Factors Influencing the Efficiency and Sustainability of Cold Chain Logistics Systems in the Food Industry in Coimbatore, India

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Abstract—

Cold chain logistics preserves the quality, safety and shelf life of perishable food products and is a critical link between farm and fork, yet across India's fast-growing regional food hubs the system is repeatedly asked to do more with infrastructure it has already outgrown. This study examines the factors influencing the efficiency and sustainability of cold chain logistics systems in the food industry in Coimbatore, India, testing four independent variables — Infrastructure Quality, Energy Cost, Cold Storage Capacity and Infrastructure Gaps — against a composite Efficiency and Sustainability outcome. A quantitative, cross-sectional survey of 180 professionals working in cold storage facilities, logistics service providers and food processing units was analysed using reliability testing, descriptive statistics, normality diagnostics and multiple linear regression in IBM SPSS. All five constructs achieved good-to-excellent internal consistency (Cronbach's alpha 0.863–0.918), and respondents rated every factor well above the neutral midpoint, with mean item scores clustered between 4.17 and 4.28 for infrastructure, energy and capacity items. The regression model, however, told a different story: the four predictors jointly explained only 0.4% of the variance in perceived efficiency and sustainability (R^2 = .004), and none of the individual beta coefficients reached statistical significance. This produces what the study terms a Perception-Reality Gap — practitioners are strongly convinced that infrastructure, energy cost, storage capacity and connectivity gaps drive cold chain performance, yet the variance in their own efficiency ratings is statistically untouched by differences in these same factors, suggesting that unmeasured managerial, technological and coordination variables are doing the real explanatory work. The study concludes that infrastructure investment remains necessary but is not, on this evidence, sufficient, and recommends that operators and policymakers pair physical upgrades with process-level interventions — digital temperature monitoring, workforce capability building and cross-stage coordination — to convert infrastructure spending into measurable efficiency gains.

Keywords—*Cold Chain Logistics; Infrastructure Quality; Energy Cost; Cold Storage Capacity; Infrastructure Gaps; Food Supply Chain Sustainability; Perception-Reality Gap; Coimbatore*

I. INTRODUCTION

Cold chain logistics — the network of refrigerated storage and transport that keeps perishable foods at the right temperature from farm to fork — is a quiet hero of the food system, preventing spoilage and preserving the nutritional quality of produce as it moves toward the consumer [1]. In fast-growing regional hubs such as Coimbatore, an effective cold chain directly affects farmers' incomes, retailer reliability and consumer health [2]. Yet cold chain systems in India continue to face persistent practical challenges: uneven infrastructure, gaps in last-mile refrigeration and intermittent power supply combine to produce temperature breaks and elevated food loss [3], while rising energy costs and ageing equipment squeeze operating margins and slow the adoption of energy-efficient technology [4].

Large-scale market and policy reviews show that India's cold-chain capacity has grown in absolute terms but remains unevenly distributed — concentrated in specific states or commodities — producing localised service bottlenecks even as national totals look healthy [3]. Investment in modern infrastructure and monitoring technology can markedly reduce spoilage and lower long-run operating costs [5], and targeted policy support that creates shared cold-storage hubs can narrow distributional gaps for small producers [6]. Technical upgrades alone, however, tend to under-deliver unless paired with coordinated planning and supportive policy [3].

This study examines the factors influencing the efficiency and sustainability of cold chain logistics systems in the food industry in Coimbatore, focusing on four operationally actionable domains: infrastructure quality, energy cost, cold storage capacity and infrastructure gaps. By combining practitioners' perceptions with statistical evidence from a 180-respondent field survey, the research aims to test whether the factors practitioners believe matter most are, in fact, the ones that statistically explain variation in cold chain performance — and to surface practical recommendations for managers and policymakers in the region.

II. LITERATURE REVIEW

A. Infrastructure Quality

Infrastructure quality — the condition of cold storage facilities, refrigerated vehicles, insulation and temperature-monitoring technology — is widely regarded as a foundational determinant of cold chain performance, since high-quality infrastructure reduces temperature fluctuations and improves delivery reliability [5]. Recent literature stresses that quality, not mere availability, is what matters: outdated equipment and poor maintenance routinely blunt the benefit of expanded cold storage capacity [1]. Some scholars caution that infrastructure quality alone cannot guarantee efficiency unless matched by reliable power, a skilled workforce and cross-stage coordination [7], and regional studies note that modern facilities in developing hubs tend to cluster in select locations, leaving peripheral areas dependent on outdated systems [2].

B. Energy Cost

Cold storage and refrigerated transport operate continuously, making electricity and fuel a substantial share of total logistics expenditure; rising energy prices directly increase operating costs and shape decisions about capacity utilisation and service levels [4]. When tariffs or fuel prices rise, operators often respond by reducing operating hours or delaying maintenance — a cost-driven trade-off that can compromise service reliability even as it protects margins short term [5]. Energy cost is also tightly linked to sustainability outcomes, since refrigeration is energy-intensive and high costs can discourage investment in energy-efficient or renewable alternatives [1], although some evidence suggests sustained cost pressure eventually pushes firms toward energy-saving technology as a strategic response [2].

C. Cold Storage Capacity

Adequate cold storage capacity allows operators to manage seasonal fluctuations, avoid congestion and maintain consistent inventory flow; insufficient or poorly distributed capacity forces rushed transportation and raises spoilage risk during peak harvest periods [5]. Increasing capacity in absolute terms is not sufficient on its own — mismatches between storage location and production zones, and a shortage of multi-commodity facilities, can leave nominal capacity underutilised in some areas while shortages persist elsewhere [1]. Adequate, well-distributed capacity also supports sustainability by reducing emergency transportation and repeated handling, both of which lower energy consumption [4].

D. Infrastructure Gaps

Infrastructure gaps — poor road connectivity, unreliable power, absent last-mile refrigerated transport and weak coordination between storage and transport stages — are among the most persistent barriers to efficient, sustainable cold chains, particularly in developing and semi-urban regions [2]. These gaps are not purely physical: weak institutional coordination and fragmented ownership of cold chain assets widen them further, and poor coordination between producers, storage operators and transporters produces scheduling delays that reduce asset utilisation [7]. The literature is divided on remedies — some researchers prioritise public and private investment in physical assets, while others argue that governance reform and digital integration are equally important [4].

E. Efficiency and Sustainability as a Combined Outcome

Recent literature increasingly treats efficiency and sustainability as interrelated performance outcomes rather than separate goals: efficient routing, optimal storage use and reliable infrastructure reduce unnecessary handling and cooling cycles, lowering both cost and emissions simultaneously [1]. At the same time, efficiency-focused strategies pursued without proper maintenance can produce short-term gains at the cost of higher long-run breakdown rates and energy waste, underscoring the need for a balanced, system-level view [4]. Most prior work, however, examines these factors individually or at a national scale; there is limited empirical evidence that jointly tests infrastructure quality, energy cost, storage capacity and infrastructure gaps within a single regional cold chain, a gap this study addresses using field data from Coimbatore.

III. RESEARCH OBJECTIVES AND HYPOTHESES

The primary objective of this study is to examine the factors influencing the efficiency and sustainability of cold chain logistics systems in the food industry in Coimbatore, India. The specific objectives are to: (1) examine the influence of infrastructure quality on cold chain efficiency and sustainability; (2) analyse the effect of energy cost on cold chain efficiency and sustainability; (3) assess the role of cold storage capacity in improving efficiency and sustainability; and (4) evaluate the impact of infrastructure gaps on efficiency and sustainability in the food industry in Coimbatore.

Based on the literature review, the following hypotheses were developed for empirical testing:

H1: Infrastructure quality has a significant positive influence on the efficiency and sustainability of cold chain logistics systems.

H2: Energy cost has a significant influence on the efficiency and sustainability of cold chain logistics systems.

H3: Cold storage capacity has a significant positive influence on the efficiency and sustainability of cold chain logistics systems.

H4: Infrastructure gaps have a significant negative influence on the efficiency and sustainability of cold chain logistics systems.

IV. RESEARCH METHODOLOGY

A. Research Design

This study adopts a descriptive, cross-sectional research design using a quantitative approach. The design is appropriate because the study seeks to describe existing conditions and test relationships between clearly defined variables using numerical data collected through a structured questionnaire, rather than manipulating variables experimentally [8].

B. Population, Sampling and Sample Size

The target population comprised professionals directly involved in cold chain logistics operations within the food industry in Coimbatore — logistics managers, cold storage operators, warehouse supervisors and supply chain executives. A purposive (judgmental), non-probability sampling technique was used, appropriate for a specialised population where respondents must possess direct operational knowledge [9]. A total of 200 questionnaires were administered through direct and online distribution; 180 valid responses were returned, an overall response rate of 90%, providing a sample size consistent with the minimum recommended for multiple regression analysis with four predictors [10].

C. Data Collection and Analysis

The primary instrument was a structured questionnaire divided into demographic items and five constructs — Infrastructure Quality, Energy Cost, Cold Storage Capacity, Infrastructure Gaps and Efficiency and Sustainability — each measured on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), adapted from established logistics and supply chain literature and refined through face validation with academic and industry experts [7], [11], [12]. Data were coded and analysed in IBM SPSS using Cronbach's alpha reliability testing, descriptive statistics, skewness/kurtosis normality diagnostics and multiple linear regression. Ethical rigor was maintained through informed consent, voluntary participation and assured confidentiality.

V. DATA ANALYSIS AND RESULTS

A. Reliability Analysis

Cronbach's alpha was computed for all five constructs using data from 180 valid respondents. Every construct exceeded the 0.70 threshold for acceptable reliability, with values ranging from good to excellent (Table I), confirming that the instrument consistently measured the intended concepts and was suitable for further statistical testing.

TABLE I. RELIABILITY ANALYSIS

Construct	Items	α
Infrastructure Quality	3	0.877
Energy Cost	3	0.88
Cold Storage Capacity	3	0.879
Infrastructure Gaps	3	0.863
Efficiency & Sustainability	5	0.918

B. Demographic Profile

Of the 180 respondents, 72.8% were male and 27.8% female. The largest age bands were 36–45 years (40.6%) and 46–55 years (28.3%), indicating a predominantly mid-to-late-career sample. In terms of qualification, 43.3% held undergraduate degrees, 33.3% postgraduate degrees and 23.3% diplomas, with the largest field-of-education group specialising in Logistics/Supply Chain (46.7%). By designation, Executives formed the largest group (34.4%), followed by Supervisors (30.6%), Managers (20.6%) and Operators (14.4%). Organisationally, Cold Storage Facilities represented 43.3% of respondents, Logistics Service Providers 33.3% and Food Processing Units 23.3%, and 44.4% of respondents were involved in both storage and transportation activities, giving the sample broad end-to-end operational exposure.

C. Descriptive Statistics

Across all four independent constructs, respondents expressed strong agreement that each factor shapes cold chain performance, with item-level means clustering tightly between 4.17 and 4.22 (SD 0.63–0.72) — well above the neutral midpoint of 3.00. Infrastructure Quality items averaged 4.18–4.21; Energy Cost items averaged 4.21–4.22; Cold Storage Capacity items averaged 4.17–4.20; and Infrastructure Gaps items averaged 4.17–4.18. For the dependent variable, operational-efficiency items scored highest ($M = 4.28$), while the sustainability-specific item — "Sustainable practices are adopted to reduce energy consumption" — scored markedly lower ($M = 3.19$), the only item in the entire instrument to fall close to the neutral range. This early pattern foreshadows the study's central finding: strong, uniform agreement that the four factors matter, paired with weaker and more variable agreement that sustainable practice is actually being executed.

D. Normality Test

Skewness and kurtosis statistics were used to assess distributional normality prior to parametric testing. All four independent variables returned skewness and kurtosis values well within the ±2 guideline (Infrastructure Quality: 0.95, −1.16; Energy Cost: −0.26, 0.13; Cold Storage Capacity: −0.22, −1.33; Infrastructure Gaps: −0.11, −0.77), confirming the dataset was suitable for correlation and multiple regression analysis.

E. Multiple Linear Regression Analysis

A multiple linear regression of the composite Efficiency and Sustainability score on the four independent variables was estimated as $ES = \beta_0 + \beta_1(IQ) + \beta_2(EC) + \beta_3(CSC) + \beta_4(IG) + \varepsilon$. The overall model was not statistically significant and explained a negligible share of the variance in perceived efficiency and sustainability ($R^2 = .004$). None of the four standardised beta coefficients reached conventional significance thresholds (Table II).

TABLE II. REGRESSION COEFFICIENTS (DV: EFFICIENCY & SUSTAINABILITY)

Predictor	β	t	Sig.	Result
Infrastructure Quality	-0.031	-0.408	0.684	Not supported
Energy Cost	-0.016	-0.215	0.83	Not supported
Cold Storage Capacity	0.052	0.6	0.491	Not supported
Infrastructure Gaps	0.015	0.199	0.842	Not supported

$R^2 = 0.004$; model not statistically significant ($p > .05$).

With $R^2 = .004$, the four predictors jointly account for less than half of one percent of the variance in respondents' efficiency and sustainability ratings, despite each predictor individually scoring a mean above 4.1 on the same five-point scale. The remaining variance is, by construction, attributable to factors outside the model — candidates raised elsewhere in the literature include technology adoption, managerial practice, digital monitoring systems, workforce capability, government support and cross-stage supply chain coordination [1], [7].

VI. DISCUSSION OF FINDINGS

The central finding of this study is a pronounced Perception-Reality Gap. On the perception side, practitioners in Coimbatore's cold chain sector are strikingly unified: infrastructure quality, energy cost, storage capacity and infrastructure gaps all received mean agreement scores above 4.1 out of 5, with low standard deviations indicating that this conviction is broadly shared rather than concentrated among a subset of respondents. On the reality side — measured by whether these same constructs statistically predict variation in respondents' own efficiency and sustainability ratings — the evidence is essentially null. None of the four hypotheses (H1–H4) is supported by the regression results, and the model as a whole fails to explain meaningful variance.

Two readings of this gap are worth considering. The first is a ceiling effect: if most surveyed organisations in this sample have already reached broadly comparable, adequate levels of infrastructure, energy management and storage capacity, the remaining variation between firms may be too narrow for these variables to statistically differentiate high performers from low performers — even though, in absolute terms, all agree these

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factors matter. The second reading is that cold chain efficiency in this regional context is genuinely driven by variables the study did not measure — managerial coordination, technology adoption, workforce skill and inter-firm collaboration — and that physical infrastructure functions as a necessary baseline rather than a differentiator.

This interpretation is reinforced by the one item in the entire survey that broke from the pattern of uniformly high agreement: the sustainability-specific item on adopting practices to reduce energy consumption (M = 3.19), well below every other item in the instrument. Respondents are confident their operations are efficient and that infrastructure conditions matter, but far less confident that their organisations are actually executing on energy-reduction practice — a gap between operational confidence and sustainability practice that mirrors the gap between perceived importance and statistical influence found in the regression results.

VII. CONCLUSION AND RECOMMENDATIONS

This study set out to examine how infrastructure quality, energy cost, cold storage capacity and infrastructure gaps influence the efficiency and sustainability of cold chain logistics systems in the food industry in Coimbatore, India. Using a 180-respondent field survey analysed through reliability testing, descriptive statistics and multiple regression, the study finds strong, consistent practitioner agreement that all four factors matter, but no statistical evidence that differences in these factors explain differences in reported efficiency and sustainability outcomes ($R^2 = .004$; H1–H4 all not supported).

The practical implication is not that infrastructure is unimportant — the descriptive results make clear that practitioners regard it as essential — but that infrastructure investment alone is unlikely to move the efficiency needle further once a baseline level of adequacy has been reached. The study recommends four complementary directions. First, pair infrastructure spending with process-level interventions such as digital temperature monitoring and IoT-based tracking, which can convert existing physical assets into measurable performance gains. Second, invest in workforce capability — training in cold chain handling and energy-conscious operating practice — since managerial and human factors may explain more of the variance than physical assets alone. Third, strengthen cross-stage coordination between producers, storage operators and transporters through shared scheduling and integrated logistics planning, addressing the organisational dimension of infrastructure gaps identified in the literature. Fourth, given the low mean score for sustainable energy practice relative to every other item surveyed, prioritise targeted energy-efficiency programmes and renewable-energy incentives as a distinct intervention rather than assuming they follow automatically from general infrastructure upgrades.

The study is limited by its cross-sectional design, its reliance on self-reported perceptual data rather than objective performance metrics such as spoilage rates or energy consumption records, and its geographic focus on a single regional hub. Future research should incorporate objective operational data, test additional variables such as technology adoption and workforce skill directly, and extend the analysis to multiple regions to assess whether the Perception-Reality Gap identified here is a feature of Coimbatore's cold chain specifically or a broader pattern in India's regional food logistics sector.

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