Assessing the Environmental Impact of Regional Sourcing Strategies for Ready-to-Use Therapeutic Food (RUTF)

by

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ABSTRACT

Severe acute malnutrition affects millions of children globally. Ready-to-Use Therapeutic Food (RUTF) is a life-saving treatment, but distributing it at scale across complex international supply chains is costly and generates substantial transportation-related carbon emissions. This capstone examines how transportation carbon emissions and costs compare when sourcing RUTF from South Asia versus other regions and identifies the trade-offs associated with each strategy. We mapped the current South Asia RUTF sourcing network, estimated shipment-level transportation carbon emissions using an expression from the Network for Transport Measures (NTM) methodology, and developed a multi-objective optimization model to evaluate baseline and alternative sourcing scenarios. Results show that optimizing the current network reduces emissions by up to 57.3% and costs by 34.6%. We recommend aligning sourcing and routing decisions with the optimization model outputs, prioritizing local South Asian suppliers to improve both sustainability and cost performance. More broadly, the NTM methodology paired with optimization modeling offers organizations a practical framework to evaluate shipment-level trade-offs in global supply chains. This demonstrates that intentional supplier and routing decisions can simultaneously cut costs and emissions, with regional sourcing often yielding gains in both metrics without compromise.

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1 Introduction

Ready-to-Use Therapeutic Food (RUTF) plays a key role in global efforts to treat severe acute malnutrition and reduce child mortality. Delivering RUTF at scale requires extensive transportation across global supply chains, which contributes significantly to carbon emissions. As a result, humanitarian organizations must balance the urgency of life-saving nutritional support with the environmental impact of the logistics systems that enable it.

This section first outlines the importance and challenges of RUTF supply chains. It then presents the key questions and expected outcomes. Finally, it outlines the organization of the capstone.

1.1 Motivation

RUTF is essential for treating millions of children affected by severe wasting each year. It is a nutrient-dense product made from milk powder, peanuts, vitamins, and minerals, providing approximately 500 calories per sachet and remaining shelf-stable for up to two years without refrigeration (UNICEF, n.d.-b), while rising raw material costs and increasing demand continue to strain limited budgets.

Meeting this demand requires a highly responsive and efficient global distribution network. RUTF must reach vulnerable populations quickly, often in regions with limited infrastructure and unstable conditions. These constraints increase reliance on complex transportation systems that span long distances and multiple modes of transport, making logistics a critical component of effective humanitarian response.

However, this heavy reliance on transportation also contributes to environmental impact. Transportation accounts for nearly one-quarter of global carbon emissions (United Nations, 2026). As organizations expand procurement and distribution to meet growing needs, the carbon footprint of RUTF supply chains becomes an increasingly important concern. These challenges highlight the need to better understand and manage the trade-offs between cost, responsiveness, and environmental sustainability.

The following section presents the specific problem this project addresses.

1.2 Problem Statement and Project Outcomes

This capstone is a joint collaboration between UNICEF and the MIT Sustainable Supply Chain Lab. The project examines transportation-related carbon emissions associated with sourcing Ready-to-Use Therapeutic Food (RUTF) from South Asia versus other regions, such as Africa and Europe, and the trade-offs associated with each sourcing strategy.

The main research question for this capstone is:

- How do transportation-related carbon emissions compare when sourcing RUTF from South Asia versus other regions, and what are the trade-offs associated with each sourcing strategy?

To answer this, we study the following related questions and objectives:

- What are the key factors to consider in measuring transportation-related carbon emissions in the current network and future alternative scenarios?
- What are the changes in transportation-related carbon emissions and the trade-offs between carbon emissions and cost in optimized scenario compared to the current flow?
- What are the feasible sourcing scenarios that minimize transportation-related carbon emissions?

To address these questions, we map the current RUTF supply chain network across sourcing regions in Europe, Africa, and Asia. We estimate transportation-related carbon emissions for UNICEF transportation activity data, including origins, destinations, distances, transport modes, and shipment volumes. We then model alternative sourcing configurations and compare the resulting changes in carbon emissions and operational trade-offs.

The project delivers three main outcomes:

- Visualization of the current RUTF supply chain network
- Estimation of carbon emissions from sourcing RUTF in the current supply chain network
- Comparative assessment of cost and carbon emissions drivers and trade-offs between different sourcing scenarios

The project focuses on transportation-related carbon emissions from suppliers to UNICEF distribution points or designated program sites. It does not include emissions from RUTF production or manufacturing, detailed cost analysis or financial feasibility assessments, downstream distribution beyond the agreed destination points, or broader environmental or social impacts outside transportation-related carbon emissions.

Figure 1 outlines the main steps to be conducted in this capstone. As needed, we will return to prior steps to reassess calculations or scenario models.

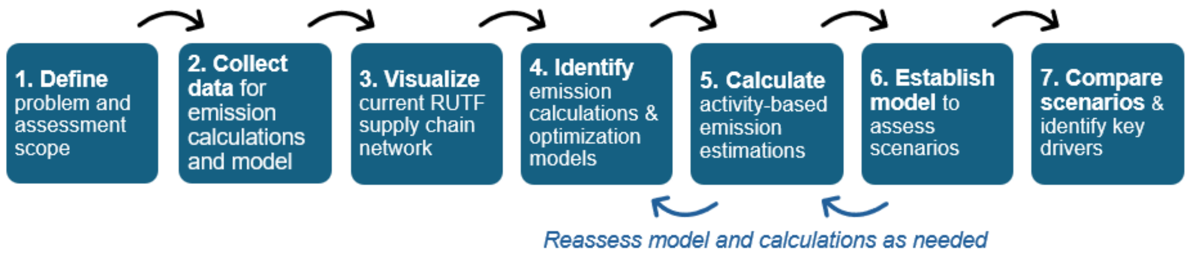


Figure 1: Progression of Main Steps of Capstone Project

Our results show that the emissions-optimized model reduces carbon emissions by 57.3% compared with the historical network while the cost-optimized model reduces costs by 34.6%. The Pareto frontier shows that near-minimum emissions can be achieved with only a small increase in cost, which suggests limited trade-offs between the two objectives in the current network.

In the local sourcing scenario, the emissions-optimized model reduces transport-related carbon emissions by 65.1% compared with the current network, and the cost-optimized model reduces costs by 48.1%. These results indicate that sourcing from local regions can significantly improve both environmental and cost performance and are discussed thoroughly in Section 4.

The remainder of this capstone is organized as follows. Section 2 presents the state of the practice and reviews the methods used to calculate transport-related carbon emissions and evaluate multi-objective optimization. Section 3 describes the methodology used to understand the current network, estimate carbon emissions, and apply the optimization model. Section 4 presents the results and discussion. Section 5 presents the alternative scenario analysis. Section 6 offers recommendations and concludes the capstone.

2 State of the Practice

This section reviews the relevant literature that informed our methodology. It focuses on carbon emissions estimation in freight transport, facility location models that incorporate carbon emissions, and multi-objective optimization, all of which guided our approach to analyzing UNICEF's RUTF sourcing network.

2.1 Carbon Emissions Calculations

Several frameworks exist for calculating freight transport carbon emissions. The ISO 14083 standard provides a globally recognized method for end-to-end carbon emissions calculations across transport activities (Biemann & Dobers, 2024). The GLEC Framework, developed by the Smart Freight Centre and aligned with ISO 14083, is widely used by large shippers and NGOs (Smart Freight Centre, 2025; Ehrler et al., 2025). Both are comprehensive but share an important limitation for this project: neither explicitly accounts for empty vehicle movements, which are the repositioning trips required before a loaded leg begins. When routes involve significant empty running, these frameworks can systematically underestimate total transport carbon emissions (McKinnon, 2010).

The NTM methodology addresses empties directly by incorporating empty vehicle positioning distances into its carbon emissions calculations. Rather than applying the full NTM methodology, we used a specific expression from the NTM framework that is designed for network design problems. This expression captures the carbon emissions impact of empty running and calculates carbon emissions at the shipment level, making it well suited for a network optimization model that also operates at the shipment level.

2.2 Facility Location with Carbon Emissions

The problem of selecting suppliers and routing supply flows to meet demand is commonly formulated as a facility location problem, where nodes represent suppliers and demand points, and arcs represent transport flows. Traditional facility location models minimize cost alone, but a growing body of literature incorporates environmental objectives. Velázquez Martínez & Fransoo (2016) show that the choice of carbon emissions calculation methodology affects which facility locations are selected as optimal. This highlights the importance of using an appropriate carbon emissions calculation methodology directly into the facility location model, rather than treating the two as separate steps.

2.3 Multi-Objective Optimization

While minimizing carbon emissions is central to this project, UNICEF also has budget constraints and must spend efficiently to maximize the reach of its humanitarian programs. This project must therefore simultaneously minimize cost and carbon emissions. Because of this, a multi-objective optimization approach is required. The two most common exact methods are weighted-sum and the epsilon-constraint (ε-constraint) method. The weighted-sum approach combines both objectives into a single function using assigned weights, but it can struggle to find optimal solutions when the objective space is non-convex (Asha et al., 2022). The ε-constraint method avoids this limitation by optimizing one objective directly while treating the other as a constraint and iterating across constraint levels to trace the Pareto frontier (Van der Plas, 2012). The Pareto frontier represents the set of solutions where neither objective can be improved without worsening the other and is a useful tool for understanding trade-offs.

Ardizzone (2024) benchmarks both methods alongside metaheuristic approaches in supply chain network design problems and finds the ε-constraint method to be the most consistent performer in achieving low cost and low carbon emissions within reasonable computation times. Given the relatively small scale of UNICEF's RUTF shipment data, exact methods are computationally feasible. The ε-constraint method was therefore selected for its robustness and its demonstrated performance in comparable settings.

2.4 Overall Approach

This literature points to an approach that pairs a shipment-level carbon emissions calculation method with a multi-objective network design framework. By using the NTM-based expression to estimate transportation-related carbon emissions and embedding those estimates within an ε-constraint facility location model, we can generate a Pareto frontier of cost-emissions trade-offs and provide UNICEF with optimized sourcing recommendations. The following section details how this approach was applied.

3 Methodology

This section presents the methodology used to investigate cost-emissions trade-offs in UNICEF's RUTF supplier selection across South Asia. As outlined in Figure 2, the methodology consists of three sequential steps. Steps 1 and 2 are covered in this section, while Step 3 is addressed in Sections 4 and 5.

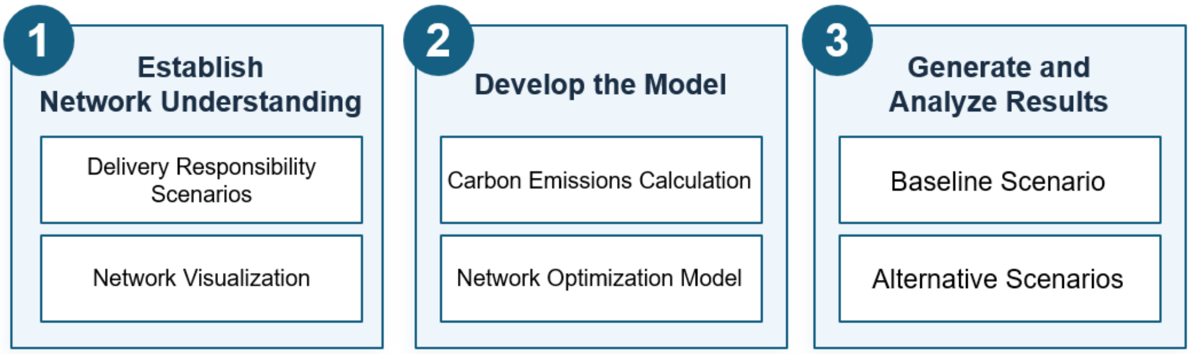


Figure 2: Key methodology steps

3.1 Establish Network Understanding

Before selecting an appropriate carbon emissions calculation and optimization methodology, it is important to develop a clear understanding of UNICEF's current RUTF supply network. To establish this baseline, we analyzed the current RUTF flows and visualized the current network.

3.1.1 Delivery Responsibility Scenarios

UNICEF's RUTF supply chain considers two end-delivery options. In Scenario 1, a UNICEF-appointed freight forwarder manages transportation from suppliers to central warehouse within the destination city via land or multimodal transportation. Once the shipment reaches the destination warehouse, outbound distribution is handled by UNICEF's implementation partner or the government.

In Scenario 2, a UNICEF-appointed freight forwarder manages transportation from suppliers to the destination port via land or multimodal transportation. Responsibility then transfers to the government at the port, including customs clearance and onward distribution.

To comprehensively capture transportation impacts, this project includes carbon emissions and costs from the supplier to the destination warehouse, regardless of delivery responsibility scenario.

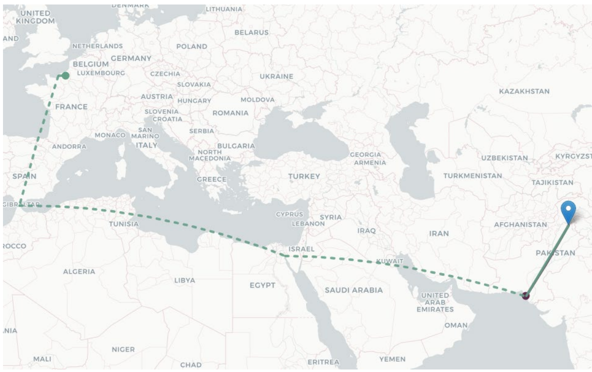
3.1.2 Network Visualization

Next, we visualized the current network to better understand the existing operating structure. Notably, a significant portion of the current RUTF supply originates from suppliers located a considerable distance from the destination country. The distinct supplier options and transport routes utilized by each destination country are influenced by several factors: total volumes required, geographic location, geopolitical conditions, and pre-existing supplier contracts. Figure 3 provides a summary of the RUTF networks currently in use for each destination country. Note that the routes are created based on the assumptions to build the baseline.

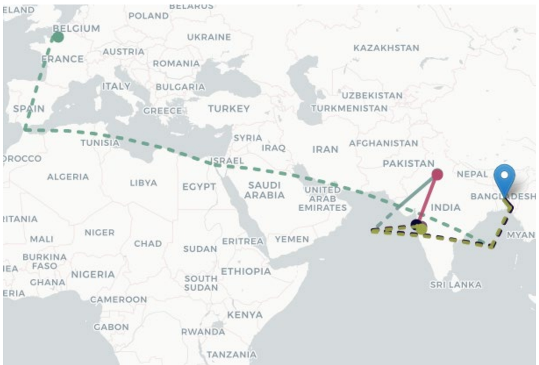
Legend: Inland transport —— Ocean - - - Origin ● Destination
Colors on map represent flows from individual suppliers

Kabul, Afghanistan
Afghanistan has received the highest volume of RUTF over the past two years. This demand necessitated the use of the most suppliers. These suppliers are geographically diverse, ranging across Africa, Europe, and more local options.

Islamabad, Pakistan
Pakistan was the recipient of the second-largest volumes of RUTF in the past two years. The country utilized two distinct supplier options: one located a significant distance away in France, and a second, local option within the country.



Dhaka, Bangladesh
Bangladesh received the third-largest volume of RUTF shipments. The country used one supplier from France and multiple suppliers from India.



Colombo, Sri Lanka
Sri Lanka required limited RUTF shipments in recent years. Shipments have been sourced from a single supplier option in Norway transported via ocean.

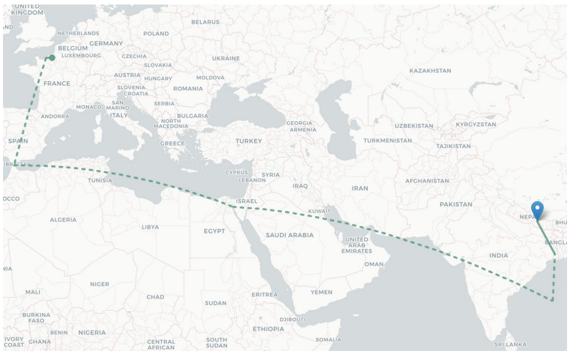
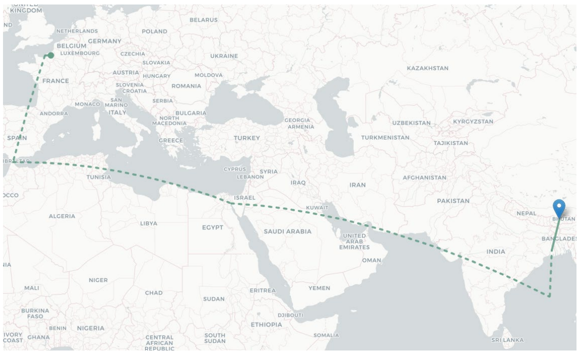
<table>
<tr>
<td>Kathmandu, Nepal
Nepal has also required limited RUTF shipments over the past two years. It has relied on a single supplier option in France.
</td>
<td>Thimphu, Bhutan
Bhutan has required limited RUTF shipments over the past two years. Like Nepal, it has relied on a single supplier option in France.
</td>
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Figure 3: Visualization of current RUTF sourcing network (UNICEF, personal communication, November 2025)

Afghanistan has the highest demand for RUTF in UNICEF's current network, so it relies on several sourcing routes to meet this demand, reflecting the complexity of serving a single high-demand destination.

3.2 Model Development

We partnered with UNICEF to gather data on their RUTF network for South Asia for the optimization model. They shared information on demand nodes, suppliers, and transportation routes, along with relevant organizational context. Shipment-level data was limited, so the analysis incorporates reasonable assumptions and publicly available sources when needed, therefore results may differ from actual operations. The collected data was cleaned and transformed to support an optimization model that can be run across multiple scenarios.

3.2.1 Carbon Emissions Calculation

To calculate carbon emissions based on NTM methodology, we need to convert distance and load factors to total transport carbon emissions, then embed that into an optimization model that balances carbon emissions and cost.

Following is an expression derived from the NTM formula for calculating truck transportation carbon emissions, as applied to the network design problem:

$$TE = D \times [2 * CEempty + (CEfull - CEempty) * LF]$$

- TE: total carbon emissions of a trip
- $CEempty$: carbon emitted per km when the vehicle is empty
- $CEfull$: carbon emitted per km when the vehicle is fully loaded
- D: distance traveled in km
- LF: load factor (how full the vehicle is, between 0 and 1)

Carbon emissions of empty and full trucks are based on NTM baselines of the 2026 global average for a 34-40 ton truck with trailer. These baselines were used because fuel consumption data was unavailable and they provide conservative estimates.

We begin with empty carbon emissions *(CEempty)*. The incremental carbon emissions between empty and full loads *(CEfull−CEempty)* are scaled by the load factor LF and added to *CEempty*. To account for return trips, empty carbon emissions are multiplied by two. Total carbon emissions are then calculated by multiplying the output by distance (D).

For ocean and air transportation, the following NTM calculation expression was utilized:

$$TE = D \times [CE * W]$$

- TE: total carbon emissions of a trip
- CE: carbon emitted per Ton/km
- W: weight of the shipment in Ton

3.2.2 Network Optimization Model

Next, we convert these formulas to be utilized in our optimization model's objective function. The optimization model aims to minimize total carbon emissions, TE, while servicing all demand seen in the historical dataset. The model is built as follows:

$$min\, TE = \sum_{(s,d,m,i)\epsilon\Omega} Y_{sdmi} * (et_i * dt_{sdm} + w_i * doa_{sdm} * eoa_m)$$

$$subject\ to$$

$$Y_{sdmi} \,\epsilon\, \{0,1\}, \qquad \forall(s,d,m,i) \in \Omega$$

$$\sum_{(s,d,m):(s,d,m,i)\epsilon\Omega,} Y_{sdmi} = 1, \qquad \forall i \in I,$$

$$\sum_{(d,m,i):(s,d,m,i)\in\Omega} Y_{sdmi} * q_i \geq c_s, \qquad \forall s \in S,$$

$$\sum_{(s,d,m,i)\in\Omega} p_{sdm} * Y_{sdmi} \leq \varepsilon$$

Sets:

- I: set of shipments
- S: set of suppliers
- D: set of destination countries
- M: set of transport modes
- $(s,d,m,i)\ \epsilon\ \Omega$: set of all feasible routing combinations

Decision variable:

- $Y_{sdmi} \in \{0,1\}$: binary variable where 1 = shipment I is fulfilled via supplier S, to destination D, and using mode M; otherwise, 0

Parameters:

- ε: maximum cost allowed [$]
- dt_{sdm}: trucking distance for route $sdm\ \epsilon\ \Omega\ [km]$
- doa_{sdm}: ocean or air distance for route $sdm\ \epsilon\ \Omega\ [km]$
- et_i: trucking carbon emissions factor for shipment $i\ \epsilon\ I\ [kg/km]$
- eoa_m: carbon emissions factor for mode $m\ \epsilon\ M\ [kg/tkm]$

- w_i: load of shipment $i \epsilon I$ $[tonnes]$
- q_i: quantity of sachets in shipment $i \epsilon I$
- c_s: minimum contractual volume per supplier $s \in S$
- p_{sdm}: cost per shipment of transport for each route $sdm \epsilon \Omega$

The formulation above serves as the baseline structure for all optimization scenarios used in this study. Throughout the remainder of the paper, we refer to two primary model variants:

1. Emissions-optimized model: This model minimizes total transportation carbon emissions while satisfying all demand and constraints. It is the formulation presented above and is used to generate the Pareto frontier by varying the cost constraint.
2. Cost-optimized model: This model minimizes total transportation cost while satisfying all demand and contract minimum constraints, without explicitly considering carbon emissions. It provides a benchmark for the lowest achievable cost within the network.

These two models are used comparatively in the results section to evaluate trade-offs between cost and carbon emissions in the transportation network.

4 Results and Discussion

This section presents the results of the optimization model and compares the historical network with the emissions-optimized and cost-optimized solutions. Optimizing the network's supplier and routing decisions creates a transportation network that achieves significant cost and carbon emissions savings. The emissions-optimized model produces a 57.3% reduction in carbon emissions compared to the historical network and 33.8% in cost savings. It shows that shifting to emissions-optimized supplier selection can significantly reduce both cost and carbon footprint, with total costs only slightly higher than the cost-optimized solution. Table 2 summarizes these comparisons.

Data/Model	**Total Cost ($)**	**Total Carbon Emissions (kg)**
Historical Transport Data	$2,547,300	2,444,423
Emissions-Optimized Model	$1,685,185 *(33.8% decrease from baseline)*	1,088,250 *(57.3% decrease from baseline)*
Cost-Optimized Model	$1,666,776 *(34.6% decrease from baseline)*	1,094,462 (*57.0% decrease from baseline)*

Table 2: Summary comparison of historical data, emissions-optimized model, and cost-optimized model

The optimization results yield two primary insights. First, cost savings are substantial. The cost-optimized model cuts total transportation costs from $2.55M to $1.67M, a 34.6% reduction. It achieves this by choosing more local suppliers which offer the lowest transportation cost for each destination while meeting all delivery constraints. Second, carbon emissions reductions are even more impactful. The emissions-optimized solution cuts carbon emissions from 2.44M kg to 1.09M kg, a 57.3% drop. This suggests the historical route was environmentally inefficient, often relying on longer-distance routes despite shorter alternatives being available.

The ε-constraint method, used to trace the cost-emissions frontier, revealed a tight trade-offs zone. As discussed further in Section 4.2, the Pareto front shows that costs range from $1.67M to $1.69M while carbon emissions range from 1.088M to 1.094M kg. This tells us that near-minimum carbon emissions can be achieved without meaningfully increasing the cost, hence the sweet spot likely is anywhere along this front.

4.1 Optimized Supplier Selection

To minimize environmental impact, the emissions-optimized model selected 14 out of the 20 available suppliers within UNICEF's RUTF supply chain. Consequently, the volume of sachets allocated to each supplier deviates from historical patterns. However, destinations served by a single supplier remained unchanged, as the model had no alternative options for optimization. Figure 4 illustrates these primary shifts within the emissions-optimized network.

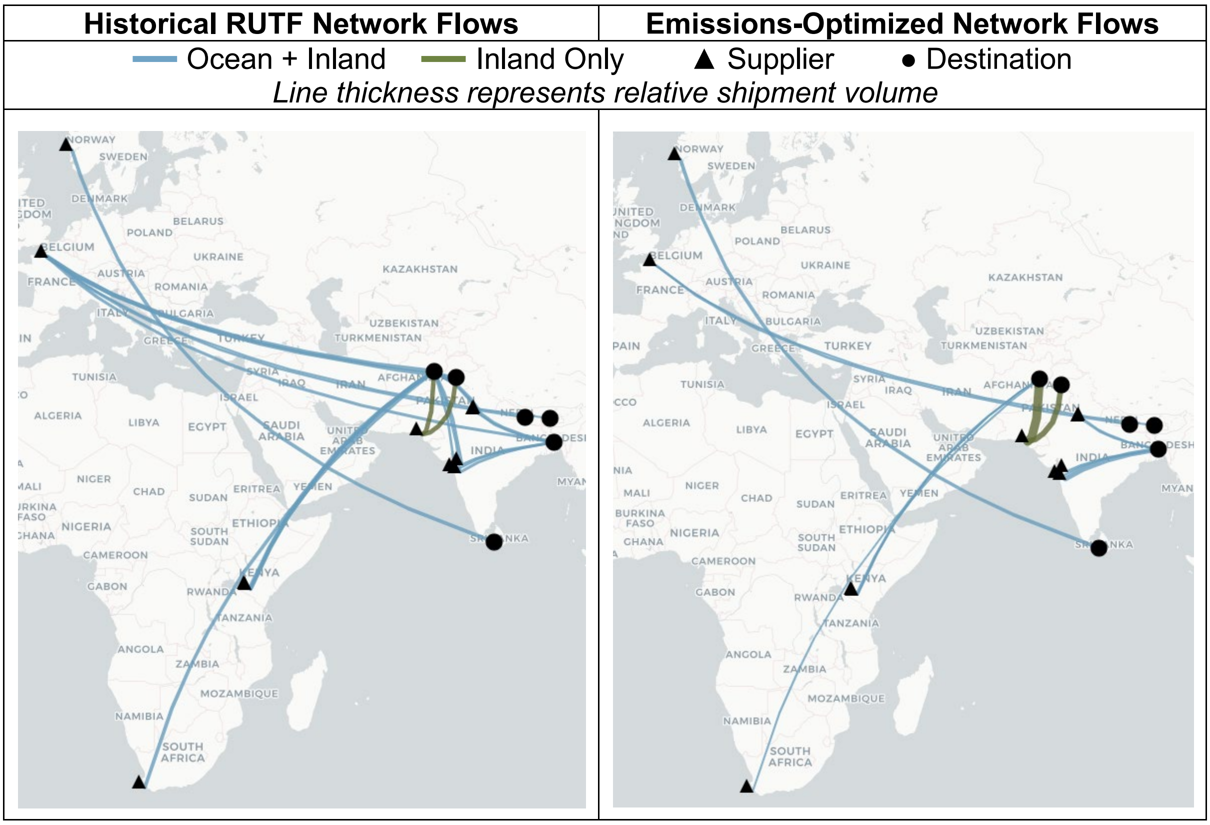

Figure 4: Comparison of historical network and emissions-optimized network flows

The emissions-optimized model maximized RUTF quantities from a supplier that is located close to each destination, as shown in Figure 4 by the thickness of the lines.

The model assigned 92% of Afghanistan's total RUTF demand to a single Pakistan-based supplier, Ismail Industries Limited, reflecting the high-volume requirements of that specific country. The model identified inland trucking from Pakistan as the most environmentally friendly option for Afghanistan, despite historical data showing that the majority of shipments originated from suppliers in France, Kenya, and South Africa. While ocean freight is generally the most sustainable mode of transport, the specific logistics of this route favored the shorter inland journey over long-distance multimodal shipping.

This tells us that distance matters when it comes to measuring carbon footprint, and therefore, a regional sourcing strategy is critical to address carbon emissions reduction in UNICEF's RUTF supply chain.

4.2 Emissions-Cost Trade-Offs Implications

As shown in Table 2, the emissions-optimized model also significantly reduces cost even though it does not optimize for cost directly. The total transportation cost differs from the cost-optimized model by only $18,409.

The limited difference between cost-optimized and emissions-optimized outcomes is driven by minimal trade-offs in supplier selection. In most cases, the lowest-cost supplier is also the lowest-emissions option. The primary exception occurs for shipments to Bangladesh. For Bangladesh, the supplier with the lowest transportation carbon emissions is Hexagon Nutrition Ltd. (Mumbai, India), while the lowest transportation cost supplier is LUMN Labs Pvt. Ltd. (Wasuli, India).

Trade-offs in Bangladesh shapes the Pareto front shown in Figure 5. While the Pareto front appears approximately linear, this is not due to continuous trade-offs between cost and carbon emissions. Instead, as tighter cost constraints are applied through the ε-constraint method, the model shifts Bangladesh shipments from Hexagon Nutrition Ltd. (lower emissions) to LUMN Labs Pvt. Ltd. (lower cost). Each point on the Pareto front reflects these stepwise shifts, which creates the appearance of linearity.

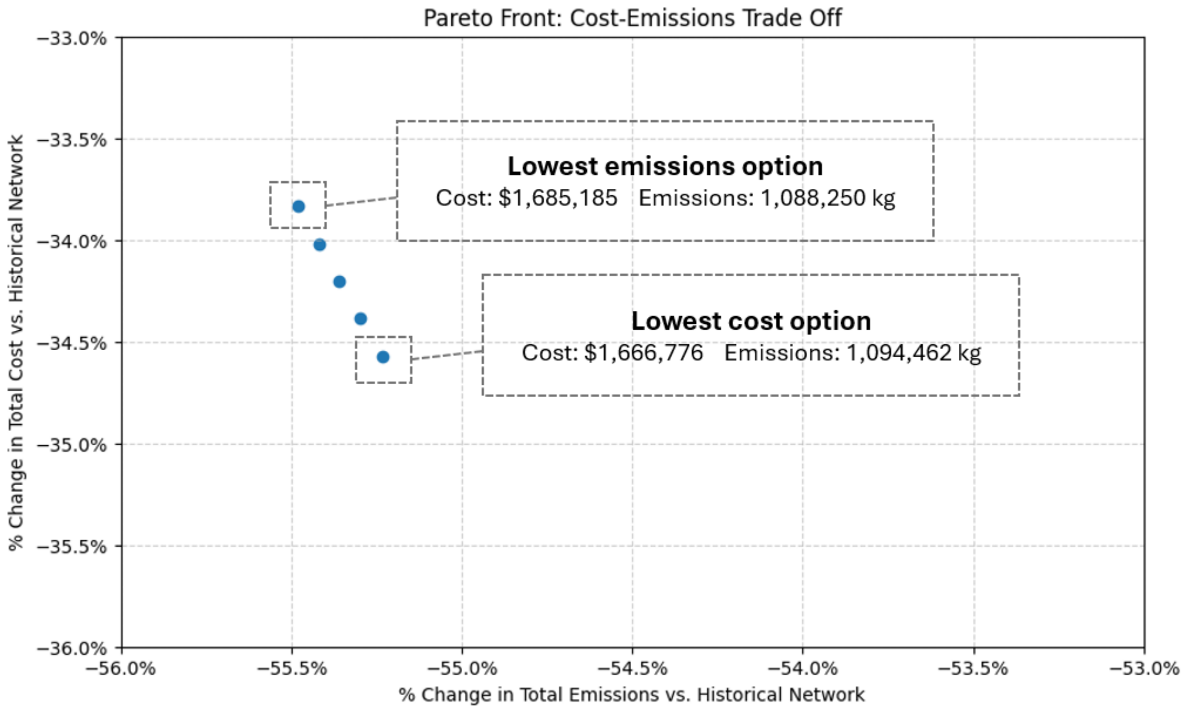

Figure 5: Pareto front displaying the cost vs. emissions trade off in optimal supplier selection

Using the Pareto front, UNICEF can choose whether they want to optimize emissions, cost, or for somewhere in between, as represented by the middle dots. However, as discussed, these tradeoffs are relatively small.

4.3 Limitations

It is important to acknowledge several limitations of this model. The scope of this capstone project was limited to transportation activity and cost. The model only captures carbon emissions and costs from the physical movement of goods–inland trucking legs and ocean freight. It excludes upstream suppliers' manufacturing carbon emissions, warehousing, lastmile delivery beyond capital cities, and any reverse logistics. The cost is also simplified to a per ton-km rate, not including fixed costs.

The model relies on limited supplier information. We worked with a fixed set of vendor data referenced from UNICEF's publicly available information and pre-defined baseline routes assumed through interviews with UNICEF staff. The model does not incorporate supplier capacity data, so it cannot assess whether suppliers can realistically absorb additional volume. Contract minimums are referenced, but supplier maximum capacities, lead times, and reliability data are absent, which limits how fully operational feasibility can be assessed.

The emissions factors used in the model are global averages from the NTM baseline, applied uniformly across all trucking legs regardless of the actual country, road infrastructure, vehicle fleet age, or fuel type used. A truck operating in rural Afghanistan on unpaved roads will have a different real-world carbon emissions profile than one on a European motorway. Similarly, ocean carbon emissions are measured using a single CO_2 per ton-km factor without differentiating by vessel type, ship size, or actual fuel used.

5 Alternative Scenario Analysis

This section explores how different sourcing scenarios impact cost and carbon emissions across the RUTF supply chain. It presents a set of alternative constraints and strategies, compared with the baseline scenario.

5.1 Local Sourcing Scenario: Allowing Pakistan and India to Serve All Demand

UNICEF employs a centralized sourcing strategy, in which headquarters in Copenhagen manage global supplier selection through a formal bidding process. This competitive framework invites global participation to ensure UNICEF achieves its core objective of "Best Value for Money" (UNICEF, n.d.-c). However, because the current process primarily prioritizes cost and quality, we further evaluate how increased local supplier selection could reduce carbon emissions and what the associated cost trade-offs might be. Based on the outcomes of the baseline network optimization in Section 4, we believe there are significant opportunities to further reduce the carbon footprint within the RUTF supply chain.

From the baseline model, we modified the parameters to ensure that the local suppliers in Pakistan and India were available as sourcing options for all destination countries. Specifically, for any destination where these suppliers were not previously included in the feasible route set, we added them as additional options.

Finally, we removed contract minimum constraints—the requirements that a specific volume be purchased from certain suppliers regardless of cost or distance—to enable the model to optimize based solely on carbon emissions and cost. This allows for a clearer assessment of the potential benefits of local sourcing. All other conditions remain identical to the baseline model, including constant demand levels and the absence of supplier-capacity constraints. Table 3 summarizes the total carbon emissions and cost savings for each model.

Data/Model	Total Cost ($)	Total Carbon Emissions (kg)
Historical Transport Data	$2,547,300	2,444,423
Emissions-Optimized Model	$1,484,011 *(41.7% decrease from baseline)*	853,068 *(65.1% decrease from baseline)*
Cost-Optimized Model	$1,321,904 *(48.1% decrease from baseline)*	909,024 *(62.8% decrease from baseline)*

Table 3: Local sourcing scenario comparison of historical data, emissions-optimized model, and cost-optimized model

The local sourcing scenario's emissions-optimized model suggests that UNICEF can reduce carbon emissions by 65.1% compared to the current network, from 2.44M kg to 853K kg. The cost-optimized model suggests that UNICEF can cut costs by 48.1% from $2.55M to $1.32M, indicating significant cost savings by adopting a local sourcing strategy. The results indicate that a local sourcing strategy further reduces both carbon emissions and costs beyond the improvements achieved in the optimized current network. By removing contract minimums in this scenario, we isolate the impact of local sourcing and identify the maximum potential scale of carbon and cost reduction.

5.2 Emergency Scenario: Air Only

Geopolitical conflicts or climate events can create humanitarian crises that require immediate response. When speed is critical, or when ports and roads are compromised, air transportation becomes necessary. RUTF deliveries from France-based suppliers to South Asia have utilized air transportation in the past.

However, fast air transport comes with much higher transportation costs and carbon emissions. To evaluate these trade-offs, we analyzed the costs and carbon emissions for air routes from every available supplier to each destination in South Asia. Table 4 summarizes these findings, identifying the routes with the lowest emissions and comparing them to the current costs of air shipments from France.

Destination Country	**Lowest-Emissions Supplier** *For air transportation*	**Δ Transportation Cost Per Shipment**	**Δ Transportation Carbon Emissions Per Shipment**
		vs. France-based Supplier	
Bangladesh	Nuflower Foods & Nutrition *New Delhi, India*	-57%	-82%
Pakistan	Nuflower Foods & Nutrition *New Delhi, India*	-45%	-88%
Nepal	Nuflower Foods & Nutrition *New Delhi, India*	-57%	-89%
Bhutan	Nuflower Foods & Nutrition *New Delhi, India*	-57%	-84%
Sri Lanka	LUMN Labs Pvt. Ltd. *Wasuli, India*	-50%	-83%
Afghanistan	Compact India Pvt. Ltd. *Gurugram, India*	-47%	-82%

Table 4: Comparison of air transportation emissions and costs for lowest-emissions supplier vs. France-based supplier

All lowest-emissions suppliers for air transportation are based in India, including four of the six destinations served from New Delhi. Compared to the France-based supplier, using India-based suppliers with ocean and land transport reduces transportation emissions by 82%–89% and cost by 45%–57%. While speed, not cost or emissions, is the primary concern in a crisis, a tradeoff may not be necessary. Because the emissions-optimized suppliers tend to be more local, they also have the potential to deliver faster. The results of this analysis can also inform supplier selection during future crises, prioritizing those with the lowest emissions impact.

5.3 Afghanistan Alternative Scenarios

Afghanistan remains at the epicenter of a prolonged nutrition crisis, with 3.7 million children under five years old currently facing acute malnutrition (UNICEF, n.d.-d). While UNICEF successfully treated 665,000 children in 2023 through the distribution of 90 million Ready-to-Use Therapeutic Food (RUTF) sachets (UNICEF, n.d.-e), escalating geopolitical tension with Pakistan and Iran are creating supply bottlenecks for life-saving aid. This section proposes alternative sourcing frameworks to reduce environmental impact without compromising treatment capacity.

5.3.1 Localized RUTF Production in Afghanistan

Given existing geopolitical constraints, diversifying to domestic Afghan production offers critical resilience for the nutritional supply chain. Transitioning from cross-border dependency to a localized model allows humanitarian organizations to leverage manufacturing capabilities within the country. This strategy not only bypasses common border closures and transit delays but also shortens the physical distance between production sites and distribution points. By utilizing local ingredients and domestic processing, agencies can establish a more stable and responsive supply of RUTF that is less vulnerable to external political or logistical shocks.

The potential impact of this localized approach is illustrated in Table 5, which compares the performance of a hypothetical domestic supplier-modeled in an example Afghan city to the current Pakistan-based supplier option. The analysis reveals that shifting toward this localized model saves 77% in transportation costs and reduces emissions by 69% per shipment. These figures demonstrate a significant opportunity to optimize both carbon emissions and costs through the development of domestic production capacity.

Supplier	Supplier Country	Δ Transportation Cost Per Shipment	Δ Transportation Carbon Emissions Per Shipment
		vs. Pakistan Supplier	
Domestic	Afghanistan	-77%	-69%

Table 5: Comparison of Afghanistan domestic supplier cost and carbon emissions

5.3.2 Neighboring Country Alternatives

Given Afghanistan's limited manufacturing capacity and ongoing instability, local RUTF production may not be viable. For that reason, we evaluated a set of neighboring countries as potential suppliers.

We assessed these countries across three dimensions: geopolitical risk, logistics capability, and current trade relationships with Afghanistan. Geopolitical risk was measured using the Global Peace Index (Institute for Economics & Peace, 2025), while logistics capability was assessed using the Logistics Performance Index (World Bank, 2023). Existing export volumes to Afghanistan were used as a proxy for established trade flows (United Nations Comtrade Database, 2026). In addition, we estimated transportation carbon emissions and costs for a representative RUTF shipment, benchmarking against the current optimal supplier in Karachi, Pakistan.

This analysis identifies Uzbekistan, Kazakhstan, and Tajikistan as the most viable alternatives, summarized in Table 6. Uzbekistan and Tajikistan benefit from proximity and lower transportation carbon emissions, while Kazakhstan offers stronger logistics performance but at significantly higher carbon emissions due to distance. Transportation estimates are based on capital city locations and would decrease if production were located closer to the Afghan border, particularly for Kazakhstan, where distance is a key driver.

Other countries, including China, Turkmenistan, and the Kyrgyz Republic, were considered but excluded due to higher geopolitical risk, weaker logistics infrastructure, or geographic constraints.

Supplier Country	Global Peace Index[1]	Logistics Performance Index[2]	Exports to Afghanistan[3]	Δ Transportation Cost Per Shipment	Δ Transportation Carbon Emissions Per Shipment
				vs. Pakistan Supplier	
Uzbekistan	1.926	2.6	$922M	-54%	-29%
Kazakhstan	1.875	2.7	$528M	+13%	+87%
Tajikistan	1.996	2.5	$64M	-76%	-59%
Less favorable → *More favorable*					

[1]Lower GPI = More peaceful
[2]Higher LPI = Better performance
[3]2024 for Uzbekistan and Kazakhstan, 2023 for Tajikistan

Table 6: Comparison of key criteria for alternative Afghanistan suppliers

6 Recommendations

Across all modeled scenarios, results consistently point to a strategic shift toward a regional sourcing model. By leveraging RUTF manufacturing in South Asia, UNICEF can achieve significant reductions in both carbon emissions and costs.

6.1 Managerial Recommendations

We propose two key recommendations to reduce carbon emissions and cost across the transportation network, supporting sustainability in a cost-conscious way: optimize the current network and focus on local suppliers.

6.1.1 Optimize Current Network

The primary recommendation is to align sourcing and routing decisions with the optimized network outputs. The baseline model indicates that UNICEF's current supply chain across South Asia (Afghanistan, Bangladesh, Pakistan, Sri Lanka, Bhutan, and Nepal) is suboptimal from both a transportation cost and carbon emissions perspective. Model results show that the opportunities for reduction are significant; using the emissions-optimized model, carbon emissions can be reduced by 57.3% while simultaneously lowering transportation costs by 33.8% relative to the current network.

These findings suggest that many current sourcing and routing decisions rely on longer or less efficient lanes, although more optimal alternatives exist. By systematically adopting the model's recommended supplier-location and routing choices, UNICEF may be able to improve both cost efficiency and sustainability outcomes.

Some of the most significant optimization opportunities include:

- Prioritize Ismail Industries Limited (Karachi, Pakistan) for shipments to Afghanistan over Kenya-based suppliers where feasible
- Prioritize Ismail Industries Limited (Karachi, Pakistan) for shipments to Pakistan over all other suppliers where feasible
- Prioritize Hexagon Nutrition. Ltd (Mumbai, India) over France-based suppliers where feasible

6.1.2 Focus on Local Suppliers

Across all optimization scenarios, suppliers within South Asia consistently minimize both transportation carbon emissions and cost. Therefore, we recommend that management consider using local suppliers when possible.

In the Emergency Scenario: Air Only, India emerges as particularly well-positioned to serve the region, offering the lowest-emissions and shortest-distance options. Continuing to foster relationships with Indian suppliers and ensuring capacity for emergency response is critical, given their central geographic advantage.

For Afghanistan specifically, transitioning to domestic production offers three distinct advantages. First, it bolsters both food security and the local economy. Strengthening the domestic market addresses malnutrition sustainably, moving beyond a total reliance on short-term emergency aid. Second, it reduces dependence on international suppliers, insulating the supply chain from geopolitical tensions. Lastly, localized production offers significant environmental and cost benefits by shortening transport distances, reducing UNICEF's carbon footprint and lead time.

Where domestic capacity for Afghanistan is insufficient, Uzbekistan, Tajikistan, and Kazakhstan offer viable regional alternatives with existing trade relationships with Afghanistan. Tajikistan is a particularly logical starting point, as UNICEF has already conducted a feasibility study for RUTF production in the country, providing a foundation for accelerated supplier development.

Though the risk analysis focused on Afghanistan, the benefits of leveraging local suppliers extend across all scenarios. Sourcing regionally reduces exposure to geopolitical tensions and cross-border disruptions, while shorter transport routes mean fewer handoffs and less transit time. Localization is not only an environmental and cost strategy. It is a resilience strategy that strengthens the overall supply chain.

The UNICEF Supply Division has already made meaningful progress in localization, expanding RUTF production from one supplier in Europe to over 20 different global suppliers today (UNICEF, n.d.-a). Building on this momentum, continued investment in South Asian supplier development represents an opportunity to improve both supply chain performance and regional service.

6.2 Future Work

Future work could focus on four main areas: data limitations, manufacturing carbon emissions and cost, domestic supplier development and expanding the analysis to include all destination regions.

We faced several challenges in collecting data needed to improve the model's ability to reflect real-world conditions. First, UNICEF was unable to provide detailed supplier and shipment-level data, requiring us to rely on publicly available information and simplifying assumptions. Access to supplier-specific capacity data would further strengthen the model by incorporating realistic operational constraints and better reflecting each supplier's feasible limits.

Second, much of our model relies on NTM global baselines, which do not reflect shipment-specific factors such as road conditions, fuel type, vehicle class, or fleet age. To improve accuracy, UNICEF could partner with key carriers and freight forwarders to collect transportation details for their highest-used lanes. Gathering this data can be operationalized by incorporating standardized data fields into carrier contracts or leveraging existing telematics and shipment tracking systems. Over time, accounting for shipment-specific factors would enable a transition from generalized emissions factors to shipment-specific estimates that better reflect real-world conditions.

Although this project focused on transportation-related costs and carbon emissions, a significant portion of the RUTF supply chain's environmental impact occurs during manufacturing. Expanding the model to include unit production costs and supplier-specific carbon emissions would provide a more holistic view. Such an analysis would enable more accurate trade-offs assessment; for instance, a distant supplier with high transport carbon emissions might still offer lower total carbon emissions through greater facility-level manufacturing efficiency.

Additionally, given ongoing geopolitical conflicts affecting Afghanistan, the highest-demand RUTF destination in South Asia, it is important to consider new strategic suppliers that can better serve the region. We recommend first evaluating the viability of expanding local production. We also recommend conducting feasibility studies for potential suppliers in neighboring Uzbekistan and Kazakhstan, noting that UNICEF completed a similar study for Tajikistan in 2024.

Our analysis focused on South Asia, while UNICEF sources and distributes RUTF globally. Expanding the model to include all regions would enable more holistic decision-making by capturing cross-region tradeoffs and shared supplier capacity. This is especially important given some suppliers serve multiple regions, meaning decisions in one region can impact cost, availability, and carbon emissions in another as they may take away supplier capacity or impact contract minimum conditions.

6.3 General Applications

Our project highlights the value of using the NTM methodology to estimate carbon emissions at the shipment level. When combined with optimization modeling, the NTM methodology can support a practical framework that other organizations can use to evaluate trade-offs and make better sourcing decisions at the shipment level.

Most importantly, this capstone shows that organizations with complex global supply chains can improve both cost and carbon emissions by making more intentional supplier and routing decisions. While this analysis focuses on UNICEF's RUTF network, the takeaway applies much more broadly: distance and routing are often the biggest drivers of both cost and carbon emissions and improving one does not necessarily mean sacrificing the other. In many cases, shifting toward more regional sourcing can reduce transportation distance, lower carbon emissions, and even cut costs.

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