Supply Chain Network Optimization
for Global Distribution of Cementitious Materials

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ABSTRACT

Companies trading cementitious materials face an increasingly volatile economic environment and continuous challenges to ensure the availability of strategic raw materials. In this context, the ability to globally source slag represents a competitive advantage for cement companies because of the limited availability of the material, its importance in the cement production process, and the complex network of supply and demand nodes. In this project, we introduce an optimization model to support managerial decision-making in the global distribution of cementitious materials for a multinational company. We develop a Mixed Integer Linear Program (MILP) to find quantitative solutions that maximize total contribution margin. In addition, we use scenario-planning techniques to assess the sensitivity of our results with regard to multiple potential futures, to account for changes in relevant demand, supply, and costs in a dynamic economic environment. The results show opportunities to increase contribution margin by 11% through an optimized allocation of existing volumes in the current network. We suggest further improvements to the contribution margin by introducing new trading routes as well as different pricing strategies for customers. Additionally, the model shows how prices and transport costs are the main determining factors for the company's profitability; increasing transportation costs by 20% results in a 51% reduction in contribution margin. Ultimately, we develop a model that is relevant to a number of different network optimization problems, and adaptable to different economic conditions.

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Hans Josef Sebastian Abt

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Germán Daniel Tisera

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1. INTRODUCTION

1.1. Introduction to the project and motivation

The cement industry is the backbone of any economy. No major infrastructure would be possible without this unique product: it is vital for manufacturing, transportation and any other kind of infrastructure that counts on long lasting physical support such as production facilities, roads or housing.

Many authors have often mentioned the importance of supply chain decisions in the cementitious material industry (Noche & Elhasia, 2013; Ligthart & Ligthart-van Elkeren, 2014; Kibria, 2015). As a capital-intensive industry (e.g. slag, cement, fly ash, etc.), the location of production facilities is a key element in the strategy of a company (Cembureau, 2017). Cement plants are normally located close to its raw material source (i.e. quarries) and with good logistic access to the markets they will serve (Agudelo, 2009; World Cement, 2007)

Hence, global cement companies rely on a well-established supply chain network enabling them to have the required raw materials, at the right time, with the right quality, and at the lowest cost possible. Sourcing strategy plays a significant role in cement companies, as they negotiate main raw materials in the global market. Therefore, they rely on trading companies to support them with import/export operations in order to secure the best sourcing alternative.

This global reach makes it necessary to have a very efficient and resilient supply chain to mitigate economic and geopolitical risks, to profit from economic growth, to facilitate cost reductions, and thus to support profit maximization. Nonetheless, supply chain management has mainly played an operational role in the past and has not developed its full potential for cost reduction, value creation and improvement of resilience (Agudelo, 2009).

In this context, slag represents both an opportunity and a threat for cement companies. An opportunity because more stringent environmental regulations are currently affecting clinker production (in particular, those related to CO_2 emissions). Therefore, slag appears as the best alternative to reduce clinker utilization in cement production, while maintaining quality standards. On the other hand, it is a threat as increasing demand and lower levels of production of steel world-wide have pushed prices up and have contributed to increase competition in the market to secure long term provision.

Competition for slag will increase in the coming years (Murray, 2015), so the priority for cement companies is to secure positions with long-term contracts to ensure supply as well as maritime transport from the sources to end markets. Considering this, most cement companies have taken the strategic decision to expand their presence in the slag market[1], increasing volumes negotiated, not only for internal consumption but also for third party sales.

[1] Sustainability reports for all major cement players disclose the environmental objective of increasing the use of slag for clinker substitution.

In this context, the sponsor company of our project (Trading Ltd[2]) deals only with seaborne import and export operations of cementitious materials and other dry bulk goods, through a diverse network of bulk vessels. Currently, the company optimizes its slag supply chain network without considering a comprehensive view of the value of the product for the customer or relevant transportation costs involved in the transaction. Although there is normally a positive margin on each transaction, the expectation is that the company can obtain higher margins from the market if they optimize the network, having a holistic view of a particular year, instead of focusing on single shipments. In addition, as the strategy of the company is to increase participation in the slag market, there is a strong incentive to define a structured methodology to evaluate and optimize the network on a periodic basis.

Inefficiencies in the allocation of slag have a significant economic impact for the company. On average, the company trades 6 million tons of slag per year with a price of 26 USD/ton, and a gross margin of 11%. An increase in the efficiency of the allocation of volumes, creating for example an additional 1% of margin, may create value for the company estimated at 1.5 million USD per year.

In this research project, we introduce an optimization model to support management decision-making in the global distribution of slag for a multinational company. We develop a Mixed Integer Linear Program (MILP) to find quantitative solutions that maximize total contribution margin. As relevant demand, supply and costs are subject to fluctuating environments, we use scenario planning techniques to assess the sensitivity of our results with regard to multiple potential futures. The model is applicable to a number of different network optimization problems affecting other major trading companies. It can also be adapted to other bulk commodities ranging from coal, corn, and sand to liquid bulk products such as crude oil. Hence, it can help to facilitate more efficient and more resilient maritime transport networks for bulk products, exemplified by the case of slag in the cement industry.

1.2. Industry context

Cementitious materials include a wide range of substances with specific chemical properties, generally used for construction. Such properties (i.e. cement properties) refer to materials that set, harden and adhere to other materials, binding them together. In this category of materials, we include clinker, cement, blast furnace slag (BFS), steel slag, fly ash, limestone fines, silica fume, among others.

Bulk cementitious materials fall in the category of functional products (Agudelo, 2009) and as such, functional products should have an efficient supply chain to ensure product availability and cost optimization. Nevertheless, as the focus in the industry is often full utilization of the production capacity (to deliver economies of scale), and as cement companies normally operate in oligopolistic markets, players have relatively low pressure to optimize costs, compared with other industries (Agudelo, 2009). Within the category of cementitious materials, blast furnace

[2] The company name has been withheld to protect confidentiality.

slag (BFS) is the product that has gained most relevance in the past years, in the cement and concrete industries, not only because of its technological advantages, but also from an economic, an ecological and a sustainable development point of view (Nkinamubanzi, et al, 1999).

Slag production is a large-scale, capital and energy-intensive process. Production process involves quenching molten iron slag (a byproduct of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product (Gencer, 2016).

As presented in figure 1, the production process follows three main phases, providing the following sub-products (Gencer, 2016):

- Blast Furnace Slag (BFS): A byproduct obtained during production of iron, composed of lime, silicon dioxide and aluminum oxide, which is very similar to the composition of cement.
- Granulated Blast Furnace Slag (GBFS): Quenched BFS, by high pressure water jets, results in a granulated product (glass like crystals of size less than 5mm) called GBFS.
- Ground Granulated Blast Furnace Slag (GGBFS): The GBFS is then ground in a rotating mill comprised of chromium-steel balls which reduces it to fine powder with surface area greater than 400 sqm/kg (finer than cement, which is around 300 sqm/kg) transforming it into GGBFS.

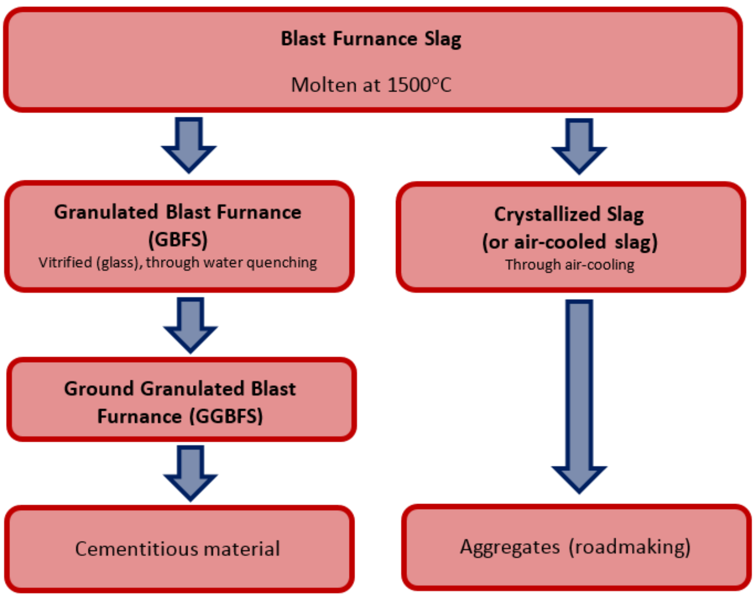

Figure 1: Different types of slag. Adapted from Gencer (2016).

1.3. Slag supply

As mentioned in the previous section, Blast Furnace Slag (BFS) is a byproduct of the iron manufacturing industry. To estimate its production and to understand the supply chain of BFS and GBFS, we should first start by looking at the production of Blast Furnace Iron (BFI). Figure 2 shows the production of Blast Furnace Iron distributed by region.

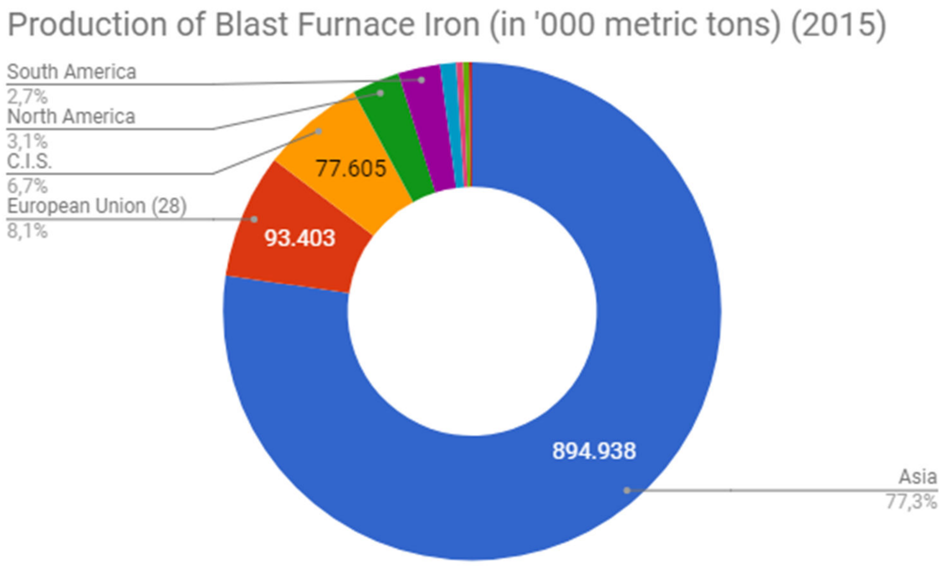

Figure 2: Production of Blast Furnace Iron (2015). Adapted from World Steel Association (2016)

Only 38 countries have a stable production of BFI, the top five being China, Japan, India, Russia and South Korea. Production is highly concentrated in a few countries: the top ten producers account for 96% of the BFI production. In only one country (China) is accumulated 60% of the production of BFI (World Steel Association, 2016).

To estimate production of Blast Furnace Slag (BFS), we have to consider a conversion factor of 30%, meaning that for each ton of BFI, 0.3 tons of BFS are produced. Following the production process, 75% of the production of BFS turns into Granulated Blast Furnace Slag (GBFS), which is the final product (World Steel Association, 2016).

Figure 3 shows an example of the production of BFI, BFS and GBFS.

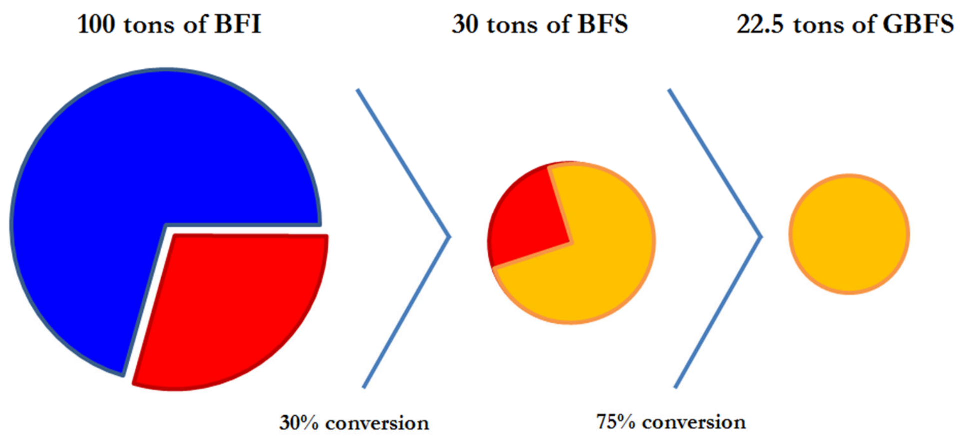

Figure 3: Conversion from BFI to GBFS. Adapted from Intercem Report (2015)

Following the same pattern as BFI, the main producers of BFS are in Asia: China, Japan and South Korea being the main suppliers, with 359.4 million tons, representing 80% of world production in 2015 (Murray, 2016).

Estimations for 2020 and 2025 do not foresee an increase in the production of BFS due to several reasons. First, as a result of overcapacity in global steel production, there was a slowdown in BFI production in 2016. Second, as countries develop, companies tend to build fewer blast furnaces. Considering this, current capacity of BFS/GBFS will not grow significantly. Taking these considerations into account, we estimate the current potential market supply of BFS as 447 million tons, of which almost 295–300 million tons consist of GBFS (Murray, 2015). Detailed information on production volumes and projections for BFS and GBFS are available in Appendices A and B.

Another key aspect of the market is the existence of a limited number of reliable suppliers in terms of production and quality. As we will see in the following sections, the different degrees of quality of GBFS are a source of differentiation in terms of pricing strategy. In this context, the challenge for trading companies is to ensure supply of slag from the most reliable suppliers and distribute the material to customers considering quality as a price driver.

1.4. International slag trade

As mentioned in the previous section, the maximum of GBFS output possible, at current levels of BFS production, could amount to 300 million tons: international trade of GBFS/GGBFS accounted for 11% of total production (32 million tons) in 2016 (Intercem, 2016).

Worldwide seaborne trade reached 11 billion metric tons in 2016: participation of minor bulk represented 1.5 billion metric tons, as presented in Figure 4. GBFS/GGBFS shipments represented 2.1% of minor bulk shipments, as presented in Figure 5.

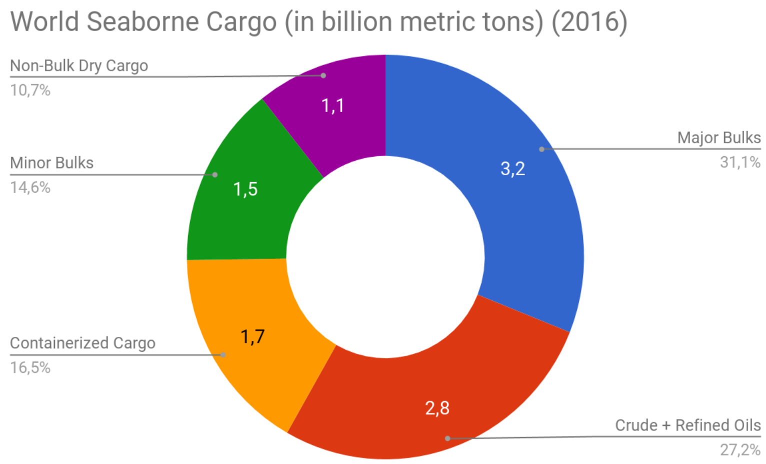

Figure 4: World Seaborne Cargo (2016). Adapted from Intercem (2016).

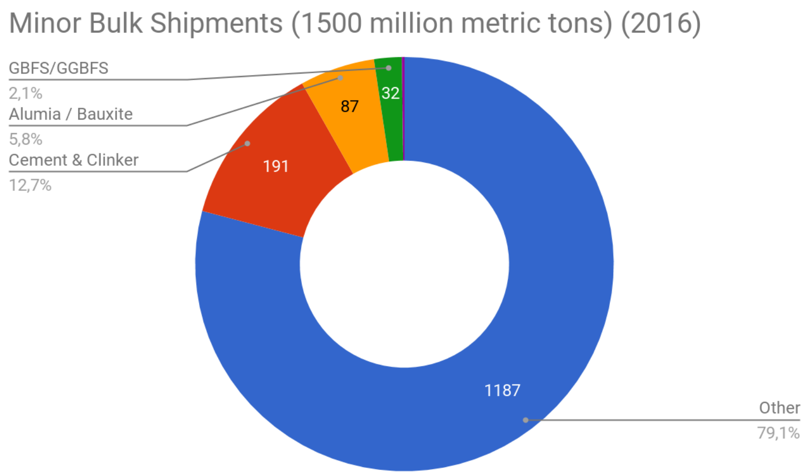

Figure 5: Minor Bulk Shipments (2016). Adapted from Intercem (2016).

Slag, as a bulk material is costly to transport over land. However, it is economically feasible to ship slag by sea and inland waterways over great distances. Distribution costs usually represent approximately 20% to 40% of net sales[3]. The proportion becomes even more relevant if we add to the equation inbound and internal logistics costs. Hence, the low value-to-weight ratio of most steel slags limits the tonnage that enters international trade. For commercial reasons, companies only ship the highest value slag (GBFS) in large vessels for long distances.

Cement companies drive the demand of GBFS. The market expects that cement companies will be under pressure to reduce both their energy consumption and their demand for newly

[3] Information extracted from management reports from the sponsor of the project.

quarried limestone and aggregate. Hence, they will increase the demand for GBFS. In this line, international cement producers have begun to set up coastal grinding installations, aiming to receive water-borne supplies of GBFS from nearby and from more distant steelworks (Murray, 2015). Considering the scenario of increasing demand, there is a high probability that demand will outrun supply over the medium-term.

1.5. Introduction to the company

The sponsor company (Trading Ltd) is an integral part of a building materials corporation (Group), providing solutions for the seaborne import and export needs of its global customers in the cement and construction industries. The company provides an excellent case study in terms of volume of exports, complexity of the network and global footprint.

Trading Ltd deals only with seaborne import and export operations of cementitious materials, gypsum, solid fuels and other dry bulk goods, through a diverse network of bulk vessels and specialized self-discharging pneumatic cement vessels.

Trading Ltd is the exclusive seaborne trading partner for Group companies, and their core strategy is to:

- Optimize seaborne trading flows, capturing value from supply and demand imbalances
- Ensure access to strategic resources
- Increase resilience and capability to deal with extreme situations

The company has presence in 120 countries, and handled 30 million tons of cement, clinker, slag, gypsum, solid fuels and other bulk materials during 2016[4]. Additionally, they make an average of 2,200 shipments per year. Following the global footprint of slag suppliers, Trading Ltd's main sources of slag are in Asia, whit the most relevant ones in Japan, China and South Korea. Europe is also a significant player for them.

Trading Ltd's slag supply chain network involves approximately 47 sources, where vessels with capacity ranging from 5,000 to 65,000 tons load and then distribute the material to a network of around 64 customers located in Americas, Europe, Asia, Africa and Middle East. In Figure 6, the map shows a summarized view of the supply and destination nodes for slag (per country) in the company's network.

[4] Information extracted from management reports from the sponsor company.

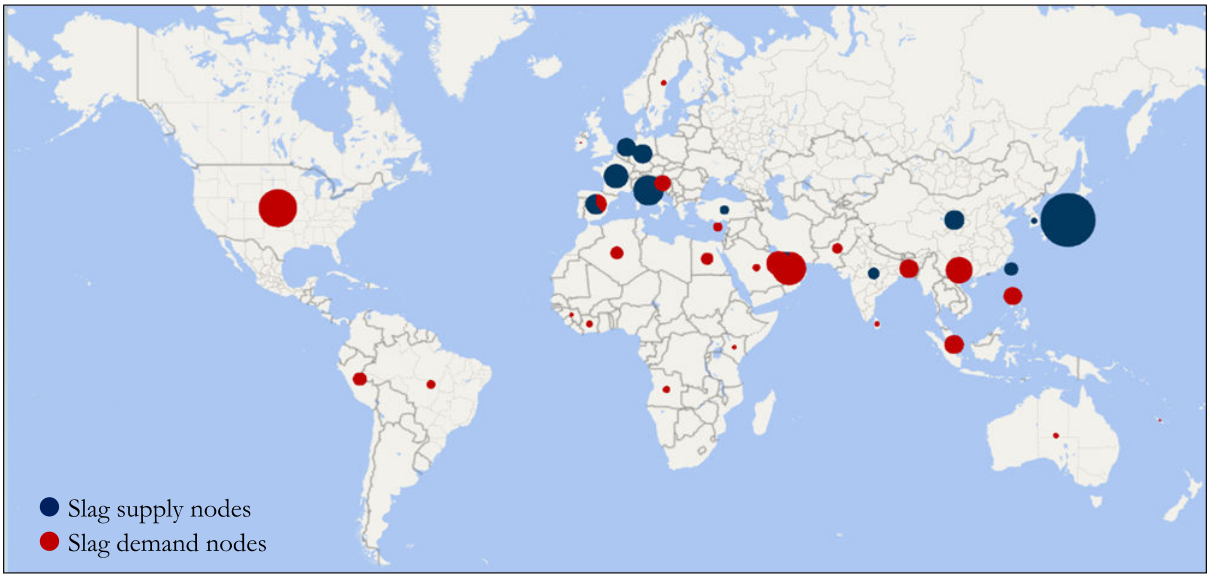

Figure 6: Trading Ltd slag network (2015-2016). Adapted from information provided by the sponsor company.

In Figure 7, the map shows Trading Ltd international slag flows. The impact of transport costs limits the distance of trading routes. For instance, material coming from Japan flows up to destinations on the east coast of Africa and the west coast of America. It is not profitable for the company to distribute the material to Europe or to the east coast of America. In the same line, slag coming from Europe normally flows to the east coast of America and west coast of Africa.

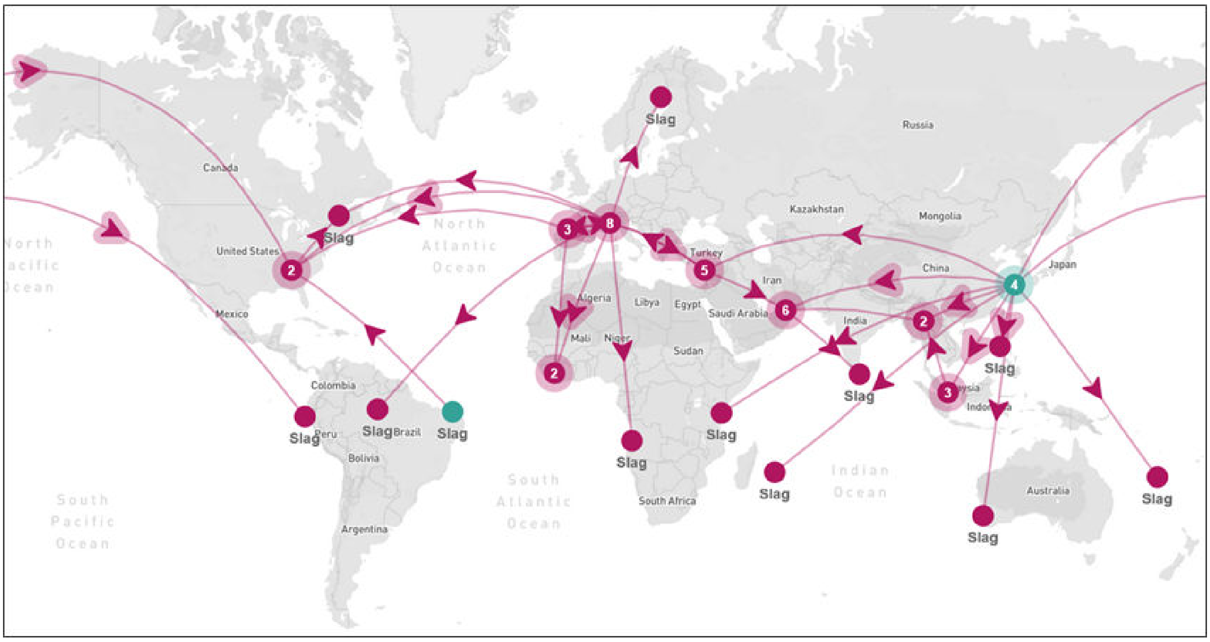

Figure 7: Trading Ltd flows of slag (2015). Adapted from information provided by the sponsor company.

One of the main topics to consider, while trading slag and hence defining different routes, is the quality of the material required by the customer, which essentially depends on the final use of the product. As an example, when companies use slag as filler material, there are no major quality requirements, and customers are not willing to pay a premium for additional quality. On the other hand, when customers use slag for special applications, companies demand high quality products. In this case, customers are willing to pay a premium to get slag with higher CaO content, fineness or reaction index, in order to achieve a better performance and higher efficiency.

Hence, the challenge is to efficiently allocate volumes to customers to maximize total contribution margin. Therefore, an optimization model for a slag network should allocate high quality slag to those customers willing to pay a premium for it, while at the same time, using slag from the less expensive source to reduce total cost of ownership.

1.6. Problem statement

The optimization of the current supply chain network is crucial for creating a competitive advantage and for supporting the strategy of the company. With slag supply not expected to grow significantly in the next years (Murray, 2015), and with an increasing trend in demand, the company needs to reevaluate its network design, looking for optimization strategies in the sourcing and distribution of the material across different regions.

Therefore, the purpose of this project is to assess the opportunities to improve the current supply chain network by delivering higher margins, cost efficiencies and creating additional value to customers.

This project includes five sections. In this section we discussed the motivation for the project, an overview of the industry under analysis and the problem statement. Section 2 provides a literature review related to network optimization models and specific network strategies for cementitious material industries. In section 3, we present our methodology, including our approach and the description of the model we use to address the problem. In section 4, we explain the results of our model comparing each scenario with actual results, followed by a discussion on managerial implications. We conclude our research in section 5, with conclusions and recommendations to improve current performance of the sponsor company.

2. LITERATURE REVIEW

In order to address the research problem, we conducted a literature review focusing our attention on optimization methods for supply chain networks. Initially, we present literature concerning general network optimization. Then, we continue our review of academic literature on network design for the cementitious materials industry.

2.1. General supply chain network optimization

Network design has a strategic dimension, when companies make decisions concerning facility locations and capacities (Vidal & Goetschalckx, 1996). These decisions have a long-term impact, as it is very costly to build, operate, move or even shut down facilities (Hugos, 2003). Hence, strategic decisions should be taken wisely and should be closely linked to the company's general competitive strategy by taking into account not only transport related metrics, such as distance to end customers, but also macroeconomic factors, such as taxes, tariffs and exchange rates (Chopra & Meindl, 2007).

In addition to defining the network design with its facility locations and capacities, supply chain network optimization has an operational dimension when focusing on the ideal flows between existing suppliers, facilities and customers (Brandimarte & Zotteri, 2007). Supply chain network optimization is a typical example of a prescriptive model, where there is a quantitative approach to find a mathematical optimum based on given parameters, constraints and functions (Shapiro, 2004). These prescriptive models indicate the ideal solution to a given mathematical, and often simplified, approximation of the reality. Hence, it is important to stress the fact that prescriptive models are only decision support tools and that users should not follow them blindly (Brandimarte & Zotteri, 2007).

Supply chains normally include a single or a multitude of different transportation modes ranging from maritime or fluvial transportation to rail, truck, or air transport (Bidgoli, 2010). Furthermore, there are goods which are predominantly transported via pipelines or others even electronically, such as crude oil or, respectively, specific multimedia contents (Hugos, 2003; Taylor, 2009). The value of the products transported, often defines the choice of the transportation mode. There is a link between high value products and responsive modes, such as air services. On the other hand, companies normally use efficient modes, such as maritime transportation, for inexpensive products (Shukla & Sharma, 2015).

Once companies have defined the facility locations, supply chain optimization concentrates its efforts on finding the most cost-efficient way to satisfy the quantity demands at a specific location with product from the different supply nodes by identifying the optimal transportation links between these locations (arcs) (Salvendy, 2001). Chopra and Meindl (2007) define the purpose of network optimization as the maximization of the overall profitability of the supply chain, and respectively the whole company, guaranteeing the required responsiveness towards customers' needs. In addition, it is important to focus on profitability after tariffs and taxes while optimizing supply chain networks, as these elements can have a very decisive impact on overall financial results and modify the optimization result (Vidal & Goetschalckx, 1996).

Companies should perform these tactical/operational optimizations at least once a year taking into account the variability of demand, prices, tariffs and exchange rates (Chopra & Meindl, 2007; Brandimarte & Zotteri, 2007).

Brandimarte and Zotteri (2007) approach classical network optimizations through mixed-integer linear programming (MILP) models. As in any quantitative model, there is an objective function with the purpose of minimizing total relevant cost of the supply chain or to maximize the profit (Ahuja et al., 1993). This objective function includes parameters, such as fix or variable costs. Furthermore, constraints define the limiting factors or the imperatives of such model (Shapiro, 2009). For example, capacities are limiting factors, while demanded quantity represents an imperative (Chopra & Meindl, 2007; Brandimarte & Zotteri, 2007).

In network optimizations, there are source nodes (S) and destination nodes (D). Each of them has either capacities (source nodes) or demanded quantities (destination nodes). The model should provide a solution that satisfies capacity and demand constraints (Ahuja et al., 1993). The arcs linking the nodes are the paths where the model theoretically transports the products. Each of these sources and arcs has fixed and/or variable costs. Some network optimization models allow as well to decide if a supply node should be open or closed. Then, fixed and variable cost will play a determining role to decide whether the respective node should be open or not. The exact number of supply nodes can be defined as a constraint, allowing certain flexibility in the number of supply nodes or forcing the model to choose a distinctive number of sources (Chopra & Meindl, 2007).

Last, optimization models are helpful to test network resilience by using simulations. For instance, we can incorporate probability into the model (e.g. probability of demand, risk, etc.) and evaluate different scenarios (Chen, Mockus, Orcun, Reklatis, 2012).

2.2. Network design for the cementitious material industry

Slag is a byproduct of the iron industry and the cement industry is the main consumer. Both iron and cement are capital-intensive industries. Cembureau (2017) states that the cost of cement plants per million ton of yearly capacity is often above 150 million euros. Furthermore, the cost of a new plant represents often three years of turnover. Hence, facility location is a very important, strategic decision. Additionally, once a plant is operational, asset utilization is a main concern; cement companies aim for continuous utilization of their kilns, as production stops have a large negative impact on costs (Noche & Elhasia, 2013).

After defining the locations and capacities, companies need to define the most efficient way of transporting the required raw materials to production facilities and then distribute final products to the markets they serve. In order to do so, companies need to select the appropriate transportation mode.

Due to the inexpensive nature of cementitious materials, ship and train are the most common transportation mode (Ligthart & Ligthart-van Elkeren, 2014). On the other hand, there is a limitation outside a radius of 200 to 300 km (depending on the country), where it might be economically infeasible to transport cementitious materials by truck (Cembureau, 2017). Hence, global trade is limited to maritime / fluvial transportation or an intermodal approach combining it with truck or train.

Using the most cost-efficient transportation mode is important since cementitious materials are very homogenous and standardized products, not allowing for much differentiation between producers and hence the producers are functionally interchangeable. In this context, pricing becomes a major decision parameter for customers and an efficient and cost-effective supply chain network represents a strategic advantage for cement producers and their suppliers (Noche & Elhasia, 2013).

Kibria (2015) exemplifies other reasons for choosing fluvial transport for cementitious products: apart from being the most cost-efficient solution for bulk commodities, it is less prone to accidents than truck transportation in developing economies, such as Bangladesh. Aniki, Mbohwa and Akinlabi (2014) stress as well the susceptibility of truck transportation for delays or impairment due to negative traffic conditions, accidents or technical failures of the trucks in countries where the cement industry rely mainly on truck transportation, such as Nigeria. Hence, maritime and river transport can be associated, especially in developing countries, to reduced loss of goods and time, which has a direct impact on profitability (Kibria, 2015).

Due to the close relationship between the cement industry and the economic situation of a region, as well as the seasonal nature of cement consumption, cement companies need to create supply chains which are flexible enough to react in an adequate time frame in order to have the required resilience and to operate efficiently under new constraints (Noche & Elhasia, 2013; Kibria, 2015).

Hence, network optimizations play a crucial role in the distribution of cementitious materials. Sahu and Victor (2016) choose Vogel's approximation method in order to find the most efficient network design, minimizing transportation cost. Christiansen et al. (2011) approach the transport of cement as a maritime inventory routing problem, based on the heterogeneity of cement, vessel types and inventory levels in different supply/destination ports. They propose a heuristic algorithm, combined with a genetic algorithm, in order to find the best solution.

Although academic literature on maritime routing problems is broad, it does not directly apply to our research. We are not focusing on tactical or operational inventory requirements, draft limitations or scheduling related problematic in maritime transportation. Rather, we concentrate our research on finding strategic network designs generating the highest margins based on transportation, handling and other relevant cost, expenses or savings related to CO_2 emissions and on dynamic pricing schemes associated to different customers.

Even though our goal is not to minimize network costs, as described for example by Simchi-Levi, Chen and Bramel (2005), but to maximize margin, the concept is still the same. Our optimization of slag transportation aims to find the most efficient allocation of product between supply ports and demand ports. Anhuja, Magnanti and Orlin (1993) refers to this problem as a transportation problem, where an algorithm defines the optimal flows between source nodes and destination nodes.

2.3. Supply chain network models

A supply chain network model is a mathematical model, with an objective function and a number of constraints. We solve this model using optimization techniques determining the best flow of products through the network structure to achieve the desired objective.

A main concern for network optimization is how to efficiently transport material from one point to another, given a number of limiting constraints, such as node capacities and costs between nodes. We find the following categories of network optimization problems (Ahuja, R.K., Magnati and Orlin, 1993):

- Shortest path problem: this category addresses the questions as how to get from one point to another in the network using the shortest and cheapest path
- Maximum flow problem: this category answers the questions as how to achieve the highest flow output between nodes in a network given capacity constraints within the network
- Minimum cost flow problem: this category answers the questions as how to assign flows to the links and through the nodes in a network in the most cost-effective way, given a cost per unit of flow in the network

Other specific problem types derived from the general categories listed above include transportation, convex cost flow, multi-commodity flow, minimum spanning tree, assignment and transshipment problems, etc. (Winston, 2004).

3. METHODOLOGY

3.1. Introduction to methodology

We approach the research problem following a 6-step methodology:

- Understand the process
- Collect relevant data
- Define the model
- Validate the model and compare results with baseline
- Conduct scenario planning and sensitivity analysis
- Draw conclusions

In the first step, we gained an understanding of the current network model for the global distribution of slag through semi-structured interviews with relevant stakeholders. We conducted a total of 15 interviews with people ranging from Heads of Trading Region (Americas, EMEA and APAC) to Business Development Managers. The objective at this stage was to understand what are the main performance drivers for the network and how we can deliver an optimization model that maximizes the contribution margin for the company while providing increased value to customers. This initial step allowed us to have a clear picture of which data was relevant for our analysis. In addition, we performed a thorough literature review to address our research problem.

In the second stage, data collection, we gathered relevant data to set the parameters of the model: main sources and destinations of slag, available supply capacity, demand, quality parameters, market prices surveys, relevant costs (FOB prices, freight, insurance) duties and tariffs per source and destination, other logistic costs as well as logistics constraints.

In the following step, we built a model using Mixed Integer Linear Programming (MILP), considering a single time period, to find quantitative results for the flows of the optimized network. Then, we tested the model and compare results with the baseline, to understand the main differences between the current network and the flows resulting from the model.

As relevant demand, supply and costs are subject to changing environments, we used scenario planning techniques to assess the sensitivity of our results with regard to multiple potential futures. For example, in emerging markets, exchange rates, inflation and demand can be highly volatile. The model requires periodic assessment to tailor the supply chain network accordingly.

Last, we formulated conclusions based on the results of the model and the different scenarios, enabling the company to get a better understanding of an optimal network and possible risks in their supply chain.

The main goal is to deliver a model that provides robust results and supports management decision-making while being flexible enough to adapt to dynamic economic environments.

3.2. Description of the model

As mentioned in previous sections, the challenge is to allocate volumes to customers in order to maximize contribution margin. The objective function depends on the following parameters:

- Revenue
- Purchase cost
- Logistic costs
- Import costs

In the following sections, we describe specific inputs for the model regarding these parameters.

3.3. Revenue

Total revenue depends on the following components: volume, price and tax savings from CO_2 emissions. Of these, volume allocated to each route is our decision variable. We expand further the concepts of pricing and tax savings from CO_2 emissions in the following sections.

3.3.1. Pricing strategies

We conducted interviews with managers from the company and learned that each customer has a unique pricing curve, which is a function of the quality of the product and the final use of the slag in the production process. While some customers are willing to pay a premium for high quality slag, others may have an inelastic pricing curve (i.e. same price regardless of the quality of the material).

An important aspect to consider is the structure of the market in which the company sells the material, as the price of the next best alternative (e.g. pozzolane) may have an impact on slag prices. In this case, the concept of value-based pricing is essential to capture a higher margin for the company.

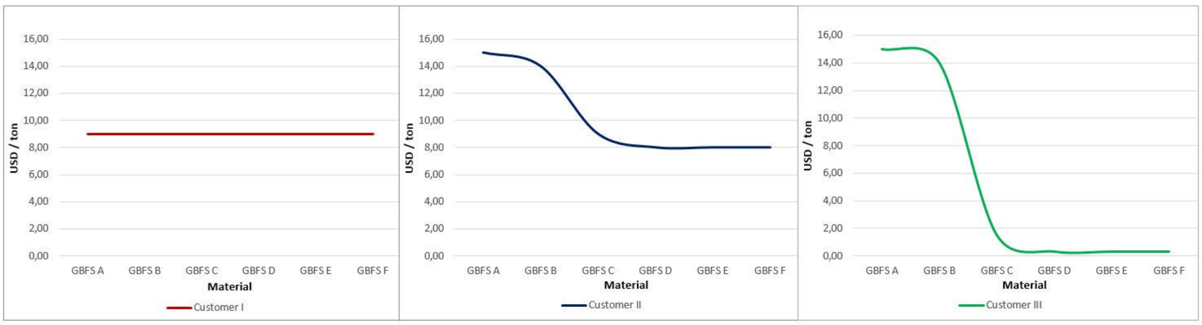

Figure 8: Examples of pricing strategies based on quality of material. Adapted from information provided by the sponsor company

In Figure 8, we present different strategies for different customers based on the concept of value-based pricing. Customer I has no preference regarding quality, so he is willing to pay the same amount for any given quality supplied. Customer II is willing to pay a premium for the material of higher quality (GBFSA and GBFSB), while he would pay the market price for the material with lower quality. Customer III will only purchase the material of the highest quality available, paying a premium for it, while he is not willing to buy material of lower quality at any given price.

This classification is important as it gives our model flexibility to allocate the material based on the best price the market is willing to pay for a specified quality.

3.3.2. Carbon pricing

Environmental sustainability has become a major issue for international companies. The reason for this is manifold, ranging from shareholder interests, reputational risk mitigation to governmental regulations (Bouchery et al., 2017). One method to curb Greenhouse Gas (GHG) emissions is to introduce a carbon pricing scheme. These schemes could either be based on an emissions trading scheme (ETS) or on carbon taxes (OECD, 2018; World Bank, 2018).

Trading Ltd is active in many geographic areas where carbon pricing is effective, but most regions are currently excluding the cement industry from these regulations (European Commission, 2014). However, this exclusion is likely to change in the coming years (The Parliament Magazine, 2017). Hence, it is essential for the company to understand the positive effects of slag on their greenhouse gas emissions, as slag has lower emissions than clinker (Kajaste & Hurme, 2015). Therefore, we decided to build a scenario where we take the highest CO_2 tax/ETS price currently applicable (state 4/1/2017) with border carbon adjustment (BCA) for imports of slag.

Table 1: Overview of CO_2 emissions reduction with BCA. Adapted from Kajaste & Hurme (2015)

Region	Cement: region specific emission (kg CO2e/t cement)	region specific clinker emissions in cement (kg CO2e/t cement)	region specific clinker emissions in cement (%)	region specific slag emissions in cement with BCA (kg CO2e/t cement)	region specific emissions reduction in cement when using slag with BCA (kg CO2e/t cement)	region specific emissions reduction in cement when using slag with BCA (%)
Europe	688	393	57%	255	138	20%
North America***	894	482	54%	296	186	21%
Japan, Australia, NZ	786	446	57%	293	153	20%
CIS	875	440	50%	248	192	22%
Central America*	695	377	54%	242	135	19%
Brazil	652	355	54%	230	125	19%
South America*	695	377	54%	245	132	19%
China	691	365	53%	232	133	19%
India	833	387	46%	254	133	16%
Asia**	761	428	56%	279	149	20%
Africa	829	457	55%	309	148	18%
Middle East	920	502	55%	324	178	19%

Note: Cement specific values (cement emissions and clinker emissions in cement) have following specificities: *based on emissions for the Americas excl. Brazil and USA; **excl. China, India, CIS and JAPAN; *** USA values. National statistics usually excludes electricity emission to avoid double counting.

We chose to base our calculations on BCA, as we expect more stringent environmental rules in the future, where companies need to account for CO_2 emissions generated abroad.

In Table 1, we show the region-specific emission reduction linked to the use of slag in cement. Appendices C and D provide a detailed analysis of the reductions and the pricing strategies with the calculations and the prices used.

3.4. Purchase cost

Purchase cost includes mainly the FOB price charged by the supplier, which depends essentially on the quality of the material. The information about the different qualities has been provided by the sponsor company.

We can classify slag types by slag quality, considering performance and grindability index for Ground Blast Furnace Slag (GBFS). For the case of Ground Granulated Blast Furnace Slag (GGBFS) we use only performance index to determine three different qualities, as the volumes operated is much smaller than GBFS. In Figure 9, we present the classification of GBFS and GGBFS that we use in our model.

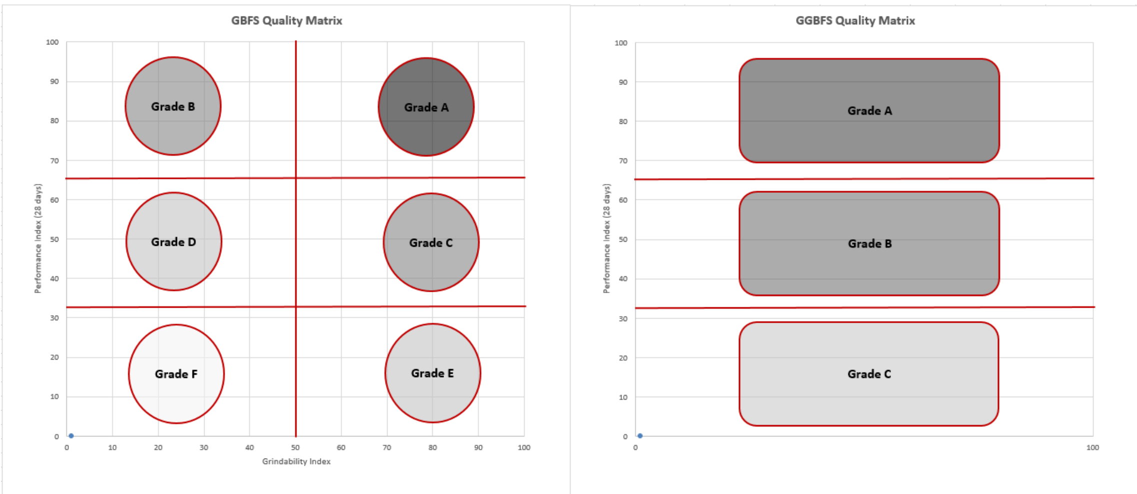

Figure 9: GBFS and GGBFS Quality matrix. Adapted from information provided by the sponsor company.

In Appendix E, there is a detailed analysis of the quality parameters relevant for slag.

The definition of different quality boundaries for slag is important in determining the categories that lead to a price premium, depending on the sensibility of the customer regarding quality requirements. As we can see in figure 10, there is a correlation between different qualities of slag and FOB prices paid to suppliers for GBFS and GGBFS.

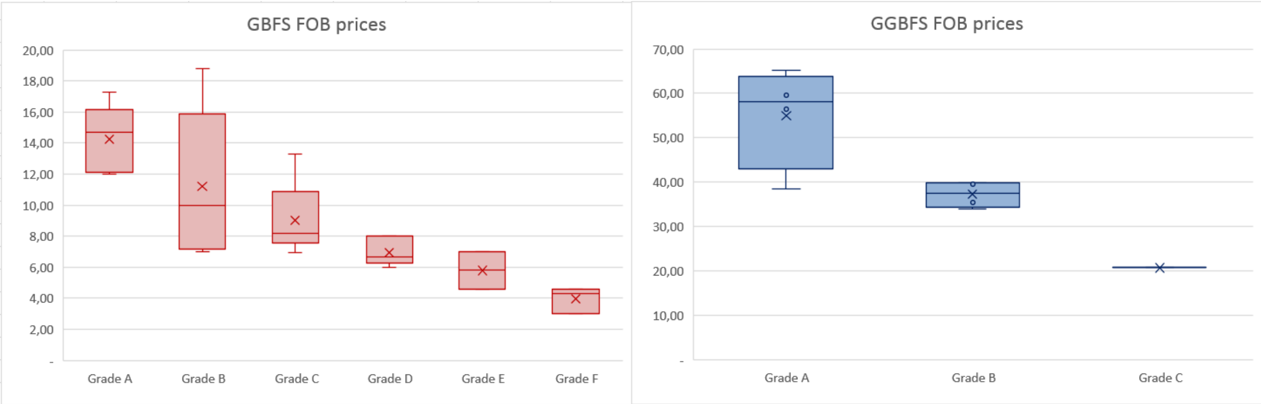

Figure 10: GBFS and GBFS FOB prices dispersion. Adapted from information provided by the sponsor company.

3.5.Logistics costs

3.5.1. Maritime transportation

As mentioned in chapter 2, companies transport cementitious materials using the most efficient transportation mode, which means ocean transportation. In this context, we define the vessel types, their capacities and the related freights.

3.5.2. Vessel types

In maritime transportation, we differentiate vessels based on the cargo they can transport (e.g. container ships, liquid commodities and dry bulk products). Companies normally transport cementitious materials using dry bulk ships. This category of vessel has seven different vessel types, based on the application and the quantity transported (Psaraftis & Kontovas 2009), as shown in Table 2.

Table 2: Vessel types and capacities. Adapted from Psaraftis & Kontovas (2009)

Vessel Type	Capacity (DWT, '000)
Small Vessels	0 - 5
Coastal	5 - 15
Handysize	15 - 35
Handymax	35 - 60
Panamax	60 - 85
Post-Panamax	85 - 120
Capesize	120

In this research, we assign the vessel types for the different routes based on historical data from Trading Ltd using 2016 and 2017 information. The company uses four different types of dry bulk ships for the transportation of slag: small vessels, coastal, handysize and handymax.

3.5.3. Transportation freight

Sea freights depend on many parameters: distance, type of transported good, vessel type and quantity. In addition, there are many less graspable parameters influencing the price of transportation: global economic factors, the direction of trade flows and number of ships available in the market (Jugović, Komadina & Perić Hadžić 2015).

We have received historical data on maritime freights from Trading Ltd, which we use to create the optimization model. Furthermore, we need to use new freight rates in order to analyze additional routes. For this, we received estimations from the sponsor company adjusted to reflect historical market conditions.

3.6. Incoterms and import costs

Trading Ltd performs operations with customers using essentially two incoterms: FOB and CIF. In FOB operations, Trading Ltd bears all costs and risks up to the point the goods are loaded on board the vessel, designated by the buyer in a manner customary at the port. On the other hand, the buyer pays cost of marine freight transportation, bill of lading fees, insurance, unloading and transportation cost from the arrival port to destination (Griffin, 2003).

For CIF customers, Trading Ltd pays for the carriage and insurance of the goods up to the named port of destination. The company performs transactions under FOB incoterm only with third parties, while most of the CIF operations belongs to transactions with companies of the Group.

Although CIF transactions do not consider import costs, we need to include the effect of duties and tariffs in the objective function of our model as they are part of the company's cost structure. The underlying idea is that the model should optimize all the cost involved in the trading activity, regardless of who pays the cost (Trading Ltd or Group companies). By doing this, we prevent the model from allocating volumes to a route where high duties make the transaction unprofitable. We then subtract the effect of duties and tariffs from the contribution margin calculation for Trading Ltd in our analysis.

3.7. Model formulation

3.7.1. General description of a transportation problem

Our model is an example of a transportation problem. The transportation problem is a special case of the minimum cost flow problem (Ahuja, R.K., Magnati and Orlin, 1993).

In general, we specify a transportation problem by the following information (Winston, 2004):

- A set of *m* supply points from which we ship goods (A). Supply point i can supply at most S_i units.
- A set of *n* demand points to which the good is shipped (B). Demand point *j* must receive at least D_j units of the shipped good.
- Each unit produced at supply point *i* and shipped to demand point *j* incurs a variable cost of c_{ij}.

Let

x_{ij} number of units shipped from supply point *i* to demand point *j*.

Then the general formulation of a transportation problem is:

$$minimize \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}\, x_{ij}$$

Subject to,

$$\sum_{j=1}^{n} x_{ij} \leq S_i \quad \forall\, i \in \text{A} \qquad \text{(Supply constraints)}$$

$$\sum_{i=1}^{m} x_{ij} \geq D_j \quad \forall\, j \in \text{B} \qquad \text{(Demand constraints)}$$

$$x_{ij} \geq 0 \quad \forall\, i \in \text{A}, \forall\, j \in \text{B}$$

If a problem has the constraints given above and is a maximization problem, then it is still a transportation problem. If

$$\sum_{i=1}^{m} S_i = \sum_{j=1}^{n} D_j$$

then total supply equals total demand, and the problem is said to be a balanced transportation problem.

We normally solve these transportation problems by using linear programming, as associated costs vary linearly with the amount transported on the different arcs. Each arc has an associated cost (c_{ij}), a maximum capacity (u_{ij}) and a minimum capacity (l_{ij}), and source nodes and destinations with a respective capacity or demand. The decision variable is the quantity transported on the respective arc, denoted as x_{ij} (Anhuja, Magnanti and Orlin 1993).

In order to provide the most realistic solution concerning ideal flows, the model needs to consider the number of shipments required for the transportation of this material, and in particular, the capacity of the transportation mode, as it has a direct impact on the choice of the most appropriate route. Considering this, the model needs to use each transport unit in full (i.e. no partial loads) in order to minimize transportation cost. Therefore, we introduce an integer value for the number of units used for each shipment.

Considering this, let

y_{ij} number of full shipments from supply point *i* to demand point j.

Subject to

U_{ij} the shipment maximum capacity for the route between supply point *i* and demand point j.

β a minimum shipment load factor coefficient.

Then the constraint to dispatch only full shipments is given by

$$x_{ij} \leq y_{ij}\, U_{ij} \qquad \forall\, i \in \text{A}, \forall\, j \in \text{B} \;\; \text{(maximum shipment load)}$$

$$x_{ij} \geq y_{ij}\ \beta\ U_{ij} \qquad \forall\, i \in \text{A}, \forall\, j \in \text{B} \;\; \text{(minimum shipment load)}$$

$$x_{ij} \geq 0$$

$$y_{ij} \in Z^{+}$$

This formulation of the model is essentially a capacity constraint: the model should ship volumes in multiples of the transportation unit capacity, adjusted by a load factor. This makes the formulation of the transportation problem a Mixed Integer Linear Program (MILP).

3.7.2. Formulation of the optimization model

In this section we present the formulation of the transportation model, and the variables and parameters we consider in the solution.

Let

x_{ghij} be the flow of product h from source i to customer j incoterm g (in tons) $\forall$ g,h,i,j and ϵ R

y_{gij} be the number of full shipments from source i to customer j incoterm g (#) $\forall$ g,i,j and ϵ Z^+

We use x_{ghij} as a decision variable to determine the flow of slag going from the sources to the destination.

We also use y_{gij} as an auxiliary variable to ensure that the model allocates only fully loaded ships. It is important to mention that y_{gij} is an integer and is not part of our objective function but serves as a constraint to prevent the model from adopting transportation costs as a variable amount depending on the quantity, i.e. avoiding fractional shipments, which are not possible in reality. With this, we define all relevant costs and prices on a unit basis (cost per ton), but the model will allocate only full ships to the solution, treating all relevant costs as fixed per shipment.

Let the following parameters to set the constraints of the model be,

S_{hi} the maximum available supply of product quality h from source i (tons)
W_{hi} the minimum required supply of product quality h from source i (tons)
D_{gj} the maximum total demand with incoterm g for customer j (tons)
E_{gj} the minimum total demand with incoterm g for customer j (tons)
F_{hj} the maximum specific demand of product quality h for customer j (tons)
G_{hj} the minimum specific demand of product quality h for customer j (tons)
U_{gij} the maximum ship capacity for a defined route for incoterm g between source i and customer j (tons)

The first set of parameters (S, W) define the maximum supply available at the source, and the minimum in case there is a contractual obligation to transport a certain number of tons per year (i.e.: take or pay contract).

The second set of parameters (D, E) define the maximum and the minimum total demand for a customer. In this case, we define the minimum total demand as the required demand that needs to be fulfilled by the allocation process. Note that we specify this demand only in terms of customer and incoterm; the assumption is that this demand is the accumulation of different product qualities available in the market.

The third set of parameters (F, G) define the maximum and minimum specific demand per type of product. This input provides the range in which the model combines products with different qualities to achieve the minimum total demand required by the customer. As an example, if a customer requires a minimum of 100 tons of slag (parameter E), parameters (G, F) will determine the composition of this requirement:

- Slag Grade A (50,100): this customer requires a minimum of 50 tons of Grade A and up to 100 tons (this is, the full order).
- Slag Grade B (0, 40): if there is not enough availability of slag Grade A, the customer can accept up to 40 tons of Grade B (probably, paying a lower price).

Last, the parameter U, represents the type of ship available for each route. It is important to mention that the model accepts only one type of ship per route, and this is based on the type of ships most used by the company (and by third parties) in each specific combination of source, destination and incoterm, considering that the company only uses four types of vessels to transport materials. Usually, port restrictions is the main driver of the decision on which ship to use. This assumption is necessary to simplify the structure (and the volume of information) for the allocation of transport costs in our model. Furthermore, we assume that the company has already analyzed which type of ship is most convenient for each route.

Also, let

β be the minimum load coefficient factor.

We use this parameter together with our decision variable y_{gij} and U, to ensure that our model allocates only fully loaded ships, but with some flexibility given by β, to allow some ships to be loaded only up to a certain percentage (e.g. 80%) of their capacity.

Next, we define the following parameters to set the objective function of our model be,

r_{ghij} the revenue of product quality h from source i to customer j with incoterm g (USD/ton)
c_{ghij} the FOB price of product quality h from source i to customer j with incoterm g (USD/ton)
t_{ghij} transport cost of product quality h from source i to customer j with incoterm g (USD/ton) $\in$ T.
b_{ghij} other logistic costs of product quality h from source i to customer j with incoterm g (USD/ton)
a_{ghij} the insurance cost of product quality h from source i to customer j with incoterm g (USD/ton)
d_{ghij} the import/export duties of product quality h from source i to customer j with incoterm g (%)

Note that all cost and revenue parameters depend on four factors: incoterm (g), product quality (h), sources (i), customers (j). Although the number of combinations (and possible solutions) increase with each additional dimension of the problem, it is necessary to include all of them to provide the required flexibility to the model.

Last, let

$$r_{ghij} = q_{ghij} + v_{ghij}$$

With q_{ghij} being the price a customer *j* pays for the product *h* from source *i* with incoterm *g* and v_{ghij} the proportional tax savings from CO_2 emissions the customer *j* gets for importing the product *h* from source *i*.

Then, the general formulation of our transportation problem is given by:

Maximize

$$\sum_{g=1}^{n}\sum_{h=1}^{m}\sum_{i=1}^{o}\sum_{j=1}^{p} x_{ghij}\{ r_{ghij} - c_{ghij} - (t_{ghij} + a_{ghij} + b_{ghij}) - d_{ghij}\,(c_{ghij} + t_{ghij} + a_{ghij} + b_{ghij})\}$$

The first term of the expression in brackets defines the revenue function; the second is the total purchase cost; the third accounts for the logistic costs (transport, insurance and other costs); and the last terms account for the impact of duties/tariffs.

Subject to

$$\sum_{g=1}^{n}\sum_{j=1}^{p} x_{ghij} \leq S_{hi}\ \forall\ h, i\ \in\ \mathrm{S}$$ (maximum supply constraint)

$$\sum_{g=1}^{n}\sum_{j=1}^{p} x_{ghij} \geq W_{hi}\ \forall\ h, i\ \in\ \mathrm{W}$$ (minimum required supply constraint)

$$\sum_{h=1}^{m}\sum_{i=1}^{o} x_{ghij} \leq D_{gj}\ \forall\ g, j\ \in\ \mathrm{D}$$ (maximum total demand constraint)

$$\sum_{h=1}^{m}\sum_{i=1}^{o} x_{ghij} \geq E_{gj}\ \forall\ g, j\ \in\ \mathrm{E}$$ (minimum total demand constraints)

$$\sum_{g=1}^{n}\sum_{i=1}^{o} x_{ghij} \leq F_{hj}\ \forall\ h, j\ \in\ \mathrm{F}$$ (maximum specific demand constraint)

$$\sum_{g=1}^{n}\sum_{i=1}^{o} x_{ghij} \geq G_{hj} \; \forall \, h, j \; \in \; \mathrm{G} \qquad \text{(minimum specific demand constraint)}$$

$$\sum_{h=1}^{m} x_{ghij} \leq \; y_{gij} \; U_{gij} \; \forall \, \mathrm{g}, \mathrm{i}, j \; \in \; \mathrm{U} \qquad \text{(maximum capacity per ship constraint)}$$

$$\sum_{h=1}^{m} x_{ghij} \geq \; y_{gij} \; \beta \; U_{gij} \; \forall \, \mathrm{g}, \mathrm{i}, j \; \in \; \mathrm{U} \qquad \text{(minimum capacity per ship constraint)}$$

The constraints above represent the area in which the mixed integer linear program has flexibility to find an optimal solution, satisfying the requirements for customer, suppliers and logistic capacities.

The constraint below states that the model allocates x_{ghij} (flows) only if there is a valid transport route, t_{ghij}, set in the system. With this constraint, we limit the number of possible solutions only to available routes, eliminating from the database those combinations of source and destination which are not feasible due to economic reasons (i.e. ship from Japan to the East Coast of the United States) or international trading restrictions.

$$\forall \; x_{ghij} \; \exists \; T \; \text{(use of available routes constraint)}$$

Last, we have the non-negativity constraints,

$$x_{ghij} \geq 0 \; \in \; R \; \text{(non-negativity constraint and real number)}$$

$$y_{gij} \geq 0 \; \in \; Z \; \text{(non-negativity constraint and integer number)}$$

We write and solve the model using Python-Gurobi. Please refer to appendix N for the script.

In the following chapter we validate the model using historical data from the company for 2017. In addition, we perform several simulations to test the sensitivity of the model to changes in certain parameters.

4. RESULTS AND DISCUSSION

4.1. Model validation and simulation stages

In this section, we present the results for eight scenarios that we use to validate the outcome of the model and to perform sensitivity analysis. Also, we compare the results of each scenario with the actual performance of the network in 2017. In each scenario, we evaluate the main changes in the volumes and routes selected, how much our solution diverges from the actual performance, and what the impact is in terms of margins for the company.

We use the following metrics to assess differences between actual performance and simulated scenarios:

- Total contribution margin, performing the analysis for FOB and CIF customers
- Volume traded
- Route match rate (%): percentage of routes used in the simulated scenario which are present in the actual performance of the network. A value closer to 100% means that the company is using the same trading routes as the simulation
- Mean of differences in volumes: this is the average of the differences of volumes between actual performance and calculated scenarios
- Standard deviation of differences in volumes: this is the standard deviation of the differences of volumes between actual performance and scenarios calculated

We defined the following scenarios:

- Base scenarios [SC01, SC02]: we use these scenarios to validate the model using actual data observed during period 2017 regarding:
    - Demand and supply volumes
    - Types of vessels
    - Trading routes
    - Prices, purchase costs, logistic costs and custom duties
    - Product mix
    - For [SC01] we use 50% as a minimum specific demand to be fulfilled for each material; while for [SC02] we use 80%.

The objective at this stage is to analyze how realistic is the simulation and whether there are any "quick wins" in terms of allocation of volumes using the same trading routes the company is using.

- New routes [SC03]: we use the same information from scenarios [SC01, SC02] and add additional trading routes currently not used by the company. While we raise the number of possible arcs in the model, we increase the potential to find a better optimal solution.
- New routes and value-based pricing [SC04]: we use the same information from scenarios [SC01, SC02 and SC03] and we add value-based pricing. By increasing the range on which prices can vary depending on the product quality, the model will provide a better solution in comparison to the base scenario.

- Special cases:
    - Carbon tax schemes [SC05]: as presented in section 3, carbon tax schemes might modify flows in this supply chain, so we will consider how the introduction of taxes may affect the allocation of volumes of slag.
    - Increased duties in the USA [SC06]: we evaluate how an increase in duties may affect the current network.
    - Increase in freight rates [SC07]: we evaluate the impact of increased freight rate on the design of the supply chain network.
    - Risk management approach [SC08]: currently, the company strongly depends on the Japanese production of slag to serve most of its customers (42% of the volume traded comes from Japan). In this scenario we consider the effect of a reduction in the supply from Japan and evaluate the impact on the customers.

4.2. Base scenarios

4.2.1. Base scenario [SC01]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped the demand for each product to actual purchases
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 50%

The last assumption means that even in the case that a customer has a negative margin, the model still needs to fulfill the demand up to 50%.

Table 3: Results for scenario [SC01]. See detailed results in Appendix F.

	Baseline (2017)	[SC01]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,607,137	5,127,400	(479,737)	-9%
Contribution margin (USD)	16,751,680	19,646,144	2,894,464	17%
FOB				
Volume traded (tons)	904,817	739,100	(165,717)	-18%
Contribution margin (USD)	856,450	787,298	(69,152)	-8%
CIF				
Volume traded (tons)	4,702,320	4,388,300	(314,020)	-7%
Contribution margin (USD)	15,895,230	18,858,846	2,963,616	19%
Route match rate	82%			
Mean of differences	4,750			
SD of differences	65,605			

As we can see in table 3, if we optimize the flows for the network, we increase the contribution margin by USD 2.89 million (17%), while reducing volume traded by 480,000 tons. This is possible because the model eliminates routes with negative margins and supplies the minimum amount of demand (50%) for those customers that are not profitable, such as:

- Croatia-Koromacno (CIF)
- Ghana-Takoradi (CIF)
- Kenia-Mombasa (CIF)
- Vietnam-Thi Vai Terminal (CIF)
- Vietnam –Nhon Trach (CIF)
- USA-Camdem (FOB)
- USA-Milwaukee (FOB)

With this, the optimization model releases volumes allocated to negative (and low) margin customers, and reallocates to higher margin customers (in general, CIF customers).

As FOB customers are generally less profitable, the model moves volume from FOB customers to CIF. In the optimal solution, the model reduces the contribution margin by USD 69,000 for FOB customers but increases the contribution margin for CIF customers by USD 2.96 million.

The main changes in routing from the baseline scenario are:

- Volume of GBFSA from Italy-Taranto reallocated to USA-Sparrow's Point as it has a higher contribution margin than the other alternatives (6.37 USD/ton)
- Volume of GBFSA from Japan-Fukuyama reallocated to Qatar-Mesaieed as it has higher a contribution margin than the other alternatives (5.60 USD/ton)
- Volume of GBFSA from Japan-Kashima reallocated to Bangladesh-Chittagong as it has a higher contribution margin than the other alternatives (8.61 USD/ton)

- Volume of GBFSA from Japan-Mizushima reallocated to USA-Seattle as it has a higher contribution margin than the other alternatives (7.66 USD/ton).

Overall, route match rate is high (82%), so the decisions made by the company regarding the allocation of routes are not far from the ones in the optimization model. The main improvement provided by the model is the change in the routing for GBFSA and the reduction in the supply for those customers which are not profitable.

In the scenario [SC02], we will fix the minimum demand to 80%, instead of 50% in this current scenario.

4.2.2. Base scenario [SC02]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped the demand for each product to actual purchases
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 80%

The last assumption means that even in the case that a customer has a negative margin, the model still needs to fulfill the demand up to an 80%. Results for this simulation are closer than the actual results for year 2017.

Table 4: Results for scenario [SC02]. See detailed results in Appendix G.

	Baseline (2017)	[SC02]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,607,137	5,512,460	(94,677)	-2%
Contribution margin (USD)	16,751,680	18,606,693	1,855,013	11%
FOB				
Volume traded (tons)	904,817	873,440	(31,377)	-3%
Contribution margin (USD)	856,450	559,955	(296,495)	-35%
CIF				
Volume traded (tons)	4,702,320	4,639,020	(63,300)	-1%
Contribution margin (USD)	15,895,230	18,046,737	2,151,507	14%
Route match rate	77%			
Mean of differences	937			
SD of differences	59,513			

As we can see in table 4, if we optimize the flows for the network, we increase the contribution margin by USD 1.85 million (11%), while reducing volume traded by 95,000 tons. This is possible because the model reallocates volume from less to more profitable routes. It is also eliminating routes with negative margins, and sourcing a minimum amount of demand (80%) for those customers that are not profitable, such as:

- Croatia-Koromacno (CIF)
- Ghana-Takoradi (CIF)
- Kenia-Mombasa (CIF)
- Morocco-Nador (CIF)
- Singapore-Jurong (CIF)
- Vietnam-Thi Vai Terminal (CIF)
- USA-Camdem (FOB)
- USA-Milwaukee (FOB)

With this, the optimization model releases volumes, which are then reallocated to higher margin customers. In the optimal solution, the model reduces the contribution margin by USD 296,000 for FOB customers but increases the contribution margin by USD 2.15 million for CIF customers.

The main changes in routing from the baseline scenario are:

- Volume of GBFSA from Japan-Fukuyama reallocated to Qatar-Mesaieed as it has a higher contribution margin than the other alternatives (5.60 USD/ton)
- Volume of GBFSA from Japan-Kashima reallocated to Bangladesh-Chittagong as it has a higher contribution margin than the other alternatives (8.61 USD/ton)
- Volume of GBFSA from Japan-Mizushima reallocated only to Unites Arab Emirates-Mina Zayed, USA-Seattle and Vietnam-Thi Vai Terminal as they have higher contribution margins than other alternatives (5.81 USD/ton, 7.66 USD/ton, 0.22 USD/ton)

The case of Thi Vai Terminal is special, as the model must fulfill a minimum of 80% of the total demand (437,000 tons) even though it is a customer with low margin. The best alternative for this customer is sourcing from:

- Japan-Kawasaki (0.12 USD/ton)
- Japan-Kimitsi-Kisarazu (1.30 USD/ton)
- JPN-Mizushima (0.22 USD/ton)
- TWN-Kaohsiung (1.29 USD/ton)

If we allow the possibility of not fulfilling low margin customers, the model immediately reallocates the volume from Thi Vai Terminal to more profitable customers with a contribution margin of ~4 USD/ton

Overall, route match rate is high (77%), so the decisions made by the company regarding allocation of routes are not far from the ones in the optimization model. The average difference per route is low (937 tons) and the standard deviation of differences is lower than in scenario [SC01]. This is because when we increase the fulfillment of demand up to 80%, we force the model to be close to the actual performance in 2017.

Still, there are improvement opportunities for margin decisions, by changing routing for GBFSA customers, which we will analyze in the following section.

4.3. Adapted base cases

4.3.1. New routes [SC03]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- Limited flexibility regarding product mix
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 50%
- 106 new routes, including:
    - Ports from Brazil connected with ports in Africa
    - Ports of Japan connected with all demand nodes in Asia and America
    - Ports of France and Spain connected with Croatia

Table 5: Results for scenario [SC03]. See detailed results in Appendix H.

	Baseline (2017)	**[SC01]**	**[SC03]**	**Difference (ABS) [SC01] vs [SC03]**	**(%)**	**Difference (ABS) Base vs [SC03]**	**(%)**
Volume traded (tons)	5,607,137	5,127,400	5,274,900	147,500	3%	(332,237)	-6%
Cont. margin (USD)	16,751,680	19,646,144	21,810,012	2,163,868	11%	5,058,332	30%
FOB							
Volume traded (tons)	904,817	739,100	772,100	33,000	4%	(132,717)	-15%
Cont. margin (USD)	856,450	787,298	952,298	165,000	21%	95,848	11%
CIF							
Volume traded (tons)	4,702,320	4,388,300	4,502,800	114,500	3%	(199,520)	-4%
Cont. margin (USD)	15,895,230	18,858,846	20,857,714	1,998,868	11%	4,962,484	31%
Route match rate	72%						
Mean of differences	9,678						
SD of differences	78,707						

As we can see in table 5, with the inclusion of new routes, we increase the contribution margin by USD 2.16 million (11%), compared to [SC01] while increasing volume traded by 147,500 tons. From a total of 106 new routes added to the model, the optimal solution uses only 11, the most relevant being:

- Brazil - Mucuripe to Ivory Coast - Abidjan (144,000 tons, contribution margin 12.18 USD/ton)
- Brazil - Mucuripe to Ghana - Takoradi (60,000 tons, contribution margin 5.81 USD/ton)
- France - Fos to Croatia (140,900 tons, contribution margin 3.37 USD/ton)
- Japan - Chiba to Vietnam - Thi Vai Terminal (90,000 tons, contribution margin 0.64 USD/ton)

The addition of potential new routes requires effort from management, as it is always complicated to obtain quotes and estimate the margin of each individual transaction. Nevertheless, the solution provided by the model changes significantly when we include new, profitable trading routes. As a consequence of a larger database of routes, route match rate is lower (72%), and average difference per route is higher (9,678 tons), with higher standard deviation.

4.3.2. New routes and value-based pricing [SC04]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- Limited flexibility regarding product mix
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 50%
- 106 new routes, including:
    - Ports from Brazil connected with ports in Africa
    - Ports of Japan connected with all demand nodes in Asia and America
    - Ports of France and Spain connected with Croatia
- Changes in prices for the following customers, as presented in figure 11:
    - United Arab Emirates – Mina Zayed
    - Bangladesh - Chittagong
    - USA - Seattle
    - USA – Sparrows Point

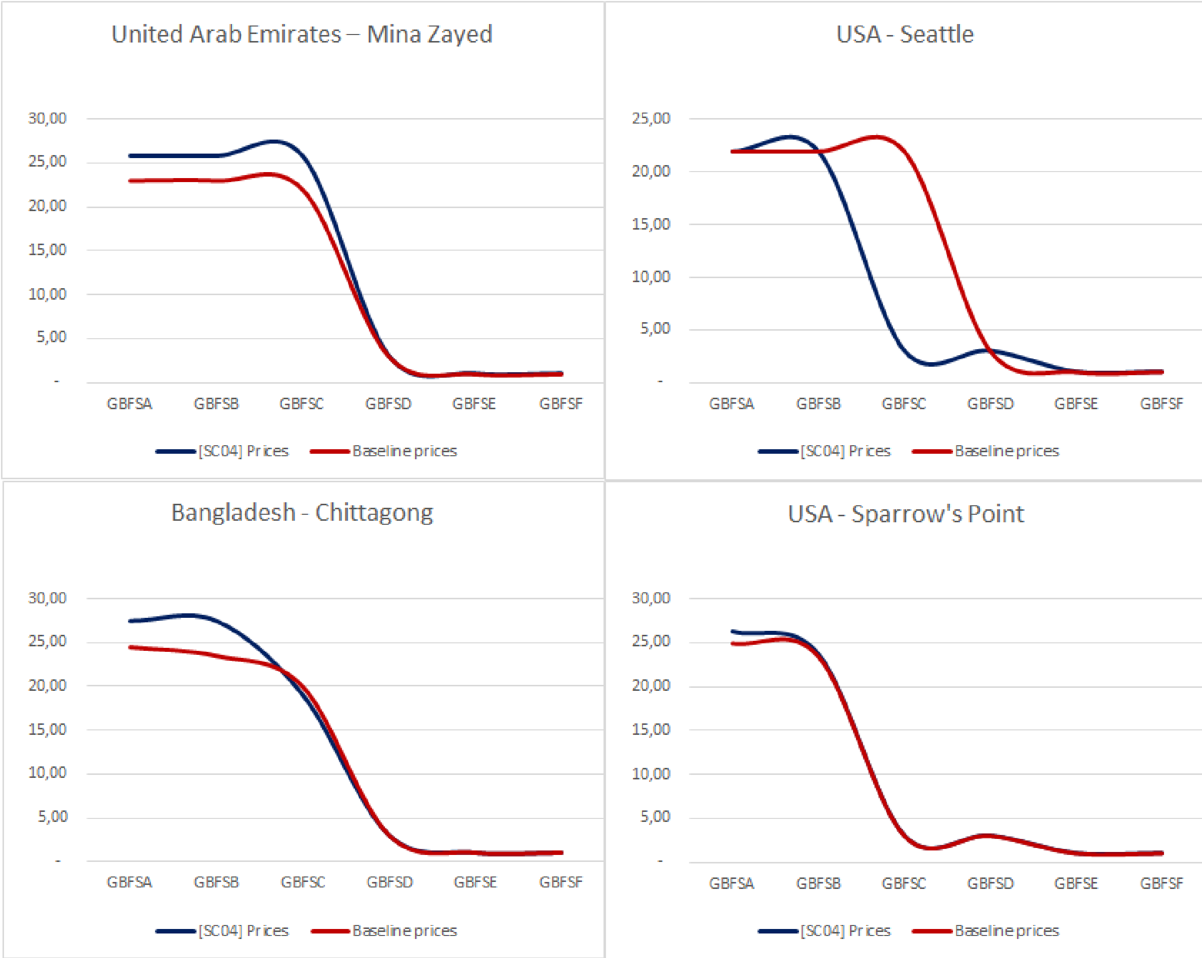

Figure 11: Price curves used for [SC04]

In this scenario we develop price assumptions using historical data, market information and overall trend in the industry. In figure 11, we present different strategies for customers based on the concept of value-based pricing, which differ from the baseline prices. For customers in USA we assume a demand pattern only for the material with the highest quality available (GBFSA and GBFSB). A similar case occurs for the customer in United Arab Emirates, using the same price for GBFSA, GBFSB and GBFSC. For the case of Bangladesh, we assume a decreasing price based on the type of material.

Table 6: Results for scenario [SC04]. See detailed results in Appendix I.

	Baseline* (2017)	[SC03]	[SC04]	Difference (ABS) [SC03] vs [SC04]	(%)	Difference (ABS) Base vs [SC4]	(%)
Volume traded (tons)	5,607,137	5,274,900	4,999,800	(275,100)	5%	(607,337)	-11%
Cont. margin (USD)	17,197,480	21,810,012	24,693,287	2,883,275	13%	7,495,807	44%
FOB							
Volume traded (tons)	904,817	772,100	739,100	(33,000)	-4%	(165,717)	-18%
Cont. margin (USD)	856,450	952,298	787,298	(165,000)	-17%	(69,152)	-8%
CIF							
Volume traded (tons)	4,702,320	4,502,800	4,260,700	(242,100)	-5%	(441,620)	-9%
Cont. margin (USD)	16,341,030	20,857,714	23,905,989	3,048,275	15%	7,564,959	46%
Route match rate	68%						
Mean of differences	15,609						
SD of differences	77,344						

*Baseline quantities using margins from SC04 for comparability.

As we can see in table 6, with the inclusion of new routes and value-based pricing assumptions, the model reallocates volumes to customers with higher margins, increasing contribution by USD 2.8 million (13%), compared to [SC03], while decreasing volume traded by 275,100 tons. From a total of 106 new routes added to the model, the optimal solution uses 15, the most relevant ones being:

- Brazil - Mucuripe to Ivory Coast - Abidjan (144,000 tons, contribution margin 12.18 USD/ton)
- Brazil - Mucuripe to Ghana - Takoradi (60,000 tons, contribution margin 5.81 USD/ton)
- France - Fos to Croatia (99,100 tons, contribution margin 3.37 USD/ton)
- Japan - Chiba to Bangladesh – Chittagong (90,000 tons, contribution margin 7.99 USD/ton)
- Japan -Kawasaki to Phillipines – Lugait (60,000 tons, contribution margin 1.16 USD/ton)
- Japan -Nagoya to Bangladesh – Chittagong (90,000 tons, contribution margin 11.81 USD/ton)
- Japan - Oita to Vietnam - Thi Vai Terminal (85,600 tons, contribution margin 2.58 USD/ton)
- Japan -Wakayama to Bangladesh – Chittagong (130,000 tons, contribution margin 11.82 USD/ton)

The addition of value-based pricing increases the margin for certain routes; therefore, the model reallocates volumes to maximize total contribution. The solution provided by the model changes significantly when we include new trading routes and value-based pricing.

4.4. Special cases

4.4.1. Carbon tax schemes [SC05]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped demand for each product to actual purchases
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 80%
- Carbon tax benefits are included for intercompany shipments

We include the last assumption to show the impact of carbon tax benefits for Trading Ltd. We chose the term "benefit" as by substituting clinker by slag, Trading Ltd can reduce its CO_2 tax, as slag emits less GHG than clinker. We allocated these savings only to intercompany shipments as Trading Ltd only perceives these benefits if a member of the Group receives the shipment and needs to pay less CO_2 taxes. End customers could profit too from these Carbon tax benefits. However, it will not be part of Trading Ltd's revenue. Therefore, we did not include it in our calculations.

We calculate the carbon tax benefits by taking in account border carbon adjustments, as carbon legislation will be more stringent in the future and will most likely include also CO_2 emissions generated outside of the importing country.

Table 7: Results for scenario [SC05]. See detailed results in Appendix J.

	Baseline* (2017)	**[SC05]**	**Difference (ABS)**	**Difference (%)**
Volume traded (tons)	5,607,137	5,516,960	(90,177)	-2%
Contribution margin (USD)	18,729,792	20,574,377	1,844,585	10%
FOB				
Volume traded (tons)	904,817	877,940	(26,877)	-3%
Contribution margin (USD)	1,909,871	1,608,755	(301,116)	-16%
CIF				
Volume traded (tons)	4,702,320	4,639,020	(63,300)	-1%
Contribution margin (USD)	16,819,920	18,965,621	2,145,701	13%
Route match rate	78%			
Mean of differences	893			
SD of differences	59,512			

*Baseline quantities using margins from [SC05] for comparability.

As we can see in table 7, if we optimize the flows for the network by including carbon tax benefits, we increase the contribution margin by USD 1.84 million (10%), while reducing volume traded by approx. 90,177 tons (-2%). This is possible, as the model is reallocating volumes from less to more profitable routes. It is also eliminating routes with negative margins and sourcing a minimum amount of demand (80%) for those customers that are not profitable. The model eliminates the same routes as [SC02]:

- Croatia-Koromacno (CIF)
- Ghana-Takoradi (CIF)
- Kenia-Mombasa (CIF)
- Morocco-Nador (CIF)
- Singapore-Jurong (CIF)
- Vietnam-Thi Vai Terminal (CIF)
- USA-Camden (FOB)
- USA-Milwaukee (FOB)

As previously discussed, the optimization model releases volumes which it allocates to higher margin customers (in general, CIF customers). The greater reduction of products delivered to FOB customers (-3% in volume and -16% in margin) is the proof of volumes reallocated from low margin to high margin customers. At the same time, the model reduced the volume for CIF customers only by 1%, while increasing their margins by 13%.

The model generated also the same main changes in routing from the actual scenario, as in [SC02]. The model reallocated:

- Volume of GBFSA from Japan-Fukuyama to Qatar-Mesaieed as it has a higher contribution margin than the other alternatives (5.60 USD/ton)
- Volume of GBFSA from Japan-Kashima to Bangladesh-Chittagong as it has a higher contribution margin than the other alternatives (8.61 USD/ton)
- Volume of GBFSA from Japan-Mizushima mainly to Unites Arab Emirates-Mina Zayed, USA-Seattle and Vietnam-Thi Vai Terminal as they have higher contribution margins than other alternatives or represent the best overall solution (5.81 USD/ton, 7.66 USD/ton, 0.22 USD/ton)
- The model used volume of GBFSA Japan-Oita to serve mainly Peru-Paita and Bangladesh-Chittagong, as these destinations had the highest contribution margins from this source (7.74 USD/ton and 7.53 USD/ton respectively)

The main difference between [SC02] and [SC05] is the shipment of 4,500 tons of GBFSB from Germany-Bremen to Sweden-Uddevalla, replacing 3,600 tons of GGBFSA, as increased quantities of this product were sent from Bremen to Glasgow, as there were carbon tax benefits by sending material to the United Kingdom.

Overall, route match rate is high (78%), so the decisions made by the company regarding allocation of routes are not far from the ones in the optimization model including carbon taxes. In fact, average difference per route is low (893 tons) and standard deviation of differences is lower than in scenario [SC01]. This is because when we increase the fulfillment of demand up to 80%, we are forcing the model to be closer than the actual performance.

Hence, carbon taxes seem to have a very limited effect on the optimal allocation of flows, especially when compared with [SC02], as the effect of the CO_2 tax benefits are too small in comparison with other cost or revenue drivers. This might change if the amount linked to carbon taxes might increase. A bigger difference in terms of carbon tax benefits between different regions might lead to different quantity allocations.

4.4.2. Increased duties in the USA [SC06]

The following parameters are used:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped demand for each product to actual purchases
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 80%
- Increased duties in the United States for different regions of the world (excluding EU and NAFTA):

Table 8: Duties used in [SC06]. Adapted from information provided by the sponsor company.

Countries / Regions	Current duties	New duties	Remarks
Brazil	4%	8%	BRIC - increased threat to USA
South Korea	2%	4%	Assumed general "low" duties for geopolitical partnership
China	0%	15%	Economic rival
India	0%	8%	BRIC - increased threat to USA
Rest Asia	0%	4%	Assumed general "low" duties for geopolitical partnership
Middle East & Turkey	0%	4%	Assumed general "low" duties for geopolitical partnership

With the last assumption, we consider the possibility of having increased duties for imports into the United States. We have chosen to increase the existing duties by a realistic amount; in this scenario we double the amounts of existing duties and we use these values for other countries currently without duties. For example, we have doubled the existing duty for products coming from Brazil. We chose the same percentage for India, as India is part of the BRIC countries, and the USA could perceive them as a threat in the future.

Table 9: Results for scenario [SC06]. See detailed results in Appendix K.

	Baseline* (2017)	[SC06]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,607,137	5,512,460	(94,677)	-2%
Contribution margin (USD)	16,751,680	18,606,693	1,855,013	11%
FOB				
Volume traded (tons)	904,817	873,440	(31,377)	-3%
Contribution margin (USD)	856,449	559,955	(296,495)	-35%
CIF				
Volume traded (tons)	4,702,320	4,639,020	(63,300)	-1%
Contribution margin (USD)	15,895,230	18,046,737	2,151,507	14%
Route match rate	77%			
Mean of differences	937			
SD of differences	59,513			

*Baseline quantities using margins from [SC06] for comparability.

In table 9, we can see that by running the optimization model, including the increasing duties for different supply nodes, we still can increase the contribution margin by USD 1.86 million (11%), while reducing volume traded by 94,677 tons (-2%).

As mentioned under the other scenarios, the optimization model releases volumes from low-profit customers and allocates them to higher margin customers (in general, CIF customers). In the optimal solution, the model reduces the FOB contribution margin by USD 296,495 (volume decreases by 35%) while increasing contribution margins for CIF customers by USD 2.15 million (volume decreases by 1%).

In this scenario, the model reduced the same routes as in [SC02], indicating that the introduction of increased duties does not have an impact on the optimal routes. Instead, the model has yielded the same pattern as [SC02]. Hence the main changes in routing in comparison to the original scenario stay also unchanged.

Furthermore, the route match rate remains high (77%). In fact, average difference per route is low (937 tons) and standard deviation of differences is lower than in scenario [SC01].

The reason for seeing no major impact of duties on the delivery patterns is that the chosen duties are relatively low, but realistic. Hence, other costs have a stronger impact on the routing of slag. Therefore, this scenario proves the robustness of the model and the results shown in [SC02].

4.4.3. Increase in freight rates [SC07]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped demand for each to actual purchases
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 50%
- Transport costs increased by 20% from the baseline

Table 10: Results for scenario [SC07]. See detailed results in Appendix L.

	Baseline* (2017)	[SC07]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,607,137	4,602,800	(1,004,337)	-18%
Contribution margin (USD)	5,314,539	9,643,003	4,328,464	81%
FOB				
Volume traded (tons)	904,817	739,100	(165,717)	-18%
Contribution margin (USD)	856,450	788,415	(68,035)	-8%
CIF				
Volume traded (tons)	4,702,320	3,863,700	(838,620)	-18%
Contribution margin (USD)	4,458,089	8,854,588	4,396,498	99%
Route match rate	74%			
Mean of differences	9,944			
SD of differences	69,370			

*Baseline quantities using transports costs from of [SC07] for comparability.

As we can see in table 10, total contribution margin is very sensitive to changes in transport costs. The gap between the baseline and this scenario increases significantly as a consequence of the impact of transport costs in contribution margin per ton. The effect is nearly exclusively driven by CIF operations, as these are the only ones affected by changes in transport costs.

In table 11, it is interesting to compare the performance of [SC01] and [SC07] by evaluating the impact of transportation costs on optimized scenarios. Total contribution margin in [SC07] drops by USD 10 million (-51%) compared to [SC01] when transport prices increases by 20%. We explain this behavior by the joint effect of two factors:

- A reduction in the average contribution margin per ton from USD 3.83 to USD 2.10 per ton (-45%).
- A reduction in the volumes traded in 524,600 tons (-10%).

Table 11: Results for scenario [SC07] compared to [SC01]

	[SC01]	[SC07]	Difference (ABS)	Difference (%)
Volume traded (tons)	5,127,400	4,602,800	(524,600)	-10%
Contribution margin (USD)	19,646,144	9,643,003	(10,003,141)	-51%
FOB				
Volume traded (tons)	739,100	739,100	-	0%
Contribution margin (USD)	787,298	788,415	(1,117)	0%
CIF				
Volume traded (tons)	4,388,300	3,863,700	(524,600)	-12%
Contribution margin (USD)	18,858,846	8,854,588	(10,004,258)	-53%

The effect of the increase in transport costs leaves many customers with only a minimum supply because of the decrease in profitability:

- United Arab Emirates – Mina Zayed (CIF): minimum demand
- Ivory Coast – Abidjan: minimum demand
- Ghana - Takoradi: minimum demand
- Croatia - Koromacno: minimum demand
- Peru - Paita (CIF) only 70% of demand
- Singapore – Jurong (CIF): minimum demand
- USA – Sparrow's Point (CIF): only 80% of demand
- Vietnam - Thi Vai Terminal (CIF): minimum demand
- Vietnam - Nhon Trach (CIF): minimum demand
- USA-Camdem (FOB): minimum demand
- USA-Milwaukee (FOB): minimum demand

With this, the optimization model leaves demand unattended for those customers which are far from the source nodes like Peru, United Arab Emirates, Cote d'Ivoire, Ghana and Sparrow's Point (USA).

The case of Sparrow's Point (USA) is particular, as it is the first time it has demand left unattended. As contribution margin per ton from the source (Ponta Ubu, Brazil) drops from USD 1.37 to negative USD 1.34, the model does not ship material from this source to Sparrow's Point.

Overall, route match rate is high (74%), as a consequence of the assumptions of this scenario: that although the proportional impact is different, changes in transport costs affect all routes in the same way. This scenario provides a good reference for the real impact of a major disruption in the supply chain.

4.4.4. Risk management approach [SC08]

For this scenario we use the following parameters:

- Actual data from period 2017: demand and supply volumes, types of vessels, trading routes, market prices, purchase costs, logistic costs and custom duties
- No flexibility regarding product mix. We capped demand for each product to actual purchases
- As Japan represents 42% of total supply, we propose a scenario with only 50% of Japan availability
- Ship load factor: 0.95
- Minimum specific required demand to be fulfilled for each material: 80%, except for Japan routes (0%)

We reduced the assumption of minimum specific required demand to be fulfilled as the reduction in the supply from Japan sources will limit the availability of material.

Table 12: Results for scenario [SC08]. See detailed results in Appendix M.

	Baseline (2017)	**[SC08]**	**Difference (ABS)**	**Difference (%)**
Volume traded (tons)	5,607,137	4,062,900	(1,544,237)	-28%
Contribution margin (USD)	16,751,680	13,790,556	(2,961,124)	-18%
FOB				
Volume traded (tons)	904,817	882,860	(21,957)	-2%
Contribution margin (USD)	856,450	547,301	(309,149)	-36%
CIF				
Volume traded (tons)	4,702,320	3,180,040	(1,522,280)	-32%
Contribution margin (USD)	15,895,230	13,243,255	(2,651,974)	-17%
Route match rate	65%			
Mean of differences	15,289			
SD of differences	43,606			

As we can see in table 12, the effect of a reduction in the supply from Japan reduces contribution margins by USD 2.96 million (18%), while reducing volume traded by 1.54 million tons. The model does not supply the following nodes as a result of the reduction in the supply:

- United Arab Emirates - Jebelali (CIF): no supply
- Bangladesh - Chittagong (CIF) only 70% of demand
- Egypt - Damietta (CIF): no supply
- Peru - Paita (CIF) only 36% of demand
- Peru - Salaverry (CIF): no supply
- Philippines - Lugait (CIF): no supply
- Philippines – Mabini (CIF): only 60% of demand

- Philippines - Mariveles (CIF): no supply
- Qatar – Mesaieed (CIF): only 52% of demand
- Saudi Arabia - Dammam (CIF): no supply
- Vietnam - Thi Vai Terminal (CIF): no supply
- Vietnam - Nhon Trach (CIF): no supply

With this, the optimization model leaves demand unattended for those customers with lower margins.

The main changes in routing from the baseline scenario are:

- Volume of GBFSA from Italy-Taranto reallocated to USA-Sparrow's Point as it has a higher contribution margin than the other alternatives (6.37 USD/ton)
- Volume of GBFSA from Japan-Fukuyama allocated only to Qatar-Mesaieed, Egypt-Adabiya and Reunion-Port Reunion as they have higher contribution margin than the other alternatives (5.60 USD/ton, 7.38 USD/ton and 9.85 USD/ton)
- Volume of GBFSA from Japan-Kashima reallocated to Bangladesh-Chittagong as it has a higher contribution margin than the other alternatives (8.61 USD/ton)
- Volume of GBFSA from Japan-Kawasaki reallocated to Bangladesh-Chittagong as it has a higher contribution margin than the other alternatives (4.60 USD/ton)
- Volume of GBFSA from Japan-Mizushima reallocated to USA-Seattle, Qatar-Mesaieed and United Arab Emirates-Mina Zayed as they have higher contribution margin than the other alternatives (7.66 USD/ton, 4.85 USD/ton, 5.81 USD/ton)

Overall, route match rate is lower (65%), as a consequence of the assumptions of this scenario, which are very restrictive. This scenario provides a good reference for the real impact of a major disruption in the supply chain.

One interesting conclusion is that volumes fell by 28%, but margins fell by only 18%. This is because the model has enough flexibility to reallocate the volumes available in the nodes to the most profitable customers, thus restricting the supply to those customers with margins below the average.

4.5. Discussion

The analysis of the solutions provided by the model for different scenarios shows improvement opportunities for the allocation of volumes in the slag network by reviewing current matching of source and demand nodes. [SC02] demonstrates that by reallocating volumes to customers with the highest margins, the model finds solutions which yield higher total contribution margin while requiring less total amounts traded. This is of importance in a market where demand will exceed supply, as Trading Ltd can use the misallocated quantities for other customers willing to pay more.

The addition of new routes ([SC03]) and a value-based pricing strategy ([SC04]) plays an important role in the design of the supply chain. As in any other network optimization, when we increase the number of arcs between nodes, there are more possibilities to find a more optimal solution. Furthermore, including value-based pricing for key customers contributes to increased profitability of certain routes, improving the total contribution margin.

Furthermore, it is relevant to mention that the optimized network model found in [SC02] is robust enough to cope with future evolutions in possible CO_2 taxation ([SC05]) and a possible increase of US duties for slag ([SC06]), as only one additional route is added to the results for [SC02]. In [SC06], the model chooses the same routes as in [SC02]. This implies that by optimizing the current state, the company can already protect itself from some future realistic scenarios.

If the magnitude of CO_2 taxes or duties increases drastically, the supply chain will change as well. Nevertheless, the current carbon taxes and duties show that these inputs have currently only a limited effect on the optimal supply chain network.

On the other hand, increased transportation costs have a major impact on the profitability of Trading Ltd and its supply chain. In [SC07], the 20% increase in transportation costs leads to a decrease of approximately 51% of total contribution margin (in comparison with [SC01]). This implies that transportation cost is one of the main determining factors for Trading Ltd's profitability. Therefore, it is crucial that the company uses risk hedging activities (e.g. long-term transportation contracts) to protect itself from the impact of a possible transportation cost increase.

Increased transportation costs have an impact not only on the profitability of the company but also on its supply chain design. The model avoids allocating additional volumes to customers that are far from supply nodes. This is an issue for strategic customers located far from sources of slag. Hence, it is important to keep in mind that this tool makes a suggestion about the best allocation of products, but management needs to decide if some customers should be served, even though their profitability is not the best at a given time.

A significant change in supply capacity, as shown in [SC08] (with only 50% of Japan's production), has a direct impact on the design of Trading Ltd's supply chain. The model will allocate as little product as possible to less profitable customers while concentrating the majority of the remaining product at the most profitable customers. Nevertheless, the effect on the profitability (-18%) is relatively low compared to the effect on volumes (-28%), as the model focuses on the profitable customers beforehand, leaving lower margin customers unattended. The opposite effect is true when there is a big increase of demand in high margin customers (e.g. USA). The model will allocate more product from less profitable sources to satisfy the new demand.

The different scenarios showed that pricing strategy, transportation cost, and supply/demand changes have an important impact on Trading Ltd's profitability and supply chain design, while CO_2 taxes and duties have a rather limited impact. This implies that it is important for Trading Ltd to hedge against transport and supply/demand uncertainty by engaging in long-term contracts with strategic customers and transportation providers. Additionally, the company should develop a pricing strategy for its major customers in order to optimize product availability, profitability and, thus, its supply chain network.

5. CONCLUSIONS

5.1. Conclusions

Our research shows that there is a clear potential in using supply chain network optimization models to improve performance and profitability in the distribution of cementitious materials. The unique combinations of different product qualities, source and destination nodes, freights, duties and other additional costs lead to a model where the best allocation of resources should be based on perceived value for the end customer and optimized margin for the company.

The model indicates potential for margin optimization by reallocating volumes to most profitable customers, while satisfying supply and demand constraints in the current network ([SC02]). There is an improvement of 11% in total margin, based on an optimal allocation of product quality and quantity, where the company would still serve unprofitable customers up to a maximum of 80% of their total needs while allocating as much product as possible to the most profitable customers.

Nevertheless, our model still enables us to allocate product to less profitable but strategic customers, if required. This function is particularly important in real life as customer relations are based not only on short-term profitability but on prosperous long-term collaboration. Not surprisingly, the solution with strategic allocation of product [SC02] is less optimal than the solution in the less restrictive allocated scenario [SC01]. By loosening constraints, such as minimum quantities for specific customers, and hence increasing the degree of liberty of not serving unprofitable customers, or by increasing the flexibility of deliveries, by adding additional routes, we were able to reach even more optimal solutions ([SC01] and [SC03]).

Another variable which has an impact on Trading Ltd's network and margin is customer specific pricing. Different customers have different price sensitivities. By adapting the offered price to customers for different product qualities, the company can steer the total consumption in a direction which can improve overall profitability. For example, by offering a more attractive price for a lower quality to a certain customer, Trading Ltd can release larger quantities of a higher quality product and allocate this quantity to a customer who is not able or willing to buy a lower quality material. Hence, the overall quantity sold is higher, generating a higher contribution margin.

However, [SC04] shows that transportation cost has a stronger impact on the allocation of sources than the dynamic pricing. This is due to the fact that the proportional transportation cost variation is normally larger (and more volatile) than the range where market prices vary.

Furthermore, by using sensitivity analysis based on different scenarios, we are able to evaluate the proneness of Trading Ltd's supply chain towards global events and risks. For example, we discover that a limited increase of US duties for imports from specific countries will not lead to an adaptation of the used arcs, as the overall impact of duties on total cost is limited. Additionally, the introduction of CO_2 taxes has a very limited impact on supply allocation for slag, as the magnitude of the tax benefit is minor in comparison to other elements of the equation, such as transportation cost. On the other hand, pricing strategy, transportation cost and supply/demand changes have a strong impact on the overall profitability and supply chain of the company.

5.2. Recommendations

It is essential to have an effective mix of practicability and flexibility in order to optimize Trading Ltd's network. Hence, the company should define a limited number of strategic customers to serve, independently of their final margin. This will allow the model to decide not to serve other customers with low profitability and favor the most profitable ones, while giving strategic customers the required service.

Furthermore, the company should gather freight rates for additional routes in order to evaluate the possibility of serving customers from other supply nodes. This increased flexibility will enable them to evaluate more optimal solutions. However, the number of additional routes should not exceed a certain threshold which would lower the practicability of this endeavor. Based on our research, we would start with the additional routes we have selected for [SC03] Trading Ltd can then add further routes based on their expected profitability.

Additionally, Trading Ltd should select the largest customers that show the strongest price sensitivity in order to fine tune the prices for the different qualities offered to these customers. This will enable them to steer these customers towards the consumption of certain qualities which might be less demanded. Hence, liberating quantities of other qualities for customers that are not able to accept lower qualities, increasing total demand and profitability.

Lastly, the company should strengthen its supply chain by having at least two source nodes for each demand node. Even though demand will exceed supply of slag, it is important to have the possibility of delivering product from different sources. This will enable Trading Ltd to react to sudden changes in freight rates, import duties or product availability. Trading Ltd does not need to use these routes in daily business but should keep them as established back-up routes in order to improve its supply chain robustness.

5.3. Future directions for research

Our research gives an initial idea of the optimization opportunities for the transportation of cementitious materials in dry bulk vessels. We limited our analysis to direct shipments from one source node to a demand node. Further research could envisage the possibility of sending larger quantities of product to a specific harbor and then use smaller vessels to supply other demand nodes from this port. In this context, future research could focus on an extension with a maritime inventory routing problem (MIRP) to tackle more operational questions in relation to smaller demand nodes.

Additionally, a more flexible allocation of vessel types for the different routes might bear better results. Hence, further research about flexible allocation of vessel types could be appropriate.

BIBLIOGRAPHY

Agudelo, I. (2009). *Supply Chain Management in the Cement Industry*. Cambridge, MA.

Ahuja, R. K., Magnati, T. L., & Orlin, J. B. (1993). *Network Flows: Theory, Algorithms, and applications*. Upper Saddle River, NJ: Prentice Hall.

Aniki, A., Mbohwa, C., & Akinlabi, E. (2014). *Improvement of Logistics and Supply Chain Management in the Cement Industry in Nigeria*. Proceedings of the World Congress on Engineering, Volume 2, WCE 2014, July 2 – 4.

Bidgoli, H. (2010). *The Handbook of Technology Management*. Hoboken, NJ: John Wiley & Sons.

Bilgen, B., & Ozkarahan, I. (2007). *A mixed-integer linear programming model for bulk grain blending and shipping.* International Journal of Production Economics 107 (2007) 555–571.

Bouchery, Y., Corbett, C. J., Fransoo, J. C., & Tan, T. (2017). *Sustainable Supply Chains.* Springer.

Brandimarte, P., & Zotteri, G. (2007). *Introduction to Distribution Logistics.* Hoboken, NJ: John Wiley & Sons.

Buttiens, K., Leroy, J., Negro, P., Thomas, J. S., Edwards, K., & De Lassat, Y. (2016). *The Carbon Cost of Slag Production in the Blast Furnace: A Scientific Approach.* J. Sustain. Metall. (2016) 2:62–72.

Chen, Y., Mockus, L., Orcun, S., & Reklatis, G. V. (2012). *Simulation-optimization approach to clinical trial supply chain management with demand scenario forecast.* Computers and Chemical Engineering 40 (2012) 82– 96

Chopra. S., & Meindl, P. (2007). *Supply Chain Management: Strategy, Planning and Operations*. Upper Saddle River, NJ: Prentice Hall.

Christiansen, M., Fagerholt, K., Flatberg, T., Haugen, O., Kloster, O., & Lund, E. (2011). *Maritime inventory routing with multiple products: A case study from the cement industry*. European Journal of Operational Research 208, 86–94.

European Commission 2014; Commission Decision of 27 October 2014- determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, a list of sectors and subsectors which are deemed to be exposed to a significant risk of carbon leakage, for the period 2015 to 2019; Official Journal of the European Union; Retrieved from: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014D0746&from=EN; accessed on the 3/18/2018.

Fouré, J., Guimbard, H., Monjon, S. (2016). *Border carbon adjustment and trade retaliation: What would be the cost for the European Union?*. Energy Economics 54 (2016) 349–362.

Gencer, M. (2016). *Granulated Blast Furnace Slag Fundamentals.* Trading Seminar notes.

Griffin, D. (2003). *The law of international trade*. Third edition. London, UK: Buttherworths.

Hugos, M. (2003). *Essentials of Supply Chain Management*. Hoboken, NJ: John Wiley & Sons.

Intercem (2015). *Global Supply, Demand and Trade of Cementitious Materials*. Miami, FL: ZAG International PTE Ltd.

Intercem (2016). *Global Freight Overview*. Hanoi, Vietnam: ZAG International PTE Ltd.

Jugović, A., Komadina, N. & Perić Hadžić, A. (2015). *Factors influencing the formation of freight rates on maritime shipping markets.* Scientific Journal of Maritime Research 29 (2015) 23-29.

Kajaste R., & Hurme M. (2015). *Cement industry greenhouse gas emissions - management options and abatement cost.* Journal of Cleaner Production.

Kamei, F. (2016). *Outlook of Japanese Granulated Blast Furnace Slag.* Bangkok, Thailand: 18th Asia CemenTrade Summit.

Kibria, G. (2015). *Exploring the Most Efficient Transportation Mode for Cement Industries: A Case Study from Bangladesh Perspective*. European Journal of Business and Management, Volume 7, Number 4, 277-279.

Ligthart, A., & Ligthart-van Elkerenm, M. (2014). *The ICR Handbook on Global Cement Trade and Distribution.* Doriking, United Kingdom: Tradeship Publications Ltd.

Murray, T. (2015). *The Future of Ferrous Slag to 2025.* Surrey, United Kingdom: Smithers Apex Ltd.

Nkinamubanzi, P. C., Aitcin, P. (1999). *The Use of Slag in Cement and Concrete in a Sustainable Development Perspective.* Montreal, Canada: WABE International Symposium on Cement and Concrete.

Noche, B., & Elhasia, T. (2013). *Approach to innovative supply chain strategies in cement industry; Analysis and Model simulation.* 2nd International Conference on Leadership, Technology and Innovation Management; Procedia - Social and Behavioral Sciences 75, 359 – 369.

OECD 2018. *Emission trading systems*. Retrieved from: http://www.oecd.org/env/tools-evaluation/emissiontradingsystems.htm; accessed on 3/17/2018.

Psaraftis H., & Kontovas C (2009). *CO_2 Emission Statistics for the World Commercial Fleet.* Laboratory for Maritime Transport, National Technical University of Athens, Greece.

Sahu, V. K., & Victor, R. (2016). *Supply Chain Management To Minimize Total Transportation Cost of Cement Plant.* International Journal of Latest Trends in Engineering and Technology (IJLTET), Volume 6, Issue 3, January, 103 – 109.

Salvendy, G. (2001). *Handbook of Industrial Engineering.* Hoboken, NJ: John Wiley & Sons.

Shapiro, J.F. (2004). *Challenges of strategic supply chain planning and modeling*. Computers and Chemical Engineering 28 (2004) 855–861.

Shapiro, J.F. (2009). *Modeling the Supply Chain*. Duxbury, MA: Cengage Learning.

Shukla, P., & Sharma, L. (2015). *Improvement of Logistics and Supply Chain Management in the Cement Industry: a Literature Review.* International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, Issue 10; 109 – 113.

Simchi-Levi, D., Chen, X., Bramel, J. (2005). *The logic of Logistics: Theory, Algorithms, and Applications for Logistics and Supply Chain Management*. New York, NY: Springer Science and Business Media

Song, J. H., & Furman, K. C. (2013). *A maritime inventory routing problem: Practical approach.* Computers & Operations Research 40 (2013) 657–665.

Taylor, G. D. (2009). *Introduction to logistics engineering.* Boca Raton, FL: Taylor & Francis Group.

The Parliament Magazine 2017. *EU ETS: Commission urged to remove cement from carbon leakage list*. Retrieved from: https://www.theparliamentmagazine.eu/articles/news/eu-ets-commission-urged-remove-cement-carbon-leakage-list; accessed on the 3/18/2018.

Vidal, C. J., and Goetschalckx, M., (1996). *Strategic production – distribution models: A critical review with emphasis on global supply chain models.* European Journal of Operational Research 98 (1997) 1-18.

Winston W. (2004). *Operations Research Applications and Algorithms.* Belmont, CA: Brooks/Cole.

World Bank (2018). *Pricing Carbon*. Retrieved from: http://www.worldbank.org/en/programs/pricing-carbon; accessed on the 3/18/2018

World Bank, Ecofys. (2017). *Carbon Pricing Watch 2017*. Washington, DC. World Bank. Retrieved from: https://openknowledge.worldbank.org/handle/10986/26565 License: CC BY 3.0 IGO. Accessed 3/19/2018.

World Cement (2007). *Emerging Markets Strategic Analysis*. Retrieved from: http://www.cementperformance.com/main/download_files/papers/cpi_papers_worldcement200703.pdf: Accessed on the 5/10/2018.

World Steel Association (2016). *Steel Statistical Yearbook 2016.* Beijing, China. World Steel Association.

APPENDICES

Appendix A: Blast Furnace Slag (BFS) production by region

Table A1: Blast Furnace Slag (BFS) production by region, 2009–2015 (in million tons). Adapted from Murray (2016).

Region	2009	2010	2011	2012	2013	2014	2015	2020(e)	2025(e)
Europe*	26,00	33,40	33,80	32,60	33,30	34,40	34,80	35,40	35,50
CIS	25,40	28,30	29,40	29,80	30,00	29,50	29,30	30,40	31,20
Americas	16,50	21,70	23,30	23,60	22,60	22,80	23,10	24,30	25,00
China	218,30	235,50	254,80	265,90	298,00	293,00	296,70	302,80	267,80
Other Asia	45,80	54,40	57,60	59,60	60,20	63,40	62,70	52,80	53,10
Rest of the world	3,80	4,40	4,00	3,60	3,60	3,80	4,70	5,50	4,80
Total	**335,90**	**377,60**	**403,00**	**415,10**	**447,70**	**446,80**	**451,30**	**451,20**	**417,40**

*Includes Turkey

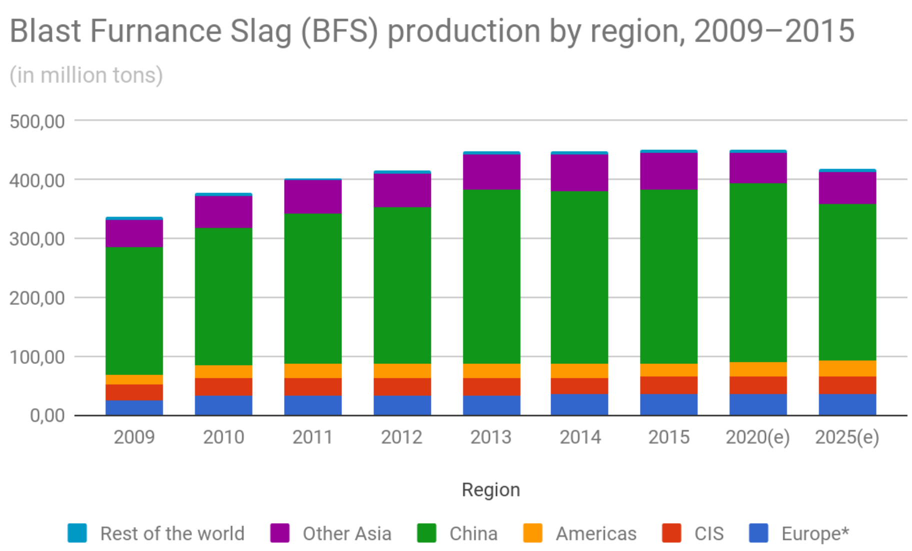

Figure A1: Blast Furnace Slag (BFS) production by region, 2009–2015 (in million tons). Adapted from Murray (2015).

Appendix B: Granulated Blast Furnace Slag (GBFS) production by region

Table B1: Granulated Blast Furnace Slag (BFS) production by region, 2009-2015 (in million tons) Adapted from Murray (2016).

Region	2009	2010	2011	2012	2013	2014	2015	2020(e)	2025(e)
Europe*	18,80	24,20	24,50	23,60	24,10	24,90	25,30	25,70	25,80
CIS	19,20	19,70	18,30	20,60	18,90	19,40	18,90	20,30	21,30
Americas	5,40	7,00	7,60	7,70	7,30	7,40	7,50	7,90	8,10
China	141,10	152,70	175,00	183,90	205,60	202,10	200,50	198,00	191,50
Japan, S. Korea and Taiwan	26,10	30,50	31,80	32,30	32,60	34,20	34,40	35,90	35,10
Rest of the world	8,10	8,70	9,10	9,60	9,70	10,10	11,00	11,40	12,30
Total	**218,80**	**242,80**	**266,40**	**277,80**	**298,20**	**298,20**	**297,60**	**299,20**	**294,10**

*Includes Turkey

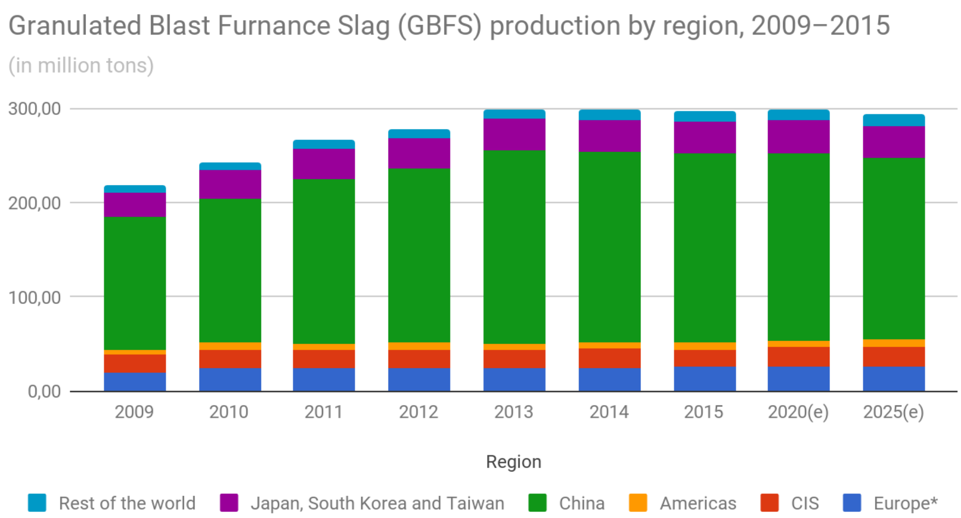

Figure B1: Granulated Blast Furnace Slag (BFS) production by region, 2009-2015 (in million tons) Adapted from Murray (2016).

Appendix C: CO_2 pricing schemes

Information about ETS & Carbon taxes

According to OECD (2018), there are two kinds of ETS:

- Cap-and-trade systems, where an absolute limit of emissions is defined by the government and where emission permits are freely or by auction allocated to different entities, based on specific criteria. Companies can then purchase or sell these emissions units in order to satisfy their emissions needs or to generate an additional revenue.
- Baseline-and-credit systems, where no fixed limits, but rather emission levels are defined. If the entities are able to reduce their emissions below these levels, they receive credits. These credits can then be sold to other companies exceeding their initially allocated emission levels.

The World Bank (2018) defines carbon tax as a tax rate directly related to emissions of GHG or to the carbon content of fossil fuels. These taxes define the amount to be paid but do not set a limit of GHG to be emitted

Information about GHG emissions of clinker and slag

The production of clinker is very energy intensive. This leads to increased GHG emissions, which are dependent on region/country specific characteristics. On the other hand, slag generates lower emissions. The below table shows the different GHG emissions for local cement and for local clinker (Kajaste R., Hurme M. 2015):

Table C1: Regional CO2e emissions for clinker and cement; Adapted from Kajaste R., Hurme M. (2015)

Region	Clinker: region specific emission (kg CO2e/t clinker)	Cement: region specific emission (kg CO2e/t cement)	region specific clinker emissions in cement (kg CO2e/t cement)	region specific clinker emissions in cement (%)
Europe	847	688	393	57%
North America***	897	894	482	54%
Japan, Australia, NZ	838	786	446	57%
CIS	976	875	440	50%
Central America*	858	695	377	54%
Brazil	850	652	355	54%
South America*	848	695	377	54%
China	867	691	365	53%
India	837	833	387	46%
Asia**	843	761	428	56%
Africa	814	829	457	55%
Middle East	851	920	502	55%

Note: Cement specific values (cement emissions and clinker emissions in cement) have following specificities: *based on emissions for the Americas excl. Brazil and USA; **excl. China, India, CIS and JAPAN; *** USA values. National statistics usually excludes electricity emission to avoid double counting. Calculations by Kajaste R., Hurme M. (2015).

Clinker emissions vary locally. Hence, we can see that clinker emissions range from 814 kg CO_2e/t clinker in Africa to 976 kg CO_2e/t clinker in the Commonwealth of the Independent States (CIS). Furthermore, the impact of clinker on the total cement emissions vary as well strongly. For example, European cement emits 688 kg CO_2e/t cement, while the contained clinker accounts for 393 kg CO_2e/t clinker of these emissions, representing approx. 57% of total cement emissions. Hence, the impact of clinker varies from 46% in India to 57% in Europe and in Japan, Australia, NZ.

On the other hand, Buttiens et al (2016) has defined the GHG emissions linked to slag at 550 kg CO_2e/t slag.

Information on chosen ETS/carbon taxes:

There are regions with CO_2 taxes and ETS. Switzerland is an example, as it has ETS (6 USD/tCO_2e) and CO_2 taxes (84 USD/tCO_2e) (World Bank, Ecofys 2017). The reason for choosing the highest regional CO_2 tax/ETS is the fact that we are not able to foresee the future evolution of these pricing schemes. However, we expect that the prices will increase in nearer future. Additionally, we use country specific ETS prices/CO_2 taxes if these were higher than the regional ones. For example, we use the Swedish CO_2 tax (126 USD/tCO_2e) instead of the standard ETS used in the European Union (5 USD/tCO_2e) (World Bank, Ecofys 2017). On the other hand, we use the regional value when the national value is lower. Therefore, by choosing the higher value of the ETS/CO_2 tax and of the national/regional amounts allows us to create a realistic but prudent scenario for the coming years.

Furthermore, we use the ETS/CO_2 tax rates as of 4/1/2017, as the World Bank's "Carbon Pricing Watch 2017" provides us with the most comprehensive and official source for these values.

As mentioned in section 3.3.2., the cement industry is currently excluded from carbon pricing in the most regions of the world. Hence, currently, there is no major impact of carbon pricing on cement. Additionally, border carbon adjustments (BCA) are generally not used when importing emission intensive products, as there is a doubt about their acceptance at the World Trade Organization (WTO) (Fouré, Guimbard and Monjon 2016). However, these two facts might change in the coming years, as governments are becoming more inclined in establishing more stringent environmental policies by including the cement industry into the carbon pricing schemes and by even asking for CO_2 taxes when importing goods (BCA).

In our model, we use the higher value of the ETS/CO_2 taxes and multiply it with the "region specific emission reduction in cement when using slag with BCA (%)" in order to get the applicable amount when using boarder carbon adjustment (BCA).

Appendix D: Prices of carbon pricing initiatives as of April 1, 2017

Table D1: Carbon prices, as of April 1, 2017; Adapted from World Bank, Ecofys. (2017) and Kajaste R., Hurme M. (2015)

Country	Country / Region	European Union	ETS (USD/tCO2e)	CO2 Tax (USD/tCO2e)	Chosen value (USD/tCO2e)	CO2e region	savings without BCA	Savings with BCA
Austria	Austria	EU	5		5	Europe	3	1
Belgium	Belgium	EU	5		5	Europe	3	1
Bulgaria	Bulgaria	EU	5		5	Europe	3	1
Canada	Alberta		23	15	23	North America***	21	4
Canada	British Columbia			23	23	North America***	21	4
Canada	Ontario		14		14	North America***	13	3
Canada	Quebec		14		14	North America***	13	3
Chile	Chile			5	5	South America*	3	1
China	Beijing		8		8	China	6	1
China	Chongqing		1		1	China	1	0
China	Fujian		5		5	China	3	1
China	Guangdong		2		2	China	1	0
China	Hubei		2		2	China	1	0
China	Shanghai		6		6	China	4	1
China	Shenzhen		5		5	China	3	1
China	Tianjin		2		2	China	1	0
Colombia	Colombia			5	5	South America*	3	1
Croatia	Croatia	EU	5		5	Europe	3	1
Cyprus	Cyprus	EU	5		5	Europe	3	1
Czech Republic	Czech Republic	EU	5		5	Europe	3	1
Denmark	Denmark	EU	5	25	25	Europe	17	3
Estonia	Estonia	EU	5	2	5	Europe	3	1
Finland	Finland	EU	5	66	66	Europe	45	9
France	France	EU	5	33	33	Europe	23	5
Germany	Germany	EU	5		5	Europe	3	1
Greece	Greece	EU	5		5	Europe	3	1
Hungary	Hungary	EU	5		5	Europe	3	1
Iceland	Iceland			11	11	Europe	8	2
Ireland	Ireland	EU	5	21	21	Europe	14	3
Italy	Italy	EU	5		5	Europe	3	1
Japan	Japan			3	3	Japan, Australia, NZ	2	0
Japan	Saitama		13		13	Japan, Australia, NZ	10	2
Latvia	Latvia	EU	5	5	5	Europe	3	1
Liechtenstein	Liechtenstein			84	84	Europe	58	12
Lithuania	Lithuania	EU	5		5	Europe	3	1
Luxembourg	Luxembourg	EU	5		5	Europe	3	1
Malta	Malta	EU	5		5	Europe	3	1
Mexico	Mexico		1	3	3	Central America*	2	0
Netherlands	Netherlands	EU	5		5	Europe	3	1
New Zealand	New Zealand		12		12	Japan, Australia, NZ	9	2
Norway	Norway		3	52	52	Europe	36	7
Poland	Poland	EU	5	1	5	Europe	3	1
Portugal	Portugal	EU	5	7	7	Europe	5	1
Romania	Romania	EU	5		5	Europe	3	1
Slovakia	Slovakia	EU	5		5	Europe	3	1
Slovenia	Slovenia	EU	5	18	18	Europe	12	2
South Korea	South Korea		18		18	Asia**	14	3
Spain	Spain	EU	5		5	Europe	3	1
Sweden	Sweden	EU	5	126	126	Europe	87	17
Switzerland	Switzerland		6	84	84	Europe	58	12
United Kingdom	United Kingdom	EU		22	22	Europe	15	3
Ukraine	Ukraine			1	1	Europe	1	0
USA	California		14		14	North America***	13	3
USA	Connecticut		3		3	North America***	3	1
USA	Delaware		3		3	North America***	3	1
USA	Maine		3		3	North America***	3	1
USA	Maryland		3		3	North America***	3	1
USA	Massachusetts		3		3	North America***	3	1
USA	New Hampshire		3		3	North America***	3	1
USA	New York		3		3	North America***	3	1
USA	Rhode Island		3		3	North America***	3	1
USA	Vermont		3		3	North America***	3	1

Appendix E: Quality parameters

The following seven parameters determine slag quality:

- TiO_2 (titanium dioxide content)
- Glass content
- Hydraulic index
- Performance index (7 days)
- Performance index (28 days)
- Grindability
- CaO / SiO_2 content

The chemical composition of slag provides a combination of these parameters. In the below figure, we can see two examples of high quality versus low quality slag. The spider web chart shows each one of the parameters using a standardize score ranking from 0 to100.

It is important to mention that there is a market price for low quality slag, as it still can be used for some applications. Nevertheless, the FOB price for low quality slag will be significantly lower.

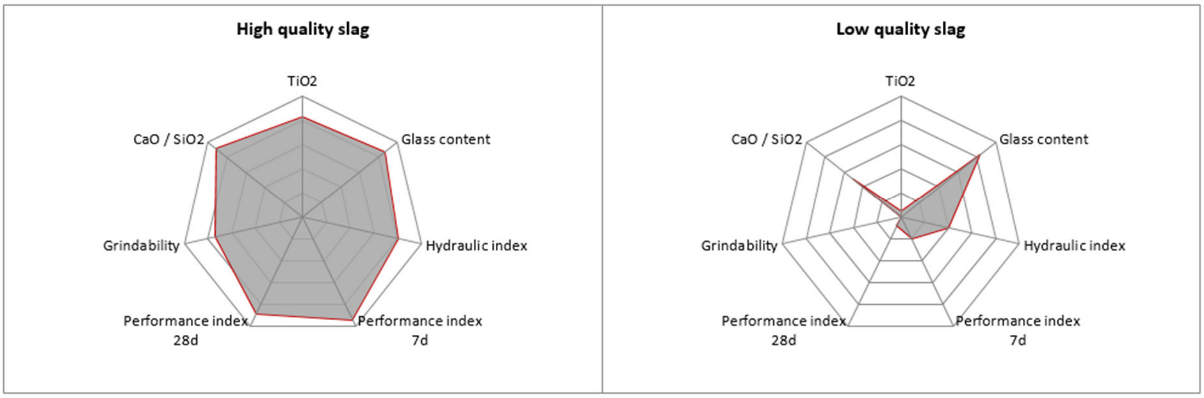

Figure E1: Example of high quality slag vs low quality slag. Adapted from information provided by the sponsor company.;

Appendix F: Results for scenario [SC01]

Table F1: Results for scenario [SC01]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC01] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	-	224.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	156.750	3.825
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	98.800	(7.202)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	62.000	-
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	52.500	-
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	26.600	17.729
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	94.000	85.121
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	57.000	2.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	268.200	(213.570)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.800	200
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	-	86.784
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	44.000	(130)
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	38.000	(450)
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	556.150	(383.569)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	-	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	154.000	(111.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	100.000	(16.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	19.000	1.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	89.000	(44.550)
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	39.900	2.000
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	25.100	1.010
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	119.700	5.089
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	39.900	1.600
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	163.400	(43.620)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	55.000	(27.500)
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	27.500	27.419
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	173.900	(129.900)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	96.100	(46.600)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	78.000	(850)
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	52.000	(690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	27.000	110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	108.000	(1.149)
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	52.250	2.741
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	44.000	(2)
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	40.000	39.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	7.000	249
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	7.000	613
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	88.000	(43.998)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	36.000	500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	41.000	943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	16.200	300
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	20.900	27.400
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	63.000	1.131
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	73.150	70.850
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC01] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	284.000	(1.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	62.700	3.300
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	57.000	62.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	-	32.423
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	62.700	45.019
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	2.500	2.150
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	5.000	12
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	9.600	(4.900)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	23.750	17.742
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	2.250	1.350
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	32.400	(9.353)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.600	2.574
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	5.400	(3.878)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

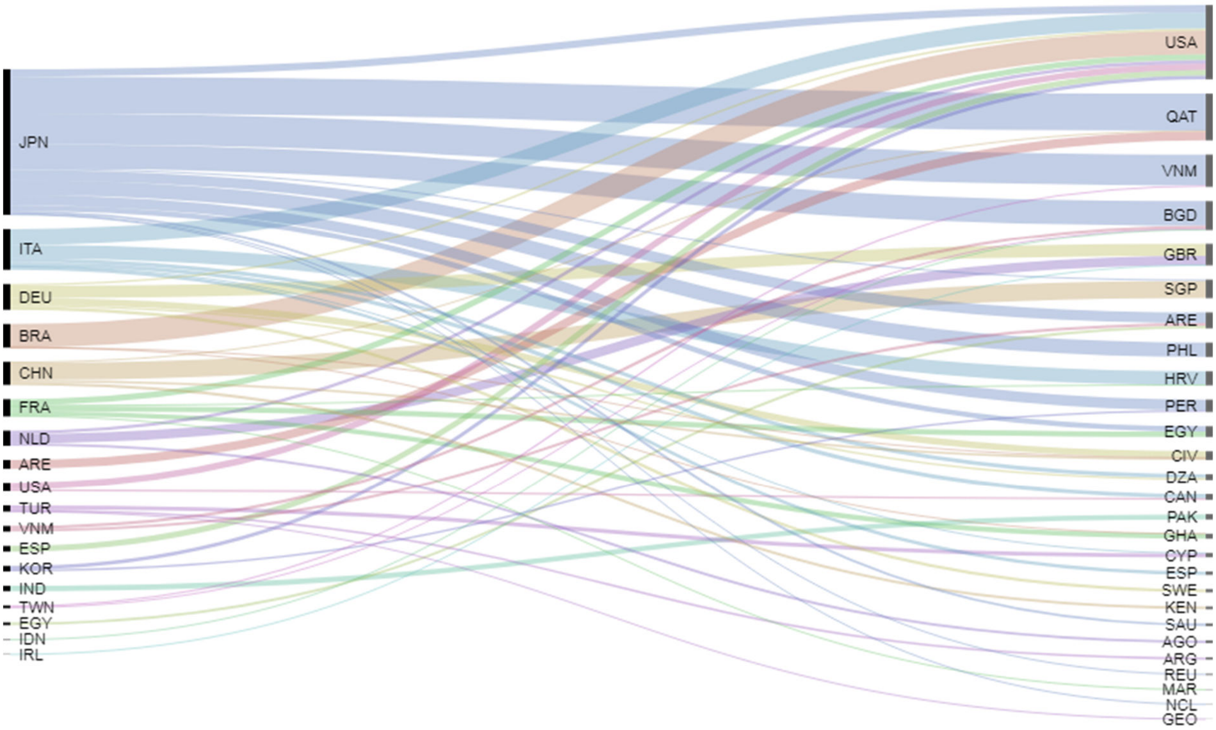

Figure F1: Alluvial diagram for baseline scenario.

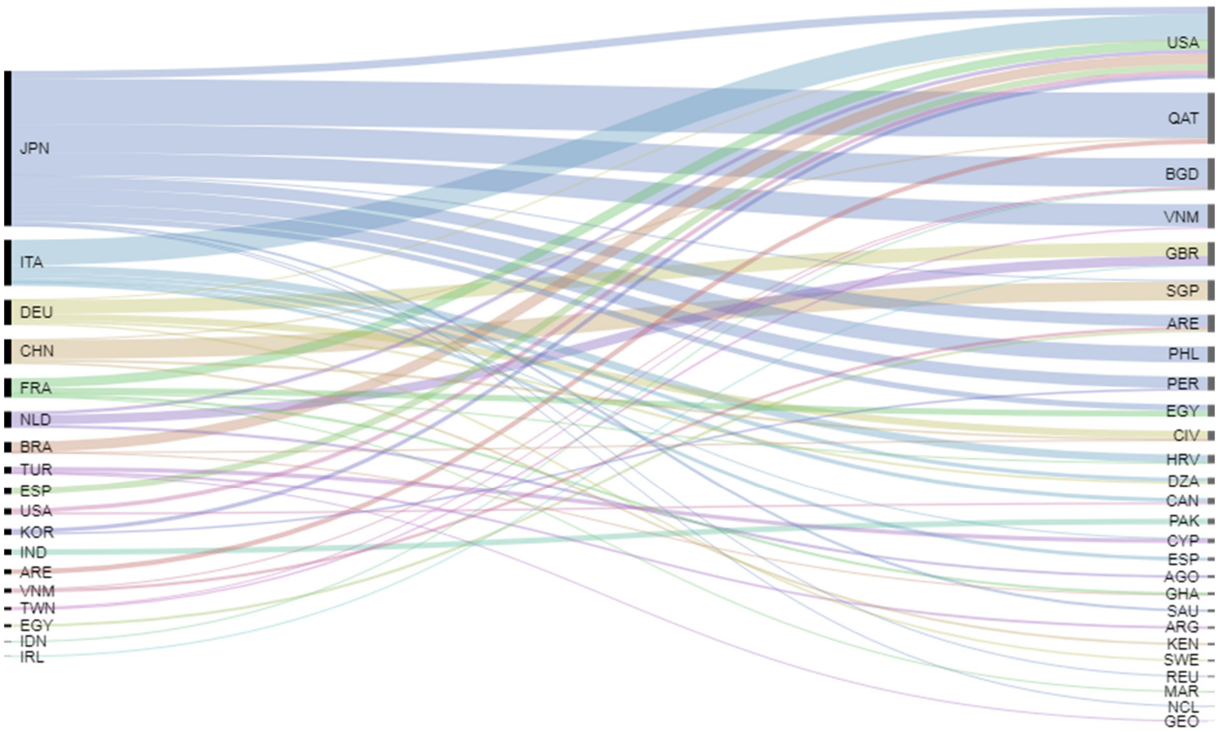

Figure F2: Alluvial diagram - Results for scenario [SC01]

Appendix G: Results for scenario [SC02]

Table G1: Results for scenario [SC02]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC02] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	162.000	62.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	164.240	(3.665)
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	58.160	3.840
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	50.880	1.620
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	44.100	229
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	172.800	6.321
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	54.000	5.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	99.000	(44.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.840	160
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	79.200	7.584
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	44.000	(130)
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	38.000	(450)
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	551.560	(378.979)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	-	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	160.000	(117.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	108.000	(24.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	-	20.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	89.000	(44.550)
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	52.000	(25.890)
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	-	124.789
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	42.000	(500)
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	294.000	(174.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	27.500	-
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	55.000	(81)
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	132.650	(88.650)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	136.000	(86.500)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	78.000	(850)
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	52.000	(690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	27.000	110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	108.000	(1.149)
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	40.240	3.758
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	72.000	7.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	-	7.249
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	-	7.613
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	83.760	(39.758)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	36.000	500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	41.000	943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	14.850	1.650
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	49.500	(1.200)
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	65.000	(869)
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	118.240	25.760
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC02] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	290.000	(7.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	63.360	2.640
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	108.000	11.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	29.700	2.723
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	103.680	4.039
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	-	4.650
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	-	5.012
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	14.000	(9.300)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	40.500	992
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	-	3.600
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	33.000	(9.953)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.000	3.174
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	6.000	(4.478)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

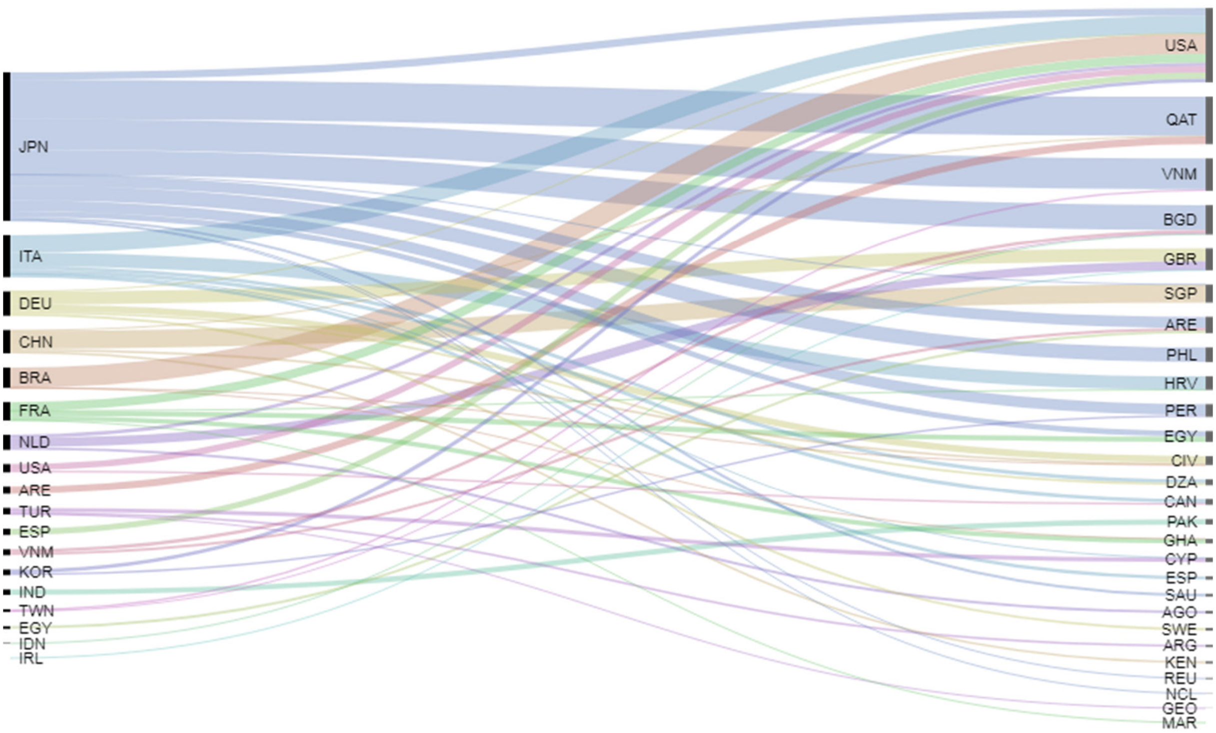

Figure G1: Alluvial diagram - Results for scenario [SC02]

Appendix H: Results for scenario [SC03]

Table H1: Results for scenario [SC03]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC03] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	-	224.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	165.000	(4.425)
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	62.000	-
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	51.700	800
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	26.600	17.729
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	-	179.121
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	57.000	2.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	330.000	(275.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.800	200
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	-	86.784
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	-	43.870
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	-	43.200
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	-	37.550
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	675.850	(503.269)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	44.000	156.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	154.000	(111.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	0	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	99.625	(15.774)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	19.000	1.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	-	44.450
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	104.000	(77.890)
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	-	124.789
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	42.000	(500)
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	215.000	(95.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	-	27.500
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	-	54.919
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	171.000	(127.000)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	99.000	(49.500)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	75.500	1.650
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	26.000	25.310
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	26.200	910
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	-	106.851
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	41.800	2.198
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	-	79.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	6.650	599
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	6.650	963
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	-	44.002
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	-	36.500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	41.000	943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	15.675	825
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	20.900	27.400
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	63.000	1.131
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	73.150	70.850
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC03] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	284.000	(1.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	62.700	3.300
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	57.000	62.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	33.000	(577)
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	62.700	45.019
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	2.500	2.150
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	5.000	12
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	9.600	(4.900)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	23.750	17.742
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	2.250	1.350
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	32.400	(9.353)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.600	2.574
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	5.400	(3.878)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)
CIF	GBFSA	BRA-MUCURIPE	CIV-ABIDJAN	-	144.000	(144.000)
CIF	GBFSA	BRA-MUCURIPE	GHA-TAKORADI	-	60.000	(60.000)
CIF	GBFSB	FRA-FOS	HRV-SPLIT	-	140.900	(140.900)
CIF	GBFSA	JPN-CHIBA	VNM-THI_VAI_TERMINAL	-	90.000	(90.000)
CIF	GBFSA	JPN-KAWASAKI	EGY-ADABIYA	-	59.500	(59.500)
CIF	GBFSA	JPN-KAWASAKI	VNM-NHON_TRACH	-	28.500	(28.500)
CIF	GBFSA	JPN-NAGOYA	ARE-JEBELALI	-	30.000	(30.000)
CIF	GBFSA	JPN-NAGOYA	PER-SALAVERRY	-	30.000	(30.000)
CIF	GBFSA	JPN-NAGOYA	VNM-THI_VAI_TERMINAL	-	30.000	(30.000)
CIF	GBFSA	JPN-WAKAYAMA	EGY-ADABIYA	-	28.500	(28.500)
CIF	GBFSA	JPN-YAWATA	BGD-CHITTAGONG	-	3.800	(3.800)

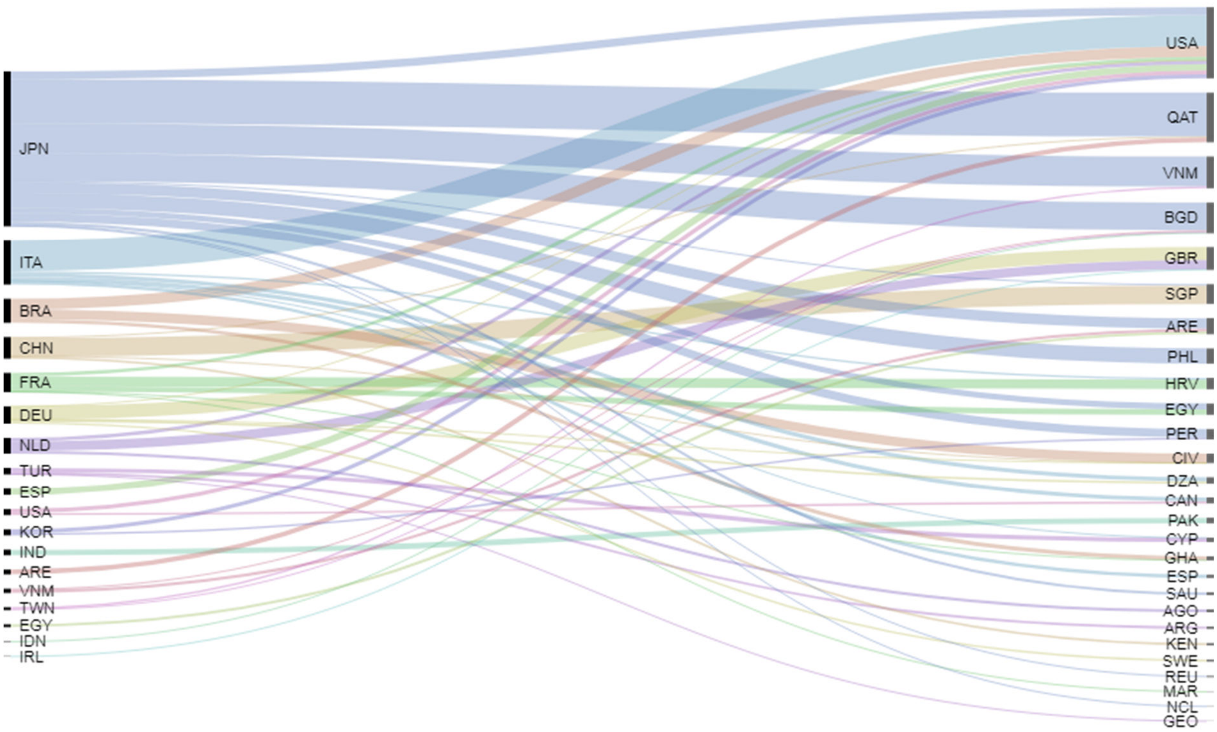

Figure H1: Alluvial diagram - Results for scenario [SC03]

Appendix I: Results for scenario [SC04]

Table I1: Results for scenario [SC04]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC04] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	-	224.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	-	160.575
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	32.000	30.000
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	52.500	-
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	33.800	10.529
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	-	179.121
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	57.000	2.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	385.000	(330.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.800	200
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	-	86.784
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	-	43.870
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	-	43.200
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	-	37.550
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	634.050	(461.469)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	88.000	112.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	-	42.790
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	41.800	2.200
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	114.425	(30.574)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	19.000	1.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	-	44.450
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	174.000	(87.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	39.900	2.000
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	130.000	(103.890)
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	0	124.789
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	42.000	(500)
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	129.000	(9.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	-	27.500
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	-	54.919
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	-	44.000
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	96.100	(46.600)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	-	77.150
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	-	51.310
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	26.000	1.110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	-	106.851
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	-	54.991
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	41.800	2.198
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	-	79.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	6.650	599
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	6.650	963
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	41.800	2.202
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	30.000	30.000
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	-	36.500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	-	41.943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	15.675	825
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	43.000	1.000
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	20.900	27.400
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	63.000	1.131
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	73.150	70.850
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC04] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	284.000	(1.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	62.700	3.300
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	57.000	62.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	-	32.423
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	62.700	45.019
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	2.500	2.150
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	5.000	12
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	9.600	(4.900)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	23.750	17.742
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	2.250	1.350
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	32.400	(9.353)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.600	2.574
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	5.400	(3.878)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)
CIF	GBFSA	BRA-MUCURIPE	CIV-ABIDJAN	-	144.000	(144.000)
CIF	GBFSA	BRA-MUCURIPE	GHA-TAKORADI	-	60.000	(60.000)
CIF	GBFSB	FRA-FOS	HRV-SPLIT	-	99.100	(99.100)
CIF	GBFSA	JPN-CHIBA	BGD-CHITTAGONG	-	90.000	(90.000)
CIF	GBFSA	JPN-KASHIMA	ARE-JEBELALI	-	30.000	(30.000)
CIF	GBFSA	JPN-KASHIMA	PER-SALAVERRY	-	30.000	(30.000)
CIF	GBFSA	JPN-KASHIMA	EGY-ADABIYA	-	58.200	(58.200)
CIF	GBFSA	JPN-KAWASAKI	PHL-LUGAIT	-	60.000	(60.000)
CIF	GBFSA	JPN-NAGOYA	BGD-CHITTAGONG	-	90.000	(90.000)
CIF	GBFSA	JPN-OITA	EGY-ADABIYA	-	29.800	(29.800)
CIF	GBFSA	JPN-OITA	USA-SEATTLE	-	30.000	(30.000)
CIF	GBFSA	JPN-OITA	VNM-THI_VAI_TERMINAL	-	85.600	(85.600)
CIF	GBFSA	JPN-OITA	VNM-NHON_TRACH	-	28.500	(28.500)
CIF	GBFSA	JPN-WAKAYAMA	BGD-CHITTAGONG	-	130.000	(130.000)
CIF	GBFSA	JPN-YAWATA	BGD-CHITTAGONG	-	4.000	(4.000)

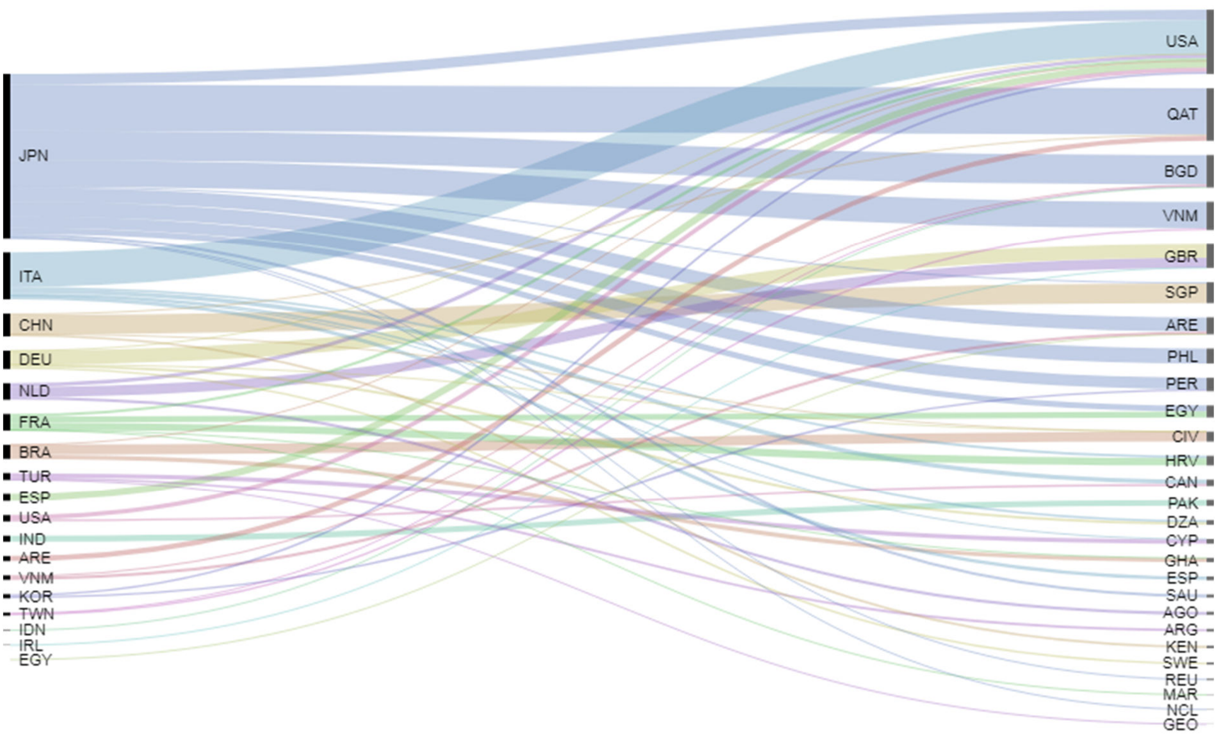

Figure I1: Alluvial diagram - Results for scenario [SC04]

Appendix J: Results for scenario [SC05]

Table J1: Results for scenario [SC05]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC05] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	162.000	62.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	164.240	(3.665)
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	58.160	3.840
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	50.880	1.620
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	44.100	229
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	172.800	6.321
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	54.000	5.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	99.000	(44.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.840	160
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	79.200	7.584
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	44.000	(130)
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	38.000	(450)
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	551.560	(378.979)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	-	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	160.000	(117.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	108.000	(24.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	-	20.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	89.000	(44.550)
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	52.000	(25.890)
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	-	124.789
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	42.000	(500)
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	294.000	(174.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	27.500	-
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	55.000	(81)
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	132.650	(88.650)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	136.000	(86.500)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	78.000	(850)
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	52.000	(690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	27.000	110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	108.000	(1.149)
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	40.240	3.758
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	72.000	7.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	-	7.249
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	-	7.613
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	83.760	(39.758)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	36.000	500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	41.000	943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	14.850	1.650
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	49.500	(1.200)
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	34.840	160
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	65.160	(1.029)
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	118.240	25.760
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC05] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	290.000	(7.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	63.360	2.640
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	108.000	11.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	29.700	2.723
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	103.680	4.039
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	4.500	150
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	-	5.012
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	14.000	(9.300)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	40.500	992
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	-	3.600
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	33.000	(9.953)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.000	3.174
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979		17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	6.000	(4.478)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

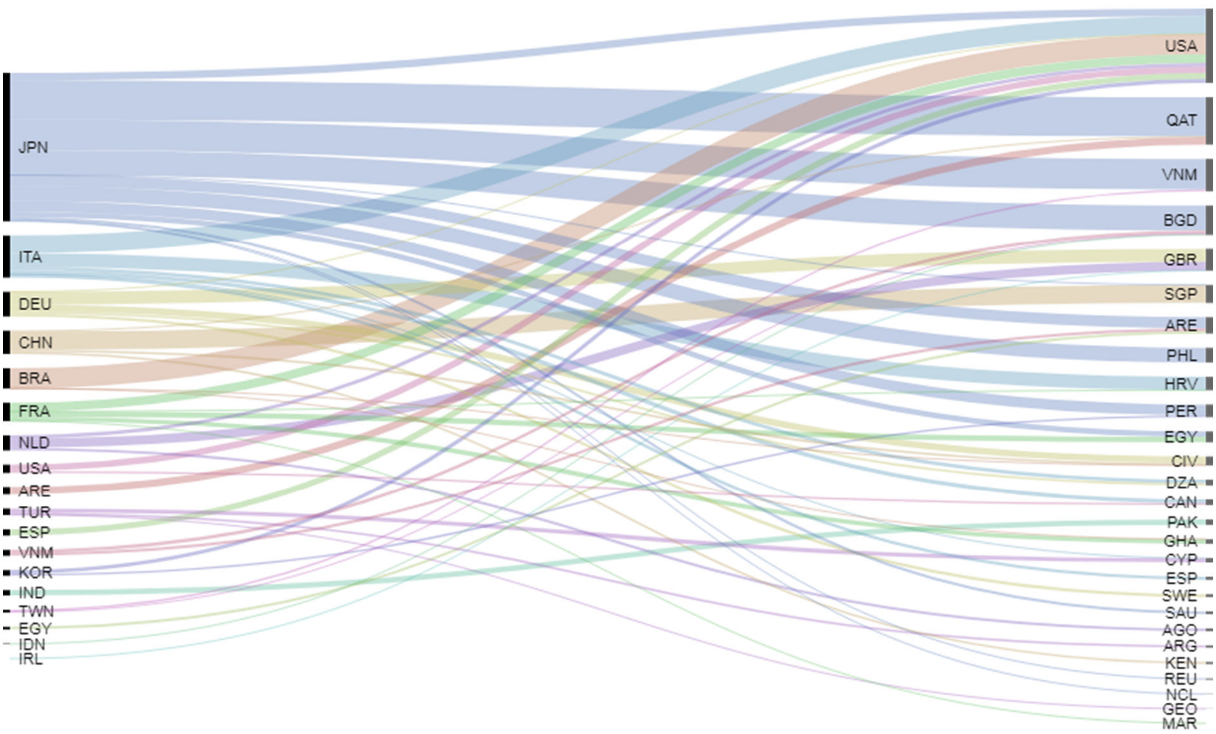

Figure J1: Alluvial diagram - Results for scenario [SC05]

Appendix K: Results for scenario [SC06]

Table K1: Results for scenario [SC06]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC06] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	162.000	62.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	164.240	(3.665)
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	58.160	3.840
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	50.880	1.620
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	44.100	229
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	172.800	6.321
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	54.000	5.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	99.000	(44.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.840	160
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	79.200	7.584
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	44.000	(130)
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	38.000	(450)
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	551.560	(378.979)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	-	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	160.000	(117.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	108.000	(24.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	27.000	100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	-	20.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	89.000	(44.550)
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	27.500	-
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	52.000	(25.890)
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	-	124.789
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	42.000	(500)
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	294.000	(174.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	27.500	-
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	55.000	(81)
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	132.650	(88.650)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	136.000	(86.500)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	78.000	(850)
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	52.000	(690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	27.000	110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	108.000	(1.149)
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	40.240	3.758
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	72.000	7.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	-	7.249
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	-	7.613
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	83.760	(39.758)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	36.000	500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	41.000	943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	14.850	1.650
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	27.000	(50)
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	49.500	(1.200)
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	65.000	(869)
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	118.240	25.760
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC06] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	290.000	(7.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	63.360	2.640
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	108.000	11.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	29.700	2.723
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	103.680	4.039
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	-	4.650
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	-	5.012
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	14.000	(9.300)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	40.500	992
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	-	3.600
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	33.000	(9.953)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.000	3.174
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	6.000	(4.478)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

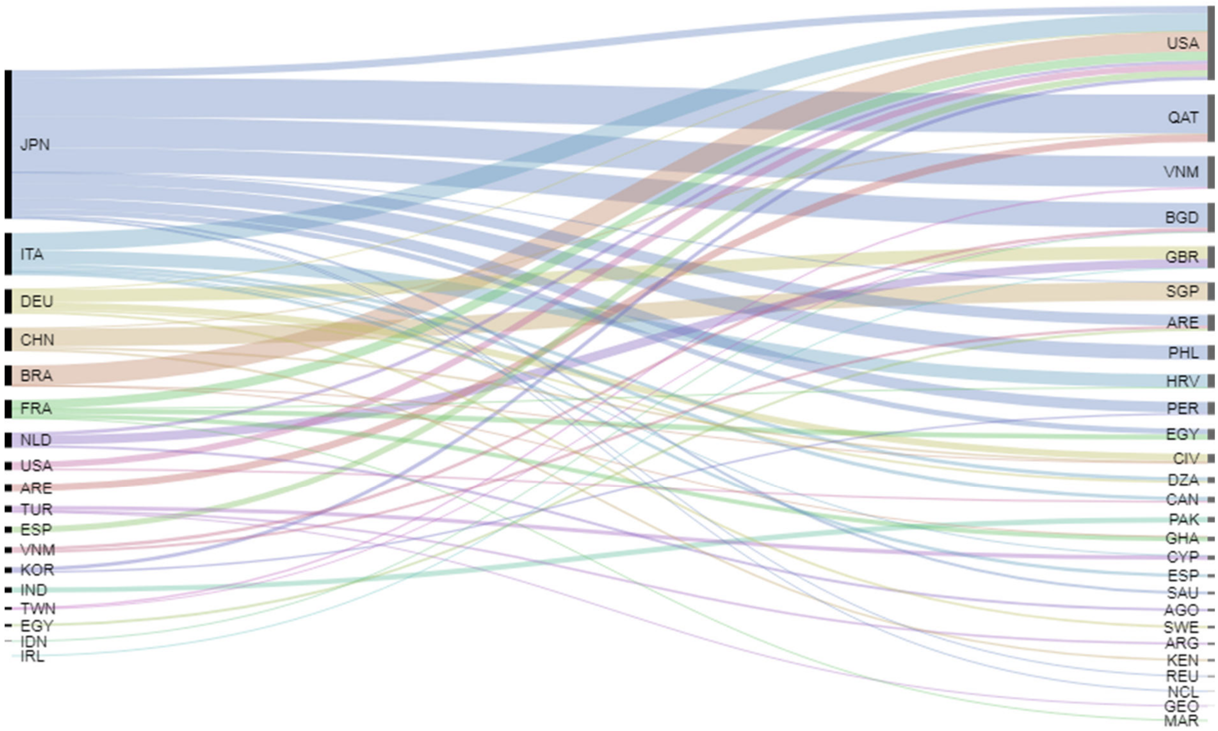

Figure K1: Alluvial diagram - Results for scenario [SC06]

Appendix L: Results for scenario [SC07]

Table L1: Results for scenario [SC07]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC07] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	-	224.630
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	-	160.575
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	62.000	-
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	49.875	2.625
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	26.600	17.729
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	91.200	87.921
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	57.000	2.228
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	273.625	(218.995)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	3.800	200
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	-	86.784
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	41.800	2.070
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	36.100	1.450
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	556.150	(383.569)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	0	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	154.000	(111.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	100.000	(16.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	25.650	1.450
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	19.000	1.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	-	44.450
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	132.000	(45.509)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	-	26.110
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	119.700	5.089
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	39.900	1.600
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	120.000	(90.000)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	210.000	(90.220)
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	55.000	(27.500)
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	27.500	27.419
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	174.425	(130.425)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	95.575	(46.075)
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	-	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	52.000	25.150
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	78.000	(26.690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	27.000	110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	68.400	38.451
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	41.800	2.198
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	40.000	39.988
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	6.650	599
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	6.650	963
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	88.000	(43.998)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	28.500	1.500
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	39.900	1.571
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	34.675	1.825
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	-	41.943
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	15.675	825
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	25.650	1.300
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	20.900	27.400
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	2.850	261
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	33.250	1.750
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	63.000	1.131
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	73.150	70.850
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	-	11.811

Incoterm	Material	Source	Destination	Baseline (tons)	[SC07] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	156.750	126.130
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	62.700	3.300
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	57.000	62.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	-	32.423
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	6.000	650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	62.700	45.019
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	2.750	1.900
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	5.000	12
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	-	4.701
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	23.750	17.742
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	2.000	1.600
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	42.000	(18.953)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	44.725	1.449
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	4.275	(2.753)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

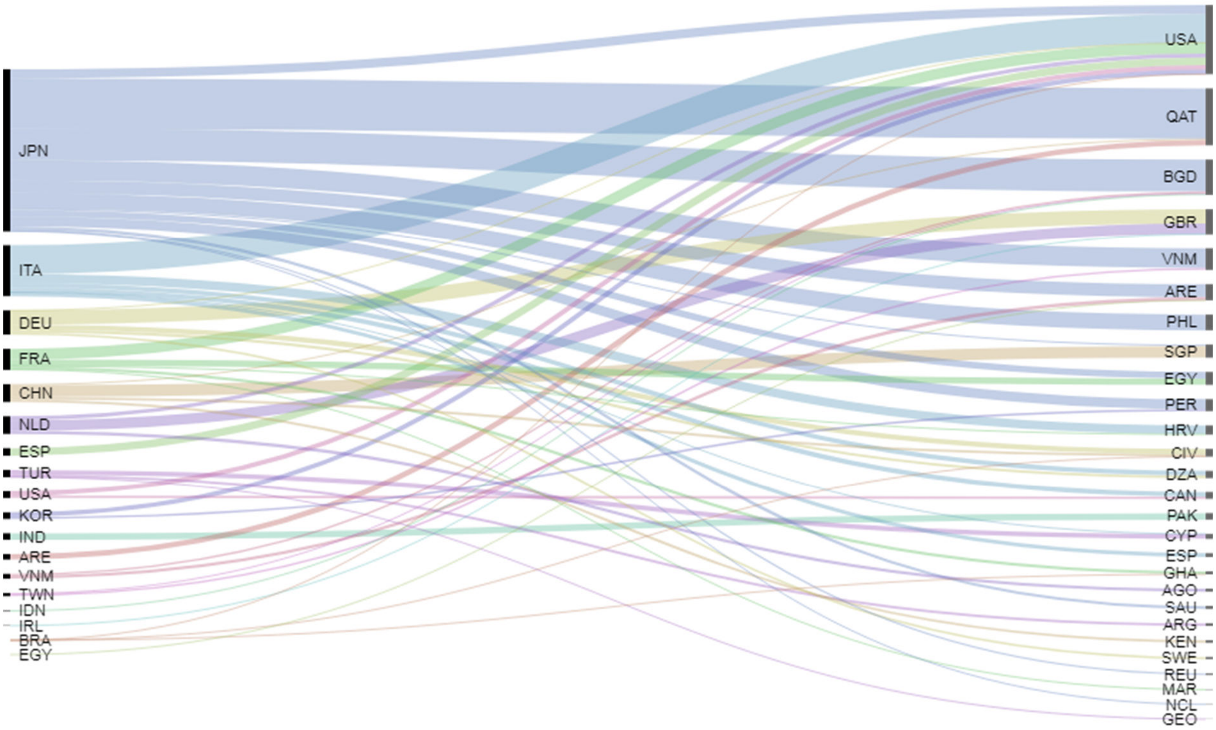

Figure L1: Alluvial diagram - Results for scenario [SC07]

Appendix M: Results for scenario [SC08]

Table M1: Results for scenario [SC08]

Incoterm	Material	Source	Destination	Baseline (tons)	[SC08] (tons)	Difference (tons)
CIF	GBFSA	BRA-MUCURIPE	USA-SPARROWS_POINT	224.630	134.400	90.230
CIF	GBFSA	BRA-PONTA_UBU	USA-SPARROWS_POINT	160.575	165.000	(4.425)
CIF	GBFSA	ESP-GIJON	USA-SPARROWS_POINT	91.598	100.000	(8.402)
CIF	GBFSA	ITA-TARANTO	DZA-ANNABA	62.000	62.000	-
CIF	GBFSA	ITA-TARANTO	ESP-CARBONERAS	52.500	52.500	-
CIF	GBFSA	ITA-TARANTO	HRV-KOROMACNO	44.329	19.950	24.379
CIF	GBFSA	ITA-TARANTO	HRV-SPLIT	179.121	166.390	12.731
CIF	GBFSA	ITA-TARANTO	USA-CAMDEN	59.228	58.800	428
CIF	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	54.630	110.000	(55.370)
CIF	GBFSA	ITA-TRIESTE	CYP-KALECIK	4.000	-	4.000
CIF	GBFSA	JPN-CHIBA	QAT-MESAIEED	86.784	44.000	42.784
CIF	GBFSA	JPN-FUKUYAMA	ARE-JEBELALI	43.870	-	43.870
CIF	GBFSA	JPN-FUKUYAMA	BGD-CHITTAGONG	102.700	-	102.700
CIF	GBFSA	JPN-FUKUYAMA	EGY-ADABIYA	43.200	88.000	(44.800)
CIF	GBFSA	JPN-FUKUYAMA	PER-PAITA	43.640	-	43.640
CIF	GBFSA	JPN-FUKUYAMA	PER-SALAVERRY	37.550	-	37.550
CIF	GBFSA	JPN-FUKUYAMA	QAT-MESAIEED	172.581	264.000	(91.419)
CIF	GBFSA	JPN-FUKUYAMA	REU-PORT_REUNION_PORT_EST	20.000	20.000	-
CIF	GBFSA	JPN-FUKUYAMA	USA-SEATTLE	60.000	-	60.000
CIF	GBFSA	JPN-FUKUYAMA	VNM-THI_VAI_TERMINAL	200.680	-	200.680
CIF	GBFSA	JPN-KASHIMA	ARE-MINA_ZAYED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	BGD-CHITTAGONG	42.790	66.000	(23.210)
CIF	GBFSA	JPN-KASHIMA	QAT-MESAIEED	44.000	-	44.000
CIF	GBFSA	JPN-KASHIMA	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-KAWASAKI	BGD-CHITTAGONG	83.851	120.000	(36.149)
CIF	GBFSA	JPN-KAWASAKI	PHL-MABINI	25.930	-	25.930
CIF	GBFSA	JPN-KAWASAKI	PHL-MARIVELES	27.100	-	27.100
CIF	GBFSA	JPN-KAWASAKI	SGP-JURONG	20.000	-	20.000
CIF	GBFSA	JPN-KAWASAKI	USA-SEATTLE	30.000	-	30.000
CIF	GBFSA	JPN-KAWASAKI	VNM-THI_VAI_TERMINAL	44.450	-	44.450
CIF	GBFSA	JPN-KIMITSU_KISARAZU	VNM-THI_VAI_TERMINAL	27.500	-	27.500
CIF	GBFSA	JPN-MIZUSHIMA	ARE-MINA_ZAYED	86.491	125.400	(38.909)
CIF	GBFSA	JPN-MIZUSHIMA	BGD-CHITTAGONG	124.874	-	124.874
CIF	GBFSA	JPN-MIZUSHIMA	EGY-ADABIYA	43.110	-	43.110
CIF	GBFSA	JPN-MIZUSHIMA	PER-PAITA	41.900	-	41.900
CIF	GBFSA	JPN-MIZUSHIMA	PHL-MABINI	26.110	-	26.110
CIF	GBFSA	JPN-MIZUSHIMA	QAT-MESAIEED	124.789	79.800	44.989
CIF	GBFSA	JPN-MIZUSHIMA	SAU-DAMMAM	41.500	-	41.500
CIF	GBFSA	JPN-MIZUSHIMA	USA-SEATTLE	30.000	114.800	(84.800)
CIF	GBFSA	JPN-MIZUSHIMA	VNM-THI_VAI_TERMINAL	119.780	-	119.780
CIF	GBFSA	JPN-NAGOYA	PHL-MABINI	27.500	27.500	-
CIF	GBFSA	JPN-NAGOYA	VNM-NHON_TRACH	54.919	-	54.919
CIF	GBFSA	JPN-OITA	BGD-CHITTAGONG	44.000	85.500	(41.500)
CIF	GBFSA	JPN-OITA	PER-PAITA	49.500	49.500	-
CIF	GBFSA	JPN-OITA	QAT-MESAIEED	176.000	0	176.000
CIF	GBFSA	JPN-WAKAYAMA	PHL-LUGAIT	77.150	-	77.150
CIF	GBFSA	JPN-WAKAYAMA	PHL-MABINI	51.310	52.000	(690)
CIF	GBFSA	JPN-YAWATA	VNM-NHON_TRACH	27.110	-	27.110
CIF	GBFSB	DEU-BREMEN	CIV-ABIDJAN	106.851	108.000	(1.149)
CIF	GBFSB	DEU-BREMEN	DZA-ANNABA	34.730	35.000	(270)
CIF	GBFSB	DEU-BREMEN	USA-SPARROWS_POINT	32.026	-	32.026
CIF	GBFSB	FRA-DUNKIRK	USA-SPARROWS_POINT	54.991	55.000	(9)
CIF	GBFSB	FRA-FOS	EGY-DAMIETTA	43.998	-	43.998
CIF	GBFSB	FRA-FOS	GHA-TAKORADI	79.988	80.000	(12)
CIF	GBFSB	FRA-FOS	HRV-KOROMACNO	7.249	7.000	249
CIF	GBFSB	FRA-FOS	MAR-NADOR	7.613	7.000	613
CIF	GBFSB	FRA-FOS	USA-SPARROWS_POINT	44.002	88.000	(43.998)
CIF	GBFSB	KOR-KWANGYANG	PER-CONCHAN	30.000	30.000	-
CIF	GBFSB	KOR-KWANGYANG	USA-SEATTLE	60.000	60.000	-
CIF	GBFSB	NLD-ROTTERDAM	AGO-LOBITO	41.471	42.000	(530)
CIF	GBFSB	NLD-ROTTERDAM	USA-SPARROWS_POINT	54.595	55.000	(405)
CIF	GBFSC	CHN-BAYUQUAN	CIV-ABIDJAN	36.500	36.000	500
CIF	GBFSC	CHN-CAOFEIDIAN	KEN-MOMBASA	16.500	20.000	(3.500)
CIF	GBFSC	CHN-JINGTANG	KEN-MOMBASA	15.401	-	15.401
CIF	GBFSC	EGY-ADABIYA	ARE-MINA_ZAYED	41.943	42.000	(57)
CIF	GBFSC	TWN-KAOHSIUNG	BGD-CHITTAGONG	16.500	49.500	(33.000)
CIF	GBFSC	TWN-KAOHSIUNG	VNM-THI_VAI_TERMINAL	26.950	-	26.950
CIF	GBFSC	VNM-SON_DUONG	ARE-MINA_ZAYED	44.000	44.000	-
CIF	GBFSC	VNM-SUN_DUONG	BGD-CHITTAGONG	48.300	-	48.300
CIF	GBFSF	TUR-ERDEMIR	GEO-POTI	3.111	3.000	111
CIF	GBFSF	TUR-ISKENDERUN	ARG-DEL_GUAZU	35.000	35.000	-
CIF	GBFSF	TUR-ISKENDERUN	CYP-KALECIK	64.131	63.000	1.131
CIF	GGBFSA	ARE-JEBELALI	QAT-MESAIEED	144.000	-	144.000
CIF	GGBFSA	CHN-CAOFEIDIAN	KEN-MOMBASA	10.999	13.000	(2.001)
CIF	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	11.811	12.000	(189)

Incoterm	Material	Source	Destination	Baseline (tons)	[SC08] (tons)	Difference (tons)
CIF	GGBFSC	CHN-LANQIAO	SGP-JURONG	282.880	290.000	(7.120)
FOB	GBFSA	ITA-TARANTO	CAN-QUEBEC	66.000	63.360	2.640
FOB	GBFSA	ITA-TARANTO	USA-CAMDEN	119.610	114.000	5.610
FOB	GBFSA	ITA-TARANTO	USA-SPARROWS_POINT	32.423	33.000	(577)
FOB	GBFSA	JPN-TOKUYAMA	NCL-NOUMEA	6.650	3.000	3.650
FOB	GBFSA	USA-EAST_CHICAGO	CAN-MISSISAUGA	28.809	29.000	(191)
FOB	GBFSA	USA-EAST_CHICAGO	USA-MILWAUKEE	107.719	104.500	3.219
FOB	GBFSB	DEU-BREMEN	SWE-UDDEVALLA	4.650	4.800	(150)
FOB	GBFSB	FRA-FOS	EGY-ALEXANDRIA	44.034	44.000	34
FOB	GBFSB	IRL-DUBLIN	GBR-GLASGOW	5.012	-	5.012
FOB	GBFSC	IDN-CIGADING	BGD-CHITTAGONG	9.000	9.000	-
FOB	GBFSC	IND-GOA	PAK-KARACHI	27.500	27.500	-
FOB	GBFSC	IND-GOA	PAK-PORT_QASIM	30.490	30.500	(10)
FOB	GBFSC	IND-MUNDRA	PAK-KARACHI	27.500	27.500	-
FOB	GGBFSA	CHN-CAOFEIDIAN	QAT-HAMAD	15.006	15.000	6
FOB	GGBFSA	DEU-BREMEN	GBR-GLASGOW	4.701	14.250	(9.550)
FOB	GGBFSA	DEU-BREMEN	GBR-RIDHAM	192.409	193.000	(591)
FOB	GGBFSA	DEU-BREMEN	SWE-LANDSKRONA	41.492	38.000	3.492
FOB	GGBFSA	DEU-BREMEN	SWE-UDDEVALLA	3.600	-	3.600
FOB	GGBFSA	NLD-DORDRECHT	GBR-ELLESMERE	46.251	47.000	(749)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GLASGOW	23.047	32.750	(9.703)
FOB	GGBFSA	NLD-DORDRECHT	GBR-GOOLE	46.174	43.015	3.159
FOB	GGBFSA	NLD-MEORDIJK	GBR-GLASGOW	17.979	-	17.979
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GOOLE	1.522	5.985	(4.463)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-GUERNSEY	510	900	(390)
FOB	GGBFSA	NLD-ROTTERDAM	GBR-JERSEY	2.729	2.800	(71)

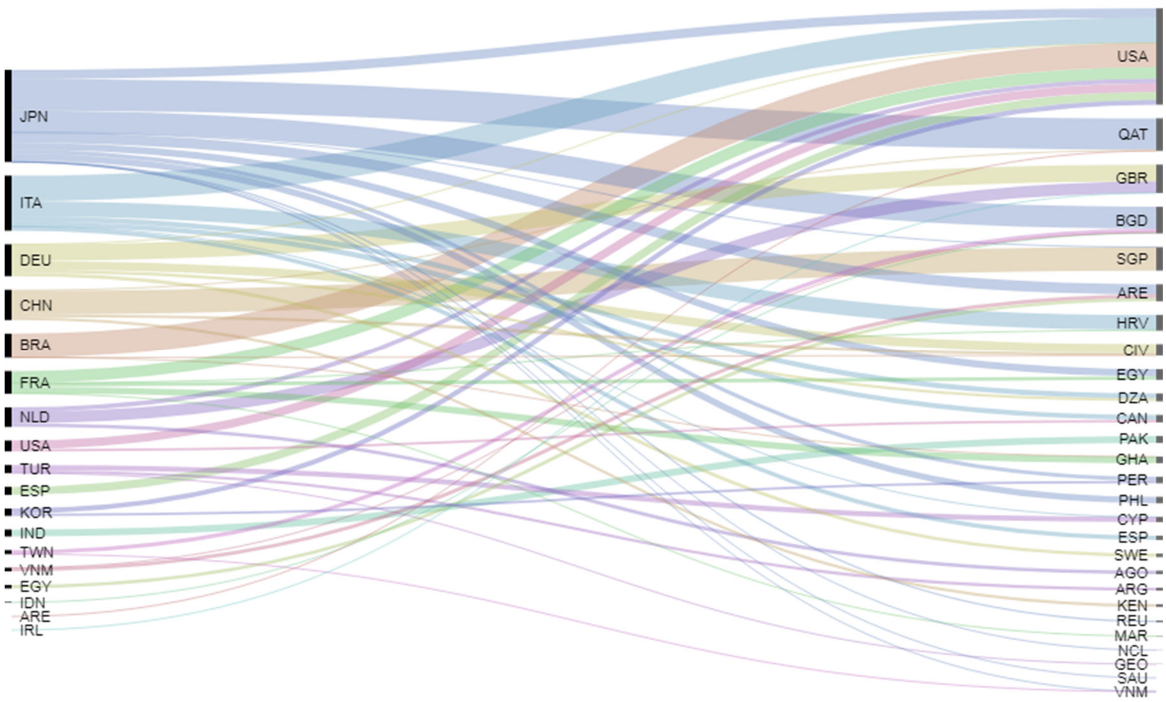

Figure M1: Alluvial diagram - Results for scenario [SC08]

Appendix N: Python script

```
## Python script
from gurobipy import *

# Import pandas
import pandas as pd

# Assign spreadsheet filename to `file`
file = 'Scenario3.xlsx'

# Load spreadsheet
xl = pd.ExcelFile(file)
# Load spreadsheet data (lists)
incoterm = xl.parse('incoterm')
incoterm=incoterm['incoterm'].values.tolist()

commodities = xl.parse('commodities')
commodities=commodities['commodities'].values.tolist()

sources = xl.parse('sources')
sources=sources['sources'].values.tolist()

customers = xl.parse('customers')
customers=customers['customers'].values.tolist()

# Load spreadsheet data (dicts)
revenue = xl.parse('revenue')
revenue = revenue.set_index(revenue[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['revenue'].to_dict()

cost= xl.parse('cost')
cost = cost.set_index(cost[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['cost'].to_dict()

transport= xl.parse('transport')
transport= (transport.set_index(transport[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['transport'].to_dict())

other = xl.parse('other')
other = other.set_index(other[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['other'].to_dict()

insurance= xl.parse('insurance')
insurance = insurance.set_index(insurance[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['insurance'].to_dict()

duties= xl.parse('duties')
duties = duties.set_index(duties[['incoterm','commodities', 'sources','customers']].apply(tuple, axis=1))['duties'].to_dict()

# Load spreadsheet data (multidicts)
maxcapacity = xl.parse('maxcapacity')
maxcapacity = maxcapacity.set_index(maxcapacity[['commodities','sources']].apply(tuple, axis=1))['maxcapacity1'].to_dict()
arcs, maxcapacity = multidict(maxcapacity)

mincapacity = xl.parse('mincapacity')
mincapacity = mincapacity.set_index(mincapacity[['commodities','sources']].apply(tuple, axis=1))['mincapacity1'].to_dict()
arcs1, mincapacity = multidict(mincapacity)

maxtotinflow = xl.parse('maxtotinflow')
maxtotinflow = maxtotinflow.set_index(maxtotinflow[['incoterm','customers']].apply(tuple, axis=1))['maxtotinflow1'].to_dict()
arcs2, maxtotinflow = multidict(maxtotinflow)

mintotinflow = xl.parse('mintotinflow')
mintotinflow = mintotinflow.set_index(mintotinflow[['incoterm','customers']].apply(tuple, axis=1))['mintotinflow1'].to_dict()
arcs3, mintotinflow = multidict(mintotinflow)

maxspecinflow = xl.parse('maxspecinflow')
maxspecinflow = maxspecinflow.set_index(maxspecinflow[['commodities','customers']].apply(tuple, axis=1))['maxspecinflow1'].to_dict()
arcs4, maxspecinflow = multidict(maxspecinflow)

minspecinflow = xl.parse('minspecinflow')
minspecinflow = minspecinflow.set_index(minspecinflow[['commodities','customers']].apply(tuple, axis=1))['minspecinflow1'].to_dict()
arcs5, minspecinflow = multidict(minspecinflow)
shipcapacity = xl.parse('shipcapacity')
shipcapacity = shipcapacity.set_index(shipcapacity[['incoterm','sources','customers']].apply(tuple, axis=1))['shipcapacity1'].to_dict()
arcs7, shipcapacity = multidict(shipcapacity)

# Create optimization model
```

```
m = Model('TradeOpt')

# Create variables y
y = m.addVars(incoterm, sources, customers, vtype=GRB.INTEGER, lb=0, ub=9999, name="y")

# Create variables flow
flow = m.addVars(incoterm, commodities, sources, customers, name="flow")

# Arc capacity constraints
m.addConstrs(
    (flow.sum('*',h,i,'*') <= maxcapacity[h,i] for h,i in arcs), "maxcap")

m.addConstrs(
    (flow.sum('*',h,i,'*') >= mincapacity[h,i] for h,i in arcs1), "mincap")

m.addConstrs(
    (flow.sum(g,'*','*',j) <= maxtotinflow[g,j] for g,j in arcs2), "maxdem")

m.addConstrs(
    (flow.sum(g,'*','*',j) >= mintotinflow[g,j] for g,j in arcs3), "mindem")

m.addConstrs(
    (flow.sum('*',h,'*',j) <= maxspecinflow[h,j] for h,j in arcs4), "maxsdem")

m.addConstrs(
    (flow.sum('*',h,'*',j) >= minspecinflow[h,j] for h,j in arcs5), "minsdem")

# Non negativity
m.addConstrs(
    (flow[(g,h,i,j)] >= 0 for g in incoterm for h in commodities for i in sources for j in customers), "nonnegativity")

# MILP constraint
m.addConstrs(
    ((y[g,i,j]*0.90*shipcapacity[g,i,j]) <= flow.sum(g,'*',i,j) for g,i,j in arcs7), "shipcap")

m.addConstrs(
    ((y[g,i,j]*shipcapacity[g,i,j]) >= flow.sum(g,'*',i,j) for g,i,j in arcs7), "shipcap1")

# Define objective function
m.setObjective(quicksum(flow[x]*(revenue[x]-cost[x]-transport[x]-other[x]-insurance[x]-
((cost[x]+transport[x]+other[x]+insurance[x])*duties[x])) for x in revenue.keys()), GRB.MAXIMIZE)
m.write('tradeopt.lp')

# Compute optimal solution
m.optimize()

# Print solution
if m.status == GRB.Status.OPTIMAL:
    solution = m.getAttr('x', flow)
    print ('\nProposed allocation (in tons)')
    for g in incoterm:
        for h in commodities:
            for i in sources:
                for j in customers:
                    if solution[g,h,i,j] > 0:
                        print('%s : %s : %s : %s : %g' % (g,h,i, j, solution[g,h,i,j]))

if m.status == GRB.Status.OPTIMAL:
    solution = m.getAttr('x', y)
    print ('\nProposed allocation (in # of ships) -> (ship capacity)\n')
    for g in incoterm:
        for i in sources:
            for j in customers:
                if solution[g,i,j] >= 1:
                    print('%s -> %s -> %s: %r ->'% (g, i, j, solution[g,i,j]), shipcapacity[g,i,j])
```