes considered is illustrated in Figure 3.

All Transport Chain Elements (TCEs) were developed on an origin to destination basis with no estimates developed for energy and GHG emissions associated with hub activities. This was due to issues with one of the ISO 14083 tools calculator's routing algorithms.

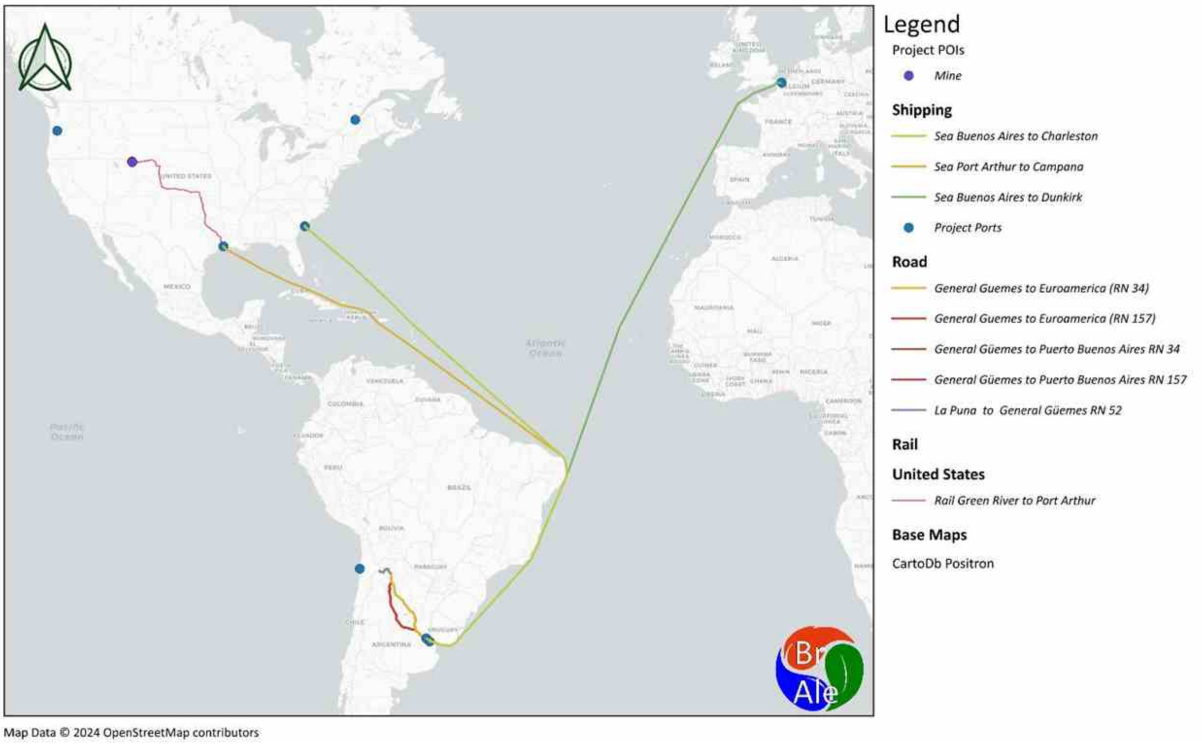


Figure 3 - Map of supply chain routes considered

2.2. Quantification methodologies according to mode

Quantifying the indicators and the associated emission factors itemized in Table 2 below requires the following parameters:

1) Origin & Destination
2) Number of journeys
3) Payload in kg or tonnes per journey
4) Route distance
5) Change in elevation
6) Fuel consumption

The origins and destinations were described and illustrated in section 2.1. Table 1 itemizes the range of methodologies have been used to establish elements 3 through 6. Where possible, complementary methodologies, e.g. energy consumption and GHG emissions from maritime, rail and road, have been checked against each other to ensure agreement within the feasibility study limits (+15%/ -10%). All calculators use values for energy consumption, GHG emissions & emissions to air taken from ISO 14083:2023 to ensure an “apples with apples” comparison.

Table 1 - Calculation methodologies used to calculate route, distance & fuel consumption

Methodology	Maritime	Rail	Road	Comments
EcoTransitWorld Calculator Certified compliant with ISO 14083:2023	Origin-destination routing Distance Fuel consumption Lubricant consumption	Origin-destination routing (US only) Distance Fuel consumption Lubricant consumption	N/A	accredited to be compliant with the Global Logistics Emissions Council (GLEC) framework.
Rail transport fuel consumption calculator Verified ±10% against EcoTransIT Calculator for selected routes	N/A	Origin-destination routing (Chile & Argentina) Distance Fuel consumption Lubricant consumption	N/A	A first principles of energy consumption for freight trains were taken from the American Railway Engineering Association's "Manual for Railway Engineering (Fixed Properties)."
Truck Transport Calculator Demonstrated accuracy of ±2% for freight operator costs	N/A	N/A	Origin-destination routing (Chile & Argentina) Distance Fuel consumption Lubricant consumption Tyres	Developed by BrAle to estimate fleet size, operating costs (in USD) and GHG emissions for Argentine truck operations.

The BrAle Truck Transport Calculator estimates fleet size, operating costs (in USD) and GHG emissions for freight truck operations according to production. Different operational scenarios may be created by varying key parameters including configuration type and route travelled. Argentina, and particularly in La Puna, has a mixed type of roads from paved highways all the way to unsealed and dirt. Each of the road freight transport scenarios identified in §2.1 were illustrated in the calculator. Road length and road type were sourced from Vialidad Nacional

Chile ("Red Vial Chile 2021," n.d.) and Vialidad Nacional Argentine (Vialidad Nacional Argentina 2022). Fuel consumption and tyre use for different routes, vehicle configurations, road types and elevation were developed using Scania's Vehicle Optimizer software. (Scania 2022) and, based on our experience, consumption of lubricants was to be 2 litres of lubricant for every 1,000 litres of diesel consumed.

2.3. Inventory boundary

This study applies the boundary of ISO 14083:2023 to the supply chain operations described in section 2.1 Table 2 itemizes references the sources of conversion and emission factors.

Table 2 - Inventory elements, reporting units and emission factors sources

Element	**Reporting unit**	**Description**	**Emission factor source**
Energy from fuel	Gigajoules (GJ)	Energy consumed derived from methodologies in §2.2	Calorific value & GHG emissions ISO 14083:2023
Energy from Lubricants	GJ	Volume of lubricants derived from methodology in §2.2	Calorific value & GHG emissions ISO 14083:2023
Tank to Wheel (TTW) GHG Emissions	Metric tonnes Carbon Dioxide equivalent (tCO_2e)	Scope 1 from fuels & lubricants	ISO 14083:2023
Well to Tank (WTT) GHG Emissions	tCO_2e	Scope 3 from fuels & lubricants	ISO 14083:2023
Nitrogen oxides (NOx)	kilograms (kg)	Associated with combustion of fuels & lubricants. Dependent on motor design regulation	EcoTransIT calculator
Sulphur Oxides (SOx)	kg	Associated with combustion of fuels. Dependent of fuel quality	EcoTransIT calculator
Non-Methane Hydrocarbons (NMHC)	kg	element of Volatile Organic Compounds (VOCs)	EcoTransIT calculator
Particulate matter (PM)	kg	specifically, those less than 10 microns (PM10)	EcoTransIT calculator

2.4. Transport Chain Element Routes

ISO 14083:2023 requires the breaking of each Option into Transport Chain Elements (TCE). A TCE is defined as "*the freight…is carried by a single vehicle…or transits through a single hub*" (International Organization for Standardization 2023, 1)

A route for each Origin-Destination pair was developed as follows:

- Maritime routes using the routing algorithm from the EcoTransIT calculator
- US rail routes from using the routing algorithm from the EcoTransIT calculator
- Argentina road routes taken from BrAle Truck Transport Cost Model

2.5. Issues with EcoTransIT calculator routing algorithm

The EcoTransIT calculator routing algorithm would not allow the creation of Transport Chain Elements (TCEs) reflective of the supply chain's stated operations in certain circumstances. As a result: all TCEs were developed on an origin to destination basis with no estimates developed for energy and GHG emissions associated with hub activities.

ISO 14083:2023 requires the quantification associated with hub activities. In the selected supply chain's case this would refer to material handling of bulk reagents and product at each of the relevant ports.

The EcoTransIT calculator does offer the facility to create TCEs with multiple waypoints and intermodal changes, which will allow the calculator to estimate the energy consumption and emissions associated with intermodal changes. However, this facility is dependent on EcoTransIT calculator's routing algorithm to permit the creation of TCEs that reflect the supply chain's stated operations.

Figure 4 illustrates the TCE provided by the EcoTransIT calculator when creating the TCE Green River Valley to Port Arthur to Campana for Sodium Carbonate. EcoTransIT calculator does not permit sailing from Port Arthur to Campana, rather forcing the sail from Galveston and adding a 180 km road journey by truck and 2 additional modal changes.

Analysis of the output of the calculator of the material handling element of this TCEs suggests that the energy consumption and associated GHG emissions are less than 0.1% of the TCE's total. Given that hub activities account for so little of the TCEs energy and GHG emissions, the authors concluded they were not material (>5% of total TCE emissions) and excluded hub activities from the analysis.

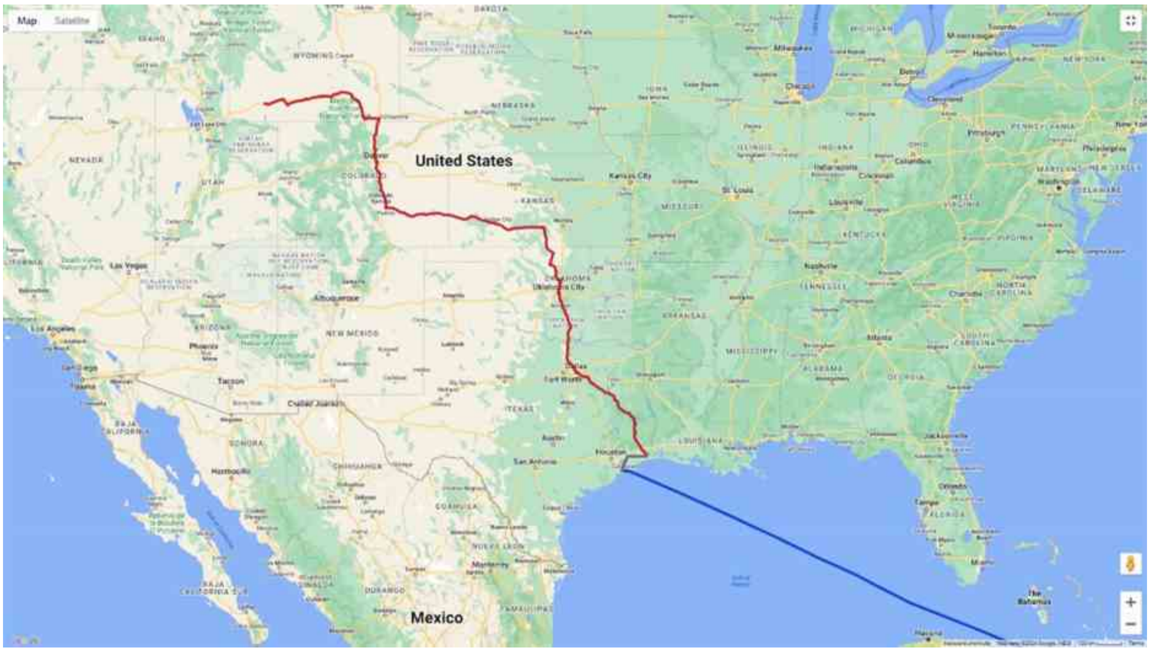


Figure 4 – Screenshot of route provided by EcoTransIT calculator for the Green River Valley to Port Arthur to Campana TCE

3. Results comparing three types of truck & semi configurations

Three types of truck and semitrailer configurations options were tested to provide the differences in the total Well to Wheel (WTW) GHG emissions:

- Option 1. Using "standard" 5 axle trucks-trailer of configuration with a Gross Vehicle Weight of 45 tonnes and 25 tonnes of payload.
- Option 2. Using trucks of "scalable" 6 axle configuration with a Gross Vehicle Weight of 52 tonnes and 32 tonnes of payload.
- Option 3. Use of B-Doubles 9 axle configuration, with a GVW of 75 tonnes and a payload capability of 52 tonnes

Truck motors were all consider to be EURO V and all configurations were consider to have equivalent safety technologies such as retarders and electronic stability controls. As a result, the only contributary variable was the mass of freight transported and its associated impact on the number of trips necessary to complete the freight task.

Table 3 Well-to-Wheel GHG emissions by Configuration option

	Standard 45tn	Scalable 52tn	B-double 75tn
Rail	7,680	7,680	7,680
Road	22,871	17,804	13,942
Ship	15,424	15,424	15,424
Total Well to Wheel GHG emissions	45,975	40,908	37,045
Total Well to Wheel GHG difference	Baseline	11%	19%
Total road mode difference	Baseline	22%	39%

Use of 75 tn B-Double reduces road transport emissions by almost 39% in comparison to the standard configuration, which is what would be anticipated given the likely fuel performance of each configuration. For the analyzed supply chain, this translates to a 19% reduction in GHG emissions for the freight transport across the whole supply chain. The scalable configuration, available in Argentina since 2018, which allows between 10 to 25% more weight per truck, captures most of the fuel reductions, however with a significant road infrastructure cost.

3.1. Quantifying Carbon Border Adjustment impact on costs

Lithium Carbonate is likely to be subject to Carbon Border Adjustments from the European Union and the United States. The potential impact was quantified assuming that any penalties would be applied to the entirety of the emissions associated with the inventory, accounting for TCEs to the respective jurisdictions. This estimate represents a worst-case scenario with actual penalties likely to be reduced by factors not considered in this study. For example, Argentina's carbon Tax on transport fuels or the GHG emissions product benchmark chosen by CBA operators.

Figure 5 illustrates how CBA costs may evolve assuming supply chain operations using standard configurations, Option 1. Additional charges of approximately USUS$ 3.8 million could be anticipated from 2026, rising to in excess of USUS$ 5.4 million by 2030.

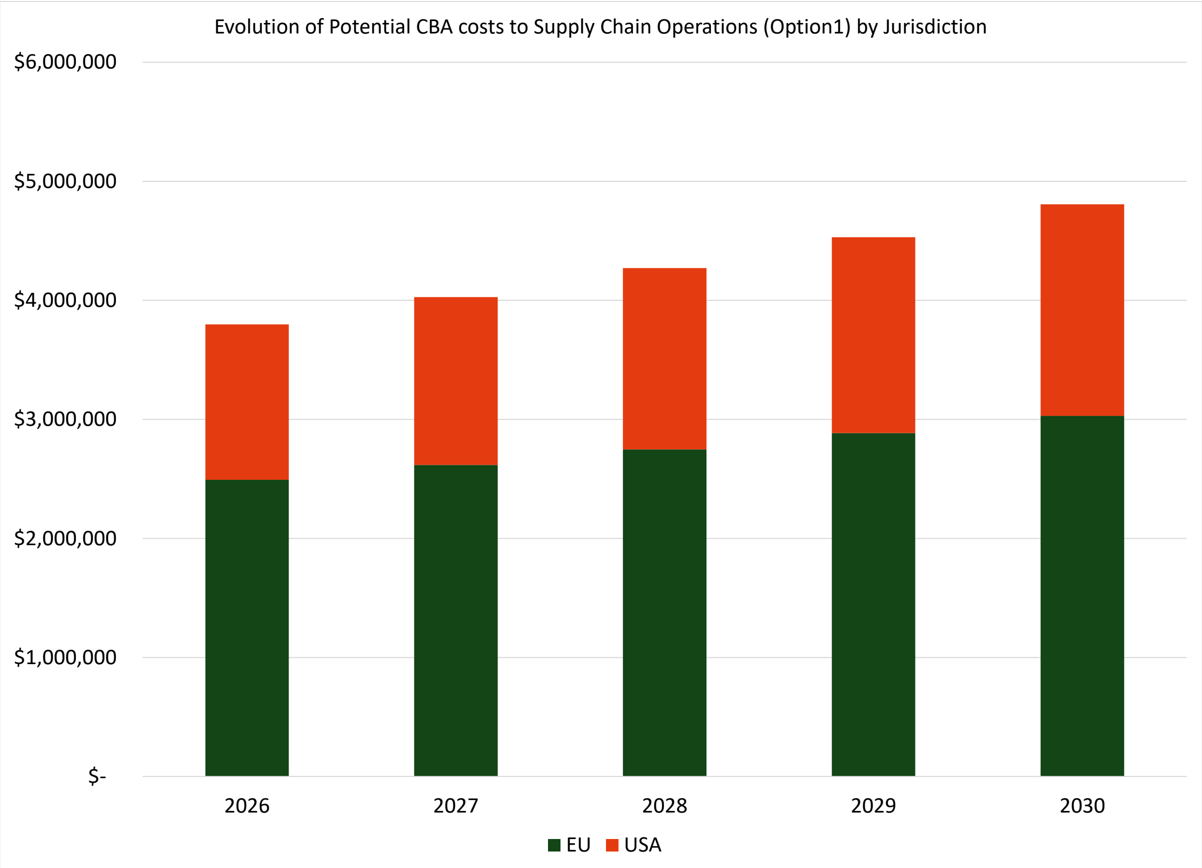


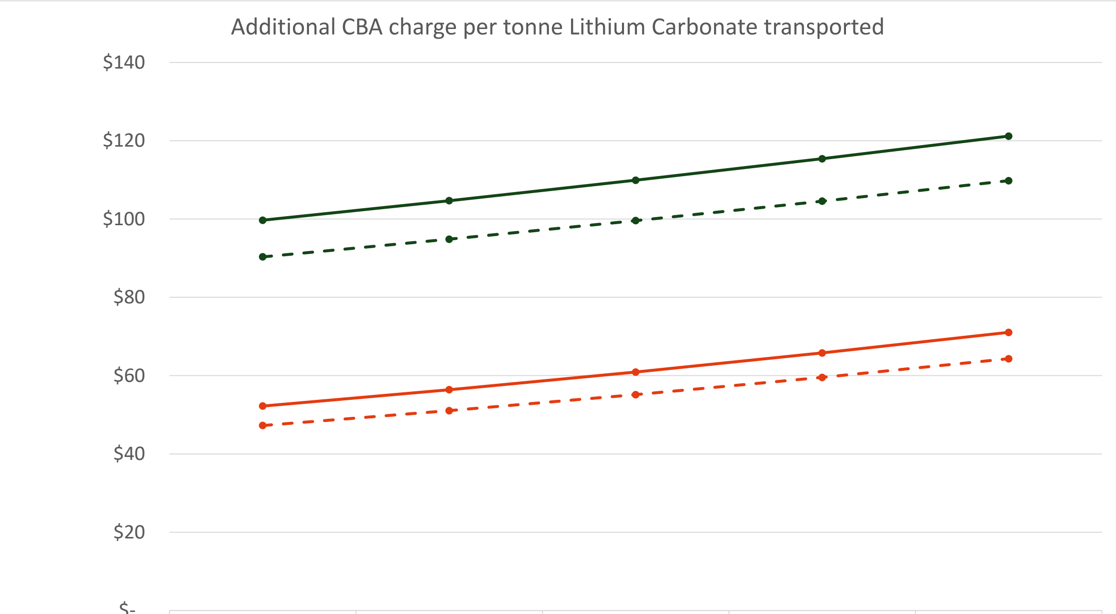
Figure 5 - Anticipated financial impact of supply chain transport costs

Transposing this into cost per tonne of Lithium Carbonate transported provide a more useful metric of the impact of CBA on the supply chain's operations. Figure 6 illustrates that a United

States CBA will add approximately US$52 to the cost of a tonne of Lithium Carbonate in 2026 rising to US$71 per tonne in 2030. The EU CBAM is likely to add US$100 to the cost of a tonne of Lithium Carbonate in 2026 rising to US$121 in 2030.

Given that Lithium Carbonate was trading at US$11,000 in September 2024 (Nasdaq 2024), this translates to between 0.4% and 1.1% of Lithium Carbonate's trading value, it is unlikely to represent a significant barrier to this commodity's international trade.

Road transport configuration selection does have a financial impact on the supply chain operation. In addition to fuel cost savings the use of B-Doubles would avoid US$0.5 million in EU CBAM charges and US$0.3 million in charges from a United States CBA.



	2026	2027	2028	2029	2030
EU Option 1	$100	$105	$110	$115	$121
US Option 1	$52	$56	$61	$66	$71
EU Option 2	$90	$95	$100	$105	$110
US Option 2	$47	$51	$55	$60	$64

Figure 6 - Anticipated evolution of cost per tonne Lithium Carbonate transported

While these value appear small for an individual supply chain, Argentina's export of Lithium Carbonate are anticipated to increase to 435,000 tonnes by 2030. (Espina 2023) Total annual CBA charges in this scenario, using standard truck-semi configurations, could translate to US$87 million. Avoided charges using B-Doubles would translate to US$ 4.35 million annually.

4. Conclusion

Since the GHG implications of supply chain design choices will increasingly have a financial impact, emphasizing the WTW concepts within a supply chain could provide an additional approach of explaining proven and well-known advantages of more productive vehicle configurations. Carbon Border Adjustments are expected to feature as part of the various financial instruments used to encourage decarbonization of international supply chains.

ISO 14083 is likely to be the basis of tools used to quantify the GHG emissions of supply chain operations going forward. The Lithium Carbonate supply chain analysed illustrated how deciding on the configuration selection, such as the use of 75tn B-Doubles can impact the GHG emissions of supply chain operations.

While the financial impact on an individual supply chain may be relatively small, it can translate into significant costs depending on the commodity context. For example, commodities with lower trading value would be more impacted by the CBA and mode and configuration selection would become more financially meaningful.

Decarbonization will not result for a single technological or systemic change, rather many decisions made at the margins of systems design and operations. CBAs and ISO 14083 represent an important additional driver in the efforts to reduce GHG emissions.

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