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# Conceptual Framework on Sustainability Cost Alignment with Cost of Transport

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## ABSTRACT

Context and Motivation: The intensification of global environmental concerns has necessitated the integration of sustainability principles into the operational frameworks of supply chain and logistics management. Outbound logistics—encompassing the distribution of finished goods to end consumers—represents one of the most carbon-intensive phases of supply chain activity, yet remains relatively underexplored in terms of monetized emission accountability.

Purpose: This paper develops a conceptual framework for calculating and incorporating sustainability costs—specifically emission costs—into the cost of transport across different modes of freight movement. Drawing upon the Social Cost of Carbon (SCC) construct and relevant policy benchmarks, the study bridges a critical gap between emission quantification and its practical financial integration.

Methodology: The study adopts a secondary data approach, synthesizing evidence from published academic literature, institutional reports, governmental policy documents, and international sustainability frameworks including the Global Logistics Emissions Council (GLEC) Framework and ISO 14083.

Findings: A structured emission-cost model is proposed, wherein carbon emission intensities (g CO2e per tonne-kilometre) for five transport modes are monetized using a per-gram emission cost factor. The resulting per-trip emission cost differentials provide a transparent basis for sustainability-informed transport mode selection.

**Keywords**- Sustainability Cost, Emission Cost, Social Cost of Carbon, Cost of Transport, Outbound Logistics, Supply Chain Management, Mode of Transport, Carbon Pricing, GLEC Framework

## INTRODUCTION:

### 1.1 Supply Chain Management and Outbound Logistics

The discipline of supply chain management (SCM) traces its formal nomenclature to 1982, when Keith Oliver, a consultant at Booz Allen Hamilton, introduced the term in a Financial Times interview. A year later, in 1983, the first documented implementation of an SCM project—led by Wolfgang Partsch—was published in the German journal Wirtschafts Woche. It was not until the mid-1990s, however, that the concept gained widespread academic and managerial currency, accompanied by a proliferation of scholarly articles and practitioner texts.

Supply chain management has been formally defined as the integration of all activities associated with the flow and transformation of goods—from the extraction of raw materials to delivery to the end user—along with the associated information flows. This integration extends beyond mere coordination; it encompasses the optimization of supply chain relationships to achieve and sustain competitive advantage (Chopra and Meindl, 2013).

Within this broader framework, logistics management constitutes the operational backbone: it entails the acquisition, storage, and movement of inventory from its point of origin to its point of consumption, with the overarching objective of delivering the right product, to the right location, at the right time, and to the right customer (Rushton, Croucher, and Baker, 2014).

### 1.2 Modes of Freight Transport

Transportation—defined as the movement of goods, people, or information between geographic locations—is a fundamental enabler of economic activity and social exchange. In the context of freight logistics, the choice of transport mode is governed by a complex interplay of cost, speed, reliability, infrastructure, and cargo characteristics. The principal modes of freight transport are:

**Road Freight:** Trucks and lorries convey goods across highway networks, offering high flexibility and door-to-door service, particularly suited to short and medium haul distances.

**Rail Freight:** Trains move bulk cargo and standardized containers over dedicated rail infrastructure, demonstrating superior efficiency for high-volume, long-distance movements.

**Maritime Freight:** Ocean-going vessels—container ships, bulk carriers, and tankers—transport goods across international sea lanes, representing the dominant mode for global trade by volume.

**Air Freight:** Cargo aircraft facilitate the rapid movement of high-value or time-sensitive consignments across international routes, albeit at significantly higher cost and emission intensity.

**Inland Waterway Freight:** Barges and river vessels operate on canals, rivers, and lakes, offering a low-cost, low-emission alternative for specific geographic corridors.

Each mode operates within a distinct regulatory, infrastructural, and environmental context, and carries differentiated cost and emission profiles that form the analytical foundation of this study.

### 1.3 Sustainability in the Context of Logistics

Sustainability—broadly understood as the capacity of present systems to function without compromising the ability of future generations to meet their needs (WCED, 1987)—has evolved from an environmental imperative into a multi-dimensional framework encompassing economic, social, and ecological considerations. Within logistics and supply chain management, sustainability has assumed particular urgency, given that the transport sector is among the largest contributors to global greenhouse gas emissions.

Sustainable transport is characterized by low or zero direct emissions, energy efficiency, and economic affordability. Achieving sustainability in logistics requires not merely the adoption of cleaner technologies but also the internalization of environmental externalities—particularly emission costs—into the financial calculus of transport decision-making.

This paper is motivated by the recognition that, while frameworks for measuring emissions exist, a practical, accessible methodology for integrating emission costs into transport pricing remains insufficiently developed, particularly within the Indian economic context.

## 2. PROBLEM STATEMENT

Despite growing awareness of the environmental consequences of freight transportation, the monetary cost of carbon emissions is seldom incorporated into the operational cost structures used by transporters and logistics managers when selecting a mode of transport. This gap between environmental accounting and commercial practice gives rise to the following research questions:

**RQ1:** What constitutes sustainability cost, and how is it theoretically and empirically defined?

**RQ2:** What is emission cost (Social Cost of Carbon), and how is it quantified in practice?

**RQ3:** How can a conceptual framework be developed to calculate emission cost per transport mode and integrate it into the total cost of transport?

## 3. RESEARCH FRAMEWORK

### 3.1 Research Gap and Motivation

The extant literature on supply chain sustainability addresses emission reduction strategies at a macro or policy level. However, a practical, operationalizable framework for computing and embedding emission costs within the cost-per-shipment calculus of transport managers—particularly with reference to modal choice in the Indian context—remains underexplored. This study seeks to fill that gap by proposing a conceptual model grounded in existing emission intensity benchmarks and carbon valuation methodologies.

### 3.2 Aim and Objectives

**Aim:** To develop a conceptual framework that operationalizes emission cost calculation and enables its systematic incorporation into the cost of transport across multiple freight modes.

The specific objective of this research is to construct and illustrate a modal emission cost model that translates carbon emission intensities into monetizable per-trip costs, thereby enabling sustainability-informed transport mode selection.

### 3.3 Research Design and Data Sources

This study adopts a conceptual-analytical research design, drawing exclusively on secondary data. Sources include peer-reviewed academic journal articles, institutional and governmental reports, international sustainability frameworks, and published policy documents. Primary data collection is not within the scope of this paper; however, empirical validation of the proposed framework constitutes a key direction for future research.

## 4. LITERATURE REVIEW

### 4.1 The Evolution of Sustainability

The scholarly understanding of sustainability has undergone substantial transformation over several decades. The foundational definition was provided by the World Commission on Environment and Development (WCED, 1987) in the landmark Brundtland Report, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This formulation introduced the concept of intergenerational equity as a central concern of development policy.

Elkington (1998) expanded the sustainability discourse by proposing the Triple Bottom Line (TBL) framework, which extended the scope of organizational responsibility beyond profit maximization to encompass environmental stewardship and social equity. Dyllick and Hockerts (2002) refined this perspective by emphasizing the importance of satisfying the needs of all present stakeholders without sacrificing the capacity of future stakeholders to do the same, thereby underscoring the inclusive and forward-looking character of genuine sustainability.

Kielczewski (2010) further advanced the theoretical landscape by articulating the coexistence of environmental preservation and socioeconomic development as complementary rather than competing imperatives. More recently, Gore (2022) and Varma et al. (2022) have emphasized the necessity of balancing economic growth with ecological integrity, arguing that sustainable practices should be integrated into—rather than opposed to—economic activity. Misztal (2023) reinforces this position, asserting that concurrent advancement across economic, social, and environmental domains is indispensable for the sustainable development of both present and future generations.

Taken collectively, this body of scholarship converges on a tripartite model of sustainability—economic, environmental, and social—wherein no single dimension can be advanced at the permanent expense of the others.

### 4.2 Logistics, Supply Chain Management, and Sustainability

The logistics and supply chain management literature has increasingly converged with sustainability scholarship. Rius et al. (2006) define logistics as a coordinated methodology designed to satisfy customer requirements while optimizing cost, resource utilization, and inventory levels across supply chain participants. Chopra and Meindl (2013) assert that supply chain design, planning, and operational decisions are determinative of firm-level performance, and that well-managed supply chains must be adaptive to evolving customer expectations and technological change.

Rushton, Croucher, and Baker (2014) conceptualize supply chain management as the integration of suppliers, logistics service providers, and customers, with an emphasis on the efficient and cost-effective movement of goods from origin to consumption while maintaining acceptable service standards. Khan and Yu (2019) extend this definition to explicitly encompass coordination and collaboration across all supply chain participants in the manufacture, distribution, and sale of goods.

From a cost perspective, Purnowidodo, Anam, and Wahyudi (2022) report that logistics expenditures account for approximately 11 percent of a firm's total operating costs, with transportation, inventory holding, storage, handling, and customer service costs constituting the principal components. Bruzzone et al. (2023) propose that operational innovations—including the integration of passenger and freight flows—can support energy-efficient and sustainable freight and logistics management.

### 4.3 Sustainability Cost

Sustainability cost refers to the full spectrum of financial outlays associated with implementing, maintaining, and advancing sustainable operational practices. These costs operate across three analytical dimensions:

#### Economic Costs

Transitioning to sustainable practices frequently entails significant upfront capital investment. The deployment of renewable energy infrastructure, for instance, demands substantial initial expenditure, even as it generates long-term operational savings and reduces dependence on fossil fuels. Research and development expenditures associated with clean technology innovation similarly represent near-term costs with deferred benefits. Sustainable agriculture and circular economy initiatives may also incur higher short-run operational costs relative to conventional alternatives (Ellen MacArthur Foundation, 2013; European Commission, 2020).

#### Environmental Costs

Environmental sustainability investments include expenditures on resource conservation, ecosystem restoration, and pollution abatement. While these outlays carry immediate financial burdens, they generate medium- and long-term value through the preservation of natural capital and the continuity of ecosystem services—including clean water provision, air purification, and biodiversity maintenance (IPCC, 2018; FAO, 2019).

#### Social Costs

Social sustainability encompasses investments in poverty alleviation, equitable access to education and healthcare, community engagement, and the empowerment of marginalized populations. These expenditures, while fiscally demanding in the short run, are foundational to the construction of resilient, inclusive, and adaptive communities (WHO, 2020; ILO, 2016).

### 4.4 Cost of Transport

The total cost of transport is a composite measure encompassing multiple direct and indirect cost components. Direct costs include fuel expenditure (petrol, diesel, and alternative fuels), vehicle maintenance and repair, driver compensation, infrastructure levies (tolls and port fees), and insurance premiums for vehicles and cargo. Freight charges—determined by weight, volume, and distance—constitute the primary commercial transaction cost, supplemented by charges for value-added services such as tracking, specialized handling, and temperature control.

Indirect costs encompass packaging materials and labor, warehousing and inventory holding costs, customs duties and compliance expenditures for cross-border movements, and—crucially for this study—the environmental cost of emissions. It is this final component that remains underrepresented in conventional transport cost accounting and whose integration constitutes the central contribution of this paper.

Table 1 presents benchmark carbon emission intensities by transport mode, expressed in grams of CO2 equivalent per tonne-kilometre (g CO2e per tkm), a standardized metric widely employed in logistics emissions accounting.

**Table 1: Carbon Emission Intensities by Mode of Transport**

| Mode of Transport | Carbon Emissions (g CO2e per tkm) |
|---|---|
| Truck (Road) | 60 – 150 |

| Mode of Transport | Carbon Emissions (g CO2e per tkm) |
|---|---|
| Rail | 20 – 30 |
| Ship (Maritime) | 10 – 15 |
| Air | 500 – 600 |
| Pipeline | 3 – 5 |

*Source: European Environment Agency (2019); GLEC Framework (Smart Freight Centre)*

### 4.5 Emission Cost: The Social Cost of Carbon

The emission cost, commonly operationalized as the Social Cost of Carbon (SCC), is defined as the net economic damage—in present-value terms—attributable to the release of one additional metric ton of carbon dioxide into the atmosphere. The SCC is a comprehensive metric that encompasses damages to agricultural productivity, human health outcomes (including morbidity and mortality from heat stress, drought, and vector-borne diseases), infrastructure losses due to sea-level rise and extreme weather events, and biodiversity depletion.

Empirical estimates of the SCC vary considerably across studies and methodological assumptions. A study conducted by researchers at the University of California, Davis estimates the SCC at approximately USD 280 per metric ton of CO2 emitted in 2020—a figure substantially exceeding the U.S. Environmental Protection Agency's central estimate of USD 190 per metric ton. These differences reflect variations in discount rates, climate sensitivity parameters, damage function specifications, and the geographic scope of impacts considered.

The SCC is calculated through an integrated assessment process involving five principal steps: (1) forecasting socioeconomic trajectories (population, GDP, and baseline emissions); (2) modeling climatic responses to incremental emission increases; (3) assessing sectoral impacts of climate change; (4) applying a discount rate to translate future damages into present values; and (5) aggregating damages across sectors and geographies to derive the composite cost estimate. The choice of discount rate is particularly consequential: lower rates amplify the present value of future damages, yielding higher SCC estimates, while higher rates produce the inverse effect.

### 4.6 Policy Frameworks for Carbon Pricing

The operationalization of emission costs in practice is governed by a variety of national and supranational regulatory mechanisms. The European Union Emissions Trading System (EU ETS), established in 2005, constitutes the world's first and largest emissions trading scheme, covering approximately 11,000 power generation and industrial installations. Canada's federal carbon pricing regime combines a direct carbon levy on fossil fuels with an output-based pricing system for large industrial emitters. China launched its national ETS in 2021 for the power sector, with planned expansion to additional sectors. The United Kingdom's Carbon Price Floor sets a minimum carbon price for the electricity generation sector. California's Cap-and-Trade Program, integrated within the state's broader climate strategy, establishes binding emission caps with tradeable allowances. Japan's carbon pricing mechanism incorporates both a carbon tax and a voluntary trading scheme.

These diverse policy instruments share a common objective: to internalize the external cost of carbon emissions into economic decision-making by making emissions financially costly, thereby incentivizing the adoption of cleaner technologies and low-carbon operational practices.

### 4.7 The GLEC Framework and ISO 14083

For the logistics sector, the Global Logistics Emissions Council (GLEC) Framework—developed by the Smart Freight Centre—provides the most widely recognized methodology for calculating and reporting greenhouse gas emissions from freight transport activities. The framework offers a harmonized, multimodal, and internationally consistent approach to emissions accounting, covering road, rail, sea, and air transport modes. Critically, the GLEC Framework forms the technical basis for ISO 14083, the first international standard specifically governing logistics emissions accounting. It is also aligned with the Greenhouse Gas Protocol, the globally dominant standard for organizational GHG reporting and management.

## 5. FINDINGS AND PROPOSED CONCEPTUAL FRAMEWORK

### 5.1 Defining Emission Cost for Transport Applications

Synthesizing the theoretical and empirical literature reviewed above, emission cost—as applied to freight transport—may be defined as the monetized economic damage attributable to the carbon dioxide (and equivalent greenhouse gas) emissions generated by the movement of one unit of cargo over a specified distance by a given transport mode. This cost encompasses health impacts, agricultural losses, infrastructure damage, and biodiversity loss attributable to the warming effect of emitted greenhouse gases.

Integrating emission cost into transport cost accounting requires three inputs: (1) the carbon emission intensity of the transport mode (g CO2e per tkm); (2) the economic value assigned to each unit of emission (per-gram cost of emission, derived from the SCC or regulatory carbon price); and (3) the operational parameters of the shipment (tonne-kilometres traveled per trip).

### 5.2 Conceptual Emission Cost Model

Based on the foregoing analysis, this paper proposes the following emission cost model for inclusion within the total cost of transport:

***Emission Cost per Trip (INR) = Emission Intensity (g CO2e/tkm) × Per-Gram Emission Cost (INR/g) × Distance (km)***

Table 2 illustrates the application of this model using illustrative parameters: a per-gram emission cost of INR 0.005 (reflecting a carbon valuation of approximately INR 5 per kilogram of CO2e, derived from prevailing SCC estimates adjusted for purchasing power parity) and a standard trip distance of 1,000 kilometres.

**Table 2: Illustrative Emission Cost Calculation by Mode of Transport (1,000 km trip, 1 tonne cargo)**

| Mode of Transport | Avg. Emission Intensity (g CO2e/tkm) | Per-Gram Cost (INR) | Emission Cost per km (INR) | Trip Distance (km) | Total Emission Cost per Trip (INR) |
|---|---|---|---|---|---|
| Truck (Road) | 105 | 0.005 | 0.525 | 1,000 | 525 |
| Rail | 25 | 0.005 | 0.125 | 1,000 | 125 |
| Ship (Maritime) | 13 | 0.005 | 0.065 | 1,000 | 65 |
| Air | 550 | 0.005 | 2.750 | 1,000 | 2,750 |
| Pipeline | 4 | 0.005 | 0.020 | 1,000 | 20 |

*Source: Authors' calculation based on GLEC Framework benchmarks; emission intensity values are mid-range estimates*

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The results in Table 2 reveal substantial variation in emission cost across modes. Air freight generates an emission cost per trip approximately 42 times greater than maritime shipping and more than five times greater than road transport, for equivalent cargo movement over the same distance. Pipeline transport exhibits the lowest emission cost profile. These differentials, while not altering the fundamental modal hierarchy that governs current transport decisions, introduce a quantified sustainability dimension into the cost comparison that may influence modal choice at the margin—particularly for environmentally committed shippers or in contexts where carbon pricing regulation is operative.

### 5.3 Factors Moderating Emission Cost in Modal Selection

The emission cost model developed above constitutes a necessary but not sufficient basis for transport mode selection. A comprehensive decision framework must account for additional factors that interact with emission cost, including: infrastructure availability at origin and destination points for each mode; total transit distance and the geographic configuration of the route; required transit time and the time-sensitivity of the cargo; the reliability and on-time performance of each mode; cargo-specific requirements (weight, volume, fragility, temperature sensitivity); frequency of scheduled services; and the risk profile of each mode in terms of loss or damage rates. The relative weighting of these factors will vary by shipper, cargo type, and market context, and their integration with emission cost in a multi-criteria decision framework represents an important avenue for future research and practical application.

## 6. CONCLUSION

This paper has presented a conceptual framework for calculating and integrating emission costs into the total cost of transport across five principal freight modes. By grounding the emission cost concept in the Social Cost of Carbon literature and aligning it with established methodologies—including the GLEC Framework and ISO 14083—the paper provides a theoretically coherent and practically accessible basis for sustainability-informed transport cost accounting.

The central contribution of the paper is the demonstration that carbon emission intensities, expressed in grams of CO2 equivalent per tonne-kilometre, can be monetized through a per-gram emission cost factor and aggregated into a per-trip emission cost that is directly comparable across transport modes. This approach enables logistics managers and policymakers to render the environmental externality of freight transport visible within conventional cost structures, thereby creating a financial incentive for modal shifts toward lower-emission alternatives.

The framework proposed herein is conceptual in nature and employs illustrative parameter values. Its empirical validation—through field studies, actual shipment data, and region-specific SCC estimates—represents a critical priority for the research agenda that this paper seeks to initiate.

## 7. FUTURE SCOPE AND LIMITATIONS

This study acknowledges several limitations that simultaneously define its future research agenda. First, the emission cost parameters employed in Table 2 are illustrative; empirical research is required to establish regionally calibrated, commodity-specific emission intensities and economically grounded per-gram cost factors for the Indian market. Second, the framework does not currently incorporate mode-specific infrastructure constraints, which vary substantially across India's transport network and exert a material influence on modal availability and cost.

Future research directions include: (1) empirical estimation of SCC-derived emission cost factors applicable to the Indian economic and regulatory context; (2) development of a multi-criteria decision model that integrates emission cost with transit time, reliability, and service frequency; (3) benchmarking of global carbon pricing mechanisms and their adaptation for policy implementation in the Indian freight sector; (4) longitudinal analysis of how carbon pricing trajectories affect modal cost competitiveness; and (5) sector-specific case studies examining the practical uptake of emission cost integration in industries with high logistics intensity, such as automotive, pharmaceuticals, and fast-moving consumer goods

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