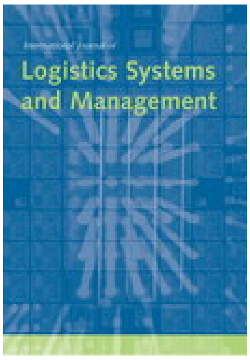

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Technological assessment of global warming inference for cold supply chain performance

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Abstract: Now a day, a need arises to maintain and improve the self-life and texture of temperature sensitive products in a wide range with a stable supermarket of cold supply chain. Since, the cold supply chain uses a very huge amount of energy consumption and hazardous refrigerants in refrigeration process of the temperature sensitive products, the attention over its operations and related emission become very important from the environmental as well as economic point of view. This paper aims to identify and analyse the most critical criteria related to the emissions from the cold supply chain and to find out the best possible alternatives that optimise the cold supply chain performance cost as well as global warming cost of the same.

Keywords: cold supply chain; HFC gases; greenhouse gases; global warming effect; AHP; TOPSIS approach.

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1 Introduction

As on the one corner world population is growing exponentially with a growth rate of 1.1% per year or approximately 83 million annually and on other side the survival of lives, the dependency of people on freeze products are being limited. Same as visualised in past few decades, due to the increase in global temperature and health consciousness of the people, the demand for healthy, hygienic, and quality products has been increased very rapidly. In a supply chain that is used to deliver the perishable and temperature sensitive products (such as fresh fruits, vegetables, meat, vaccines and pharmaceuticals), it become very difficult to maintain the quality and potency as they start biological and chemical reactions and the product gone waste as soon as the temperature of the surrounding of the same reach to out of the recommended sustainable range.

A cold supply chain plays a vital role for delivering such products from production to end consumption stage and creates an attraction of the researchers due to its vast future opportunities and market scope for research (Al Theeb et al., 2020). According to the International Dictionary of Refrigeration, "cold chain is a continuous process that maintains a desired range of sustainable temperature of perishable goods and preservation of the same to maintain the shelf life, quality, integrity and potency throughout the supply chain". James and James (2010) presented that in a cold chain, to ensure and maintain the safety, quality and self-life of product, the movement of goods from upstream (production stage) to downstream (end consumer) takes place at a specific range of their sustainable temperature of either deep freeze, freeze, chilled or cold to normal.

Mattarolo (1990) presented that about 40% of entirely foods require their storage and transportation in a temperature-controlled environment and the electricity consumed during these operations accounts for 15% of the total electricity consumed worldwide.

Similar results for electricity consumption in the refrigeration process of cold chain were estimated by Coulomb (2008) and Meneghetti and Monti (2015). The absence of cold chain units creates a huge amount of products loss. Gustavsson et al. (2017) estimated that the unavailability of sufficient cold chain facilities causes to nearly 40% of the total food produced globally that creates a risk of the food security in the near future.

According to Garnett (2007), the, due to the increasing global temperature and to avoid the risk of health and food security, the people preference about the food have moved towards refrigerated and stored products (such as chilled soft and alcoholic drinks, ice cream, cooked food, and meat) that results into higher energy consumption and increasing greenhouse gas emission. Zhang et al. (2019) presented that, in a cold supply chain, to achieve the intended objective, refrigerated trucks, railway wagons, cargo containers, cold storage and refrigerated warehouses are used as the key units that utilises a large amount of energy and hazardous refrigerants. The large amount of energy consumption in cold supply chain become as the major problem from last few years (Wu et al., 2019; James and James, 2011; Saif and Elhedhli, 2016; Hu et al., 2019). As the major part of energy used in the refrigeration process of the cold chain comes from the coal operated thermal power plant or other fuels (such as diesel and gasoline), it generates a huge amount of greenhouse gases and mounted a burden on the environment (Adekomaya et al., 2016). The cold supply chain contributes to 1% of the global greenhouse gas emission and become the third largest contributor of the same after the USA and China if it considered as a country (Heard and Miller, 2019; Hu et al., 2019). The huge amount of energy consumption in cold supply chain not only adversely affects the environment but also diminishes the performance of the same.

The carbon emission from the refrigeration process of the cold chain has become as the most critical challenge for the world and if the corrective actions are not taken to reduce the same may cause severe negative impact on our environment and may cause to lose millions of human lives (Solomon et al., 2007). The Carbon Disclosure Project Report (2006) estimated the CO_2 emission from the food cold chain to be 1% of global CO_2 emission and if the corrective actions are not taken to control the same, the expenditure required to mitigate climate change may reach to 1% of global GDP annually and the overall associated costs to 20% of global GDP annually.

Therefore, for the cold chain management, it becomes a greater challenge to reduce the negative emissions from their cold chain operations. Hence, in order to improve the performance of the cold supply chain from environmental aspect ensuring the product quality and safety, it become necessary to identify and analyse the most critical criteria which are responsible for large energy consumption and negative emissions and suggest the best possible alternative solutions to tackle the adverse influence of identified criteria.

1.1 Research objectives

The ultimate focus of the current analysis is to provide a basis for cold chain management and the researchers to identify the weakness that promotes the higher rate of emission from the CC operations. The analysis of the presented work will help the management to establish the bench mark for their emissions and take the effective measures to improve their cold chain operations. From the above motivation, the objectives of the current research work are:

- to identify, analyse, and prioritise the most critical criteria responsible for increasing the emissions from the cold chain operations.
- To tackle the influence of identified criteria and improve the performance of the cold chain from environmental and economical perspective, recommend the best possible alternatives (in terms of technological practices) that enables the management to make the continuous improvement for their organisation.

2 Literature review

Due to the increasing concern of the governmental and environmental bodies, and the awareness of the peoples towards the environmental issues have mounted an enormous pressure on the cold chain industries to reduce their emissions (Gunasekaran and Spalanzani, 2012). Ferretti et al. (2018) demonstrated that the refrigeration process in cold supply chain such as transportation and the storage not only raises financial cost but also negatively impact the environment. It has been observed from the past researches that the refrigeration in cold chain consumes about 20% of the total energy generated worldwide (Garnett, 2007; Lennon et al., 2017). Adekomaya et al. (2016) presented that the amount of energy consumption during the transportation of the refrigerated products accounts for 15% of world fossil fuel energy. Kayfeci et al. (2013) represented that the energy consumption in cold chain refrigeration contributes to 30% of the total energy consumption worldwide. Huang et al. (2009) estimated that the cold chain industries contribute to more than 75% of the total greenhouse gas emission from all the industrial sectors. Adekomaya et al. (2016) established a framework to visualise the environmental impact of diesel engine driven refrigerated vehicles during the transportation in the cold chain and stated that the emission from these refrigerated vehicles accounts for 40% of the global greenhouse effect.

In a case study related to current status of cold chain in China, Zhao et al. (2018) represented that the losses at the storage and distribution of vegetables due to the lack of sufficient availability of cold chain accounts for about 20% to 31% while for fruits this data hold the value of 10% to 15%. The large energy consumption during the movement of the perishable products from upstream to downstream arising as a global challenge. In addition to the above, large amount of energy consumption means more expensive the refrigeration process and higher the cost of the cold chain. The optimised use of energy in cold chain not only helps to reduce the hazardous emissions but also provides a security for energy conservation for the future (Wu et al., 2019). Arrieta and Gonzalez (2019) presented the energy consumption as the key responsible factor for the higher rate of GHG emission from the cold supply chain. Pierre et al. (2019) presented key factors which affecting the carbon emission. Dhrioua (2019) suggested renewable energy resources as the best alternative to reduce the carbon emission and produce the energy in a cold supply chain. In the similar experimental analysis performed by Wu et al. (2018), it was suggested to make use of buried pipe technology to achieve the optimised level of energy consumption in the refrigeration process of cold chain.

In addition to the impact of cold supply chain on global warming, reverse impact of increase in global temperature has also been observed by James and James (2010). In the consequences of fluctuation in the surrounding conditions (such as temperature, humidity and light intensity) increases the level of microorganism present in the perishable or temperature sensitive products such as meat, sea food, fresh fruits and several agro-products. This results into reduced quality and shelf life of products and increase the requirement to maintain a lower freezing or chilling temperature range while escalate the energy consumption and greenhouse gases. From the past findings it has also been observed that as the ambient temperature of surroundings increases, it significantly rises the amount of power consumption from the refrigeration units to maintain a temperature required for product sustainability.

Another critical factor that contributing to higher level of GHG emission from the cold chain is leakage of refrigerants from the refrigeration units (Zhao et al., 2018; Garnett, 2007). Saif and Elhedhli (2016) presented the effect of refrigerants leakage from the refrigeration units on the environment and commend that same factor must be taken into consideration while establishing the benchmark for performance improvement of the cold chain. It has been observed that the leakage of refrigerants omits a large amount of hydro-fluoro carbons (HFCs) and chloro-fluoro carbons (CFCs) emission that play a major role in the global warming. Garnett (2007) presented that the refrigerants leakage in the refrigeration process of cold chain accounts for 15% of the total emission from the chain. This happens because of the use of traditional refrigeration methods and higher global warming potential (GWP) refrigerants. Although the refrigerants such as CFCs and HFCs have excellent thermal properties, they have very high global warming potential (GWP) and ozone layer depletion potential (OLDP). Therefore, the immediate replacement for these refrigerants is necessary to reduce the effect of these refrigerants on global warming and ozone layer depletion.

To ensure the environment friendly emissions of the refrigerants leakage, Aktemur et al. (2020) proposed to make use of halogen centred refrigerants for the refrigeration process in cold chain. To reduce the impact of most criticised refrigerant such as R404A leakage, Kayfeci et al. (2013) suggested for the halogen-based alternative refrigerants. Andrew (2020) prohibited the use of the refrigerants that have a GWP of 2,500 or more. In the same regulation, it was estimated that R404 accounts for about 46% of worldwide F-gases in supermarket refrigeration system and introduced alternate refrigerants such as R407A and R407F which have less global warming potential (GWP, 1,924 and 1,824 resp.) which is much lower than that for R404A (i.e., 3,922). The use of technologies such as tri-generation refrigeration, air cycle refrigeration, thermo-acoustic refrigeration, solar direct drive, and sorption-absorption refrigeration system are also offering a substitute for the refrigerants like CFCs and HFCs and may significantly reduce the energy consumption and operating cost of the refrigeration in the cold supply chain.

In addition to above, the efficacy and accessibility level of the real time temperature monitoring and performance measurement system are the two most essential parameters that play a key role in the performance measurement of the cold supply chain form environmental perspective (Goransson et al., 2017; Oskarsdottir and Oddsson, 2019; Tsang et al., 2018). Lack of sufficient real time temperature monitoring of the products such as vaccines, foods and other pharmaceuticals leads in the cold chain leads to risk for product security, unnecessary equipment run and sometimes the products gone waste. Ashok et al. (2016) presented that the lack of performance management system in the cold chain industry plays a key role in reducing the energy efficiency and increase in energy consumption. Therefore, in order to optimise the energy consumption and thus lowering emissions from the cold chain, it become necessary to conduct the continuous real time temperature monitoring of the products and the surroundings. In order to optimise the environmental impact of the cold supply chain operations, Hariga et al.

(2017) advised the cold chain organisations to implement the carbon tax policies and bound the amount of carbon footprint emitted from the various activities of the same. Chandra and Kumar (2018) and Gunasekaran and Ngai (2004) identified the prime barriers for the performance measurement of vaccines supply chain. In the same study, authors have presented the lack of information exchange and inadequate temperature monitoring as the key factors responsible for higher waste and operational cost of vaccines supply chain.

The cost of rotten waste was considered as one of the most critical criteria for environmental impact analysis of cold chain by the many researchers (James and James, 2010; Adekomaya et al., 2016; Shashi et al., 2018; Raut et al., 2019; Florindo et al., 2018). Wu et al. (2019) presented a life cycle assessment analysis to analyse the effect of fruits and vegetables waste on the environment. A high volume of product waste upsurge to loss of primary energy resources and negatively affects the environment. The cases where the prime objective of the cold chain is to save the human lives such as pharmaceutical, vaccines and chemicals, a little fluctuation in the surrounding conditions may cause to product waste and some leads to danger for lives (Khoukhi et al., 2019). To develop the environmental sustainability for pharmaceutical supply chain, Abbas and Farooquie (2020) presented various reverse logistics practice models identify prominent criteria or barriers for the same. To ensure, the eminence and potential delivery such products, Haial et al. (2020) presented a framework for transportation of such products aiming to minimise the loss during this stage. Therefore, in order to ensure the least possible waste, it become vital to uptake the advanced and eco-friendly alternative technology in all the cold chain sectors including household consumer to large industrial sectors.

In cold supply chain, the nature of technology used for refrigeration, tracking and temperature monitoring process also play a key role while measuring the performance of the same. The use of traditional and outdated technology often leads to poor performance and higher energy consumption (Oskarsdottir and Oddsson, 2019; Adekomaya et al., 2016; Aktemur et al., 2020). In addition, the outdated technology cause to higher refrigerant leakage and global warming emission. To minimise the use of non-renewable energy, Shankar and Srinivas (2012) presented the importance of solar-based dual technology that realises the benefits of both refrigeration and power requirement for domestic and industrial refrigeration system. Verbalising the importance of the cascade-based refrigeration system, Aktemur et al. (2020) presented the refrigerant RE170 as the most favourable refrigerant with lowest environmental impact and higher refrigerating performance. Dabwan et al. (2020) presented the remunerations of the application of solar-based tri-generation technology in cold supply chain. The major advantage of integrating tri-generation technology with the solar system is that it requires minimum primary energy resources with lowest carbon emission (Segurado et al., 2019).

In addition, the tri-generation technology facilitates the advantages of cooling, heating and power at a time. The economical and higher coefficient of performance makes the tri-generation technology more attractive among all the refrigeration technologies. In order to improve the performance of cold supply chain from environmental perspective, Ferretti et al. (2018) and Kumar et al. (2018) presented the effect of environmental changes on cold supply chain performance and its level of GHG emissions and pointed that the use of traditional and out dated refrigeration technology as the key factor responsible for high emission of greenhouse gases from cold chain. In the similar tactics, Faisal (2011) presented an agility-based hierarchal model to acquire the priority weights for the different strategies. Saga et al. (2019) analysed the impact of energy consumption and carbon emission from the transportation process of the supply chain. To optimise the energy consumption and reduce emissions, they focussed to implement the incentives and penalty-based model in the transportation stage of the supply chain.

In a case study on vaccines cold supply chain, Kumar et al. (2021) suggested to implement the solar-based energy system on large scale as an alternative energy source to reduce the fuel and electrical energy consumption and their GHG emissions from the same. During a case study on the assessment of life cycles for the food products, Krishnan et al., (2020) identified the major causes for the operational inefficiencies in food cold supply chain. Ghorbani and Mehrpooya (2020) suggested making use of solar and thermally operated equipment's for refrigeration process. In the similar study performed by Cheng et al. (2020) suggested the use of hydrate cold storage to improve the same.

Moreover, from the comprehensive analysis of the recent literature, it has been observed that most of the researches have either specifically focused on the technological aspect or the financial and environmental aspect of the cold supply chain. Due the best of authors' knowledge, no work has been published yet that discusses the environmental aspects of the cold chain assimilating the influencing factors with their alternative solutions with a comparative analysis among them. The presented work bridges this gap incorporating all the above gaps of the past researches.

The remaining sections of the presented work are arranged as: Section 3 discusses the model development section for the intended objective in which Section 3.1 is incorporated for the inspiration for the proposed methodologies. In Section 4, the research methodologies have been discussed. Section 5 discusses how the proposed methodology has been implemented to solve the problem. Sections 6 and 7 are included to discuss the results and discussion, and the managerial and theoretical implications of the presented work respectively. Section 8 discussed the concluding remark and future scope of the presented work.

3 Model development

To achieve the objective of the presented research work, an extensive study of the literature on environmental aspect of cold supply chain operations has been performed. At the same time, the discussion sessions with indusial and academic experts were conducted. Based on literature gaps and opinions obtained from the experts, eight most critical criteria (responsible factors for higher rate of emissions from cold chain) were identified and selected for the analysis for which the literature support and their explanations are given in Table 1.

In order to mitigate the impact of GHG emissions from cold supply chain operations on the environment and improve the performance of the same, the research work proposed some best possible alternatives (in terms of technological practices and processes). Based on literature review of latest and traditional cold chain technologies, opinions obtained from conducting problem discussion sessions with the academic and industrial experts and practitioner, five best possible technological practices were identified as the alternatives. The summary of alternatives, their literature supports and definitions are given in Table 2.

Table 1 Literature support and the explanation for the criteria

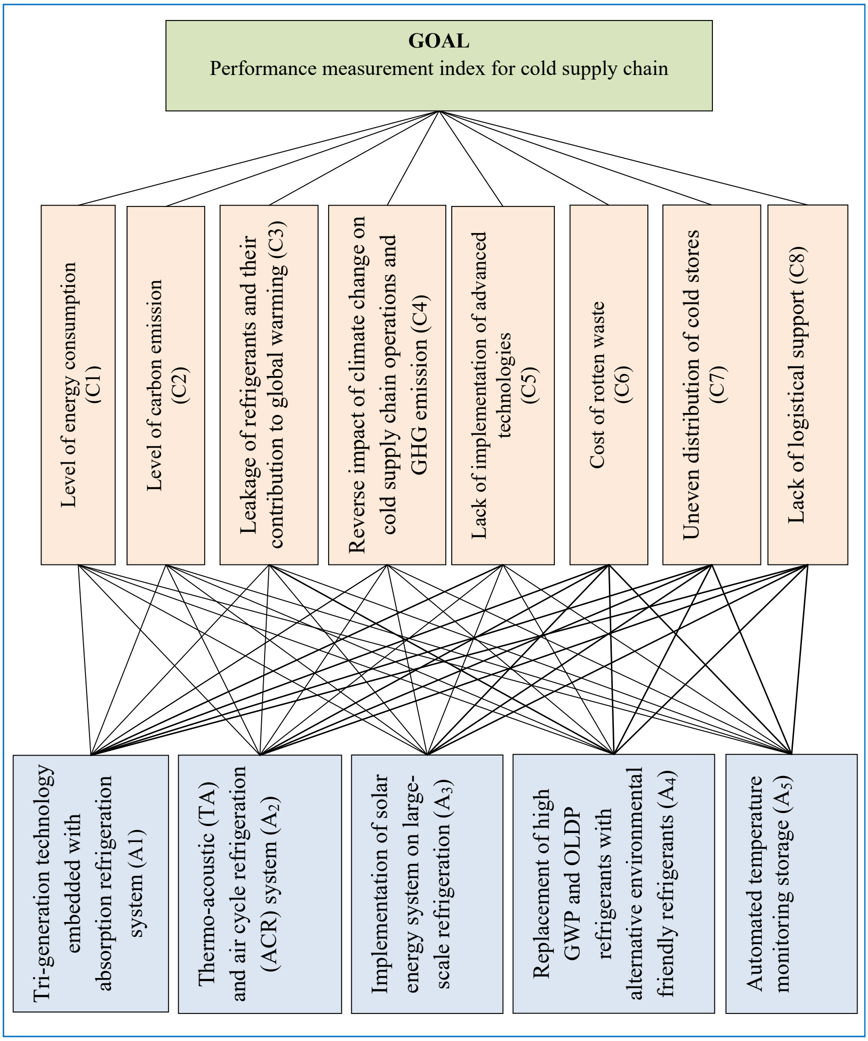
Criteria (C_i)	*Literature support*	*Definition*
Level of energy consumption (C_1)	Wu et al. (2019), Arrieta and Gonzalez (2019), James and James (2010), Saif and Elhedhli (2016), Hu et al. (2019) and Adekomaya et al. (2016)	Higher the amount of energy consumption escalates the carbon emissions from the cold supply chain. It includes the total energy consumption in all the refrigerated stages of the cold chain including storage and transportation.
Level of carbon emission (C_2)	Garnett (2007), Heard and Miller (2019), Hu et al. (2019), Gunasekaran and Spalanzani (2012), Adekomaya et al. (2016) and Aktemur et al. (2020)	Extent of the carbon emission per unit of refrigeration load. It includes emissions from energy consumption, refrigeration leakage, and product waste.
Leakage of refrigerants and their contribution to global warming (C_3)	Zhao et al. (2018), Saif and Elhedhli (2016), Garnett (2011) and Sainathan and Time (2018)	The extent of the GHG emission from high GWP refrigerants such as hydrofluorocarbons (HFCs) and chloro-fluoro carbons (CFCs)
Reverse impact of climate change on cold supply chain operations and GHG emission (C_4),	Saif and Elhedhli (2016), James and James (2010), Hu et al. (2019), Hariga et al. (2017) and Ferretti et al. (2018)	Higher the fluctuation in the climatic conditions requires more control over temperature and surroundings that intern higher the energy consumption and GHG emissions.
Lack of implementation of advanced technologies (C_5)	Oskarsdottir and Oddsson (2019), Adekomaya et al. (2016), Aktemur et al. (2020) and Ghorbani and Mehrpooya (2020)	The traditional and outdated technologies lead to higher energy consumption and refrigeration leakage that increases the GHG emission from the cold chain.
Cost of rotten waste (C_6)	James and James (2010), Adekomaya et al. (2016), Shashi et al. (2018), Raut et al. (2019), Florindo et al. (2018) and Wu et al. (2019)	Higher amount of product waste leads to degradation of primary energy resources, risk for food security and significant amount carbon die emission.
Uneven distribution of cold stores (C_7)	Zhao et al. (2018), Raut et al. (2019), Hu et al. (2019) and Al Theeb et al. (2020)	Uneven distribution of cold storage facility leads to higher energy consumption for transportation and higher chances for product waste.
Lack of logistical support (C_8)	Oskarsdottir and Oddsson (2019) and Zhang et al. (2020)	Degree of association of all the member of the cold chain such as supplier, manufacturer, retailer, distributor, and consumer.

Table 2 The summary of alternatives, their literature supports and definitions

Alternative (A_i) and literature support	*Drivers to inspire uptake*	
Tri-generation technology embedded with absorption refrigeration system (A_1) (Dabwan et al., 2020; Estrada-Flores, 2010; James and James, 2010)	1	Higher operational and energy saving efficiency (up to 90% in comparison to other processes).
	2	Facilitate the cooling, heating and power at a time.
	3	Restrict the use high GWP refrigerants such as CFCs and HFCs, thus reduces the GHG emission.
	4	Greater availability of secondary energy resources to operate the system such as solar energy system.
	5	Best suited for large refrigerated warehouses for space cooling.
Thermo-acoustic (TA) and air cycle refrigeration (ACR) system (A_2) (Siddiqui and Langde, 2020; Nathad et al., 2019)	1	Eradicate or very less harmful emissions to the environment as it utilise sound waves for refrigeration and very less or no primary energy consumption.
	2	Restrict the use of high GWP refrigerants such as HFCs by using inert gases or the mixture of inert gases such as He, Ar, or air as a for cooling.
	3	Utilises very less of no moving part in compare to other refrigeration technologies such as vapour compression refrigeration.
	4	High coefficient of performance for low temperature regions.
Implementation of solar energy system on large scale refrigeration (A_3) (Ghorbani and Mehrpooya, 2020; Kumar et al., 2021)	1	Very low or no electrical or primary energy consumption.
	2	Very low GHG emission as it utilise the solar energy as the energy source for refrigeration processes.
	3	Most suitable refrigeration technique for the case of vaccines supply chain and the regions where frequent power short falls occur.
	4	Reduces the overall cost of operation including environmental cost.
Replacement of high GWP and OLDP refrigerants with alternative environmental friendly refrigerants (A_4) (Aktemur et al., 2020; Kayfeci et al., 2013; Andrew, 2020)	1	The use of halogen-based refrigerants such as CFCs and HFCs is almost restricted and prohibited due their higher energy demand, high GWP, high Ozone layer deploying potential (OLDP) and negative climatic impact.
	2	The advancement in the technology offers the advantage using any alternative refrigerants such hydrofluoro-olefin (HFO) and hydrocarbon (HC), R41, R717, R134A, R404a, R744, R23 and R290 or the combination of any two such as R41-RE170 as they are natural, non-toxic, very low GWP and OLDP, and energy efficient.
	3	The use of CFCs and HFCs restrict the working temperature to –30°C to –35°C while the use of alternatives refrigerants as mentioned above offers the working temperature to –30°C to –100°C
Automated temperature monitoring storage (A_5) (Oskarsdottir and Oddsson, 2019; Hoffmann, 2011; Goransson et al., 2017)	1	It offers the advantage of better control over working temperature, higher shelf-life of the products and mitigate the risk of the products getting waste,
	2	Less labour required as compare to manual temperature monitoring.
	3	Make the cold chain energy efficient and lesser environmental impact

After identifying, the most critical criteria for performance evaluation of cold supply chain from environmental perspective and selecting the best possible alternative technological practices, next, an AHP-TOPSIS-based performance evaluation hierarchal model was developed as shown in Figure 1.

Figure 1 AHP-TOPSIS-based hierarchical model for cold supply chain performance (see online version for colours)



To analyse the criticality and find out the severity weights for the identified criteria, analytical hierarchy process (AHP) has been used. Technique for order preference by similarity to ideal solution (TOPSIS) method has been used to provide the ranking for the proposed alternatives and to select best one among all.

3.1 Inspiration to assimilate the AHP and TOPSIS methods

Both AHP and TOPSIS are the multi criteria decision-making (MCDM) techniques having different principles of implementation. The AHP technique is used to obtain the ranking or priority weights centred on the hierarchy-based pairwise comparison of the criteria obtained from the decision makers (Tyagi et al., 2015). While on the other hand, TOPSIS evaluate the performance of alternative-based distance principle. TOPSIS uses the positive ideal solution (PIS) and negative ideal solution (NIS) to obtain the best alternative that is nearest to PIS and farthest from the NIS thus eliminate the chances of selecting the one that offers least profit and maximum cost to the desired objective. Thus, the TOPSIS provides the alternative that provides the maximum profit and lowest cost for the problem objective. The AHP and TOPSIS techniques can be used separately to rank the set of attributes or criteria. However, lesser manual work for pairwise comparisons and data collection make an integrated AHP-TOPSIS more versatile over using separately (Shaikh et al., 2020). Many researchers have used integrated AHP-TOPSIS technique to obtain the solution for various industrial applications. Key applications of integrated AHP-TOPSIS technique are as:

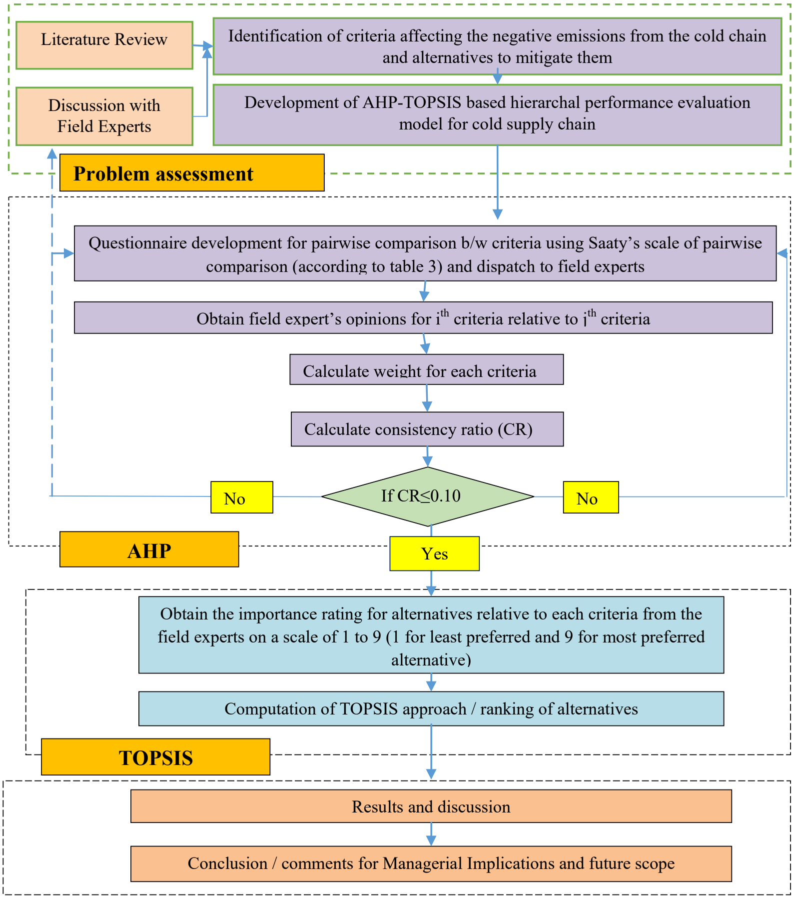
Joshi et al. (2011) used AHP-TOPSIS method to measure the performance of a cold supply chain. In integration to Delphi method, Hsieh et al. (2006) proposed AHP-TOPSIS technique to analyse the performance system of e-library of the universities situated in Taiwan. Kumar et al. (2021) used AHP-TOPSIS technique to evaluate the performance of vaccines cold supply chain. In integration with goal programming, Gardas et al. (2019) used AHP-TOPSIS method to select the best supplier for an organisation problem of supplier selection. Tyagi et al. (2014b) used AHP-TOPSIS method to evaluate the performance of e-supply chain management. By implying the fuzzy theory to AHP, Tyagi et al. (2018) used AHP-TOPSIS to obtain the weights and ranking for corporate social responsibility-based criteria and their alternatives respectively for an organisation in Indian context. Shaikh et al. (2020) applied AHP-TOPSIS technique to select the best site for commercial organisation. Bathrinath et al. (2020) used AHP-TOPSIS approach to obtain the severity weights and ranking for the risks and alternatives involved in a textile industry.

Hadad and Hanani (2011) presented an AHP-data envelopment analysis (DEA)-based methodological approach in order to prioritise and rank the criteria and alternatives, which have opinions in linguistic as well as quantifiable terms. This combination of provides a consistency check of gathered data with an ease in computation (Tyagi et al., 2014b). A one sight hierarchical view of considered criteria and alternatives is given in fig. 1 as given below.

4 Research methodology

The conceptual framework for the flow of research work and proposed methodology is given in Figure 2.

Figure 2 The conceptual framework for the flow of research work and proposed methodology (see online version for colours)



A brief introduction about the methods used and steps to implementation them for accomplishing the objective of the current research can be explained as follows.

4.1 The analytic hierarchy process method

The analytic hierarchy process (AHP) was first introduced by Thomas Saaty in 1971 and modified in 1980 (Hsieh et al., 2006). AHP is a MCDM technique that is most extensively used to obtain the weights for a set of criteria or attributes based on decision maker's pairwise comparison against the any one considered criterion among the all. The technique enables the decision maker to set the priorities for the given criterion and making decision based on these priorities to improve the performance of the cold chain. More importance is given to the higher weighted criteria and the decisions are made keeping this criterion at first priority among all. The pairwise comparison is used to determine the relative importance of criterion over each other. The AHP is a very flexible and powerful tool for decision making because it enables the decision maker to make decision based on the scores and the final ranking is obtained on the basis of pairwise relative evaluation of both the criteria and options available (Tyagi et al., 2014a). The strength of the AHP method lies in its ability to structure a complex multi-person, multi-attribute and multi-period problem (Tyagi et al., 2015).

In the current segment of the presented work, AHP method is used to obtain the criticality weights for the identified criteria. To achieve the objective at first, a hierarchal model containing the research goal at top, criteria at the middle and the alternatives at bottom was developed as given in Figure 1. Then to make the pairwise comparison between the criteria, a questionnaire was structured asking the rating for severity of the criteria using Saaty's scale of pairwise comparison on a scale of 1 to 9 as given in Table 3 and dispatched to 96 experts, out of which 37 responses were received with a response rate of 38.54%. Out of 37 received responses, five responses were rejected due to irrelevancy of the subject field. The experts were belonging to industrial and academic institutions of the Punjab, India having more than ten years of field and academic experience. Industrial experts were belonging to industries operating cold supply chain systems located in Ludhiana industrial area, Punjab while academic persons to technical institutions of Punjab and Delhi national capital region (NCR) India.

Table 3 Saaty's scale for intensity of relative importance

Definition	*Intensity of relative importance*
Equally important/preferred	1
Weakly important/preferred	3
Strongly important/preferred	5
Very strongly more important/preferred	7
Absolutely more important/preferred	9
Intermediate importance between two adjacent judgements	2, 4, 6, 8

The stepwise procedure to implement the AHP methodology can be summarised in the following steps.

Step 1 Construction of pairwise comparison matrix.

The expert's judgements are entered using a scale of 1 to 9 as proposed by Saaty (1980).

Assuming there are m number of criteria, the pairwise comparison of criterion i with criterion j gives a square matrix $[a_{ij}]_{m\times m}$, where a_{ij} denotes the relative importance of criteria i with respect to criteria j.

$$A = \left[a_{ij}\right]_{m\times m} = \begin{bmatrix} C_1 \\ \vdots \\ C_m \end{bmatrix} \begin{bmatrix} a_{11} & \cdots & a_{1m} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mm} \end{bmatrix} \tag{1}$$

The pairwise comparison matrix should satisfy the following criteria:

$$a_{ij} = 1, \text{ when } i = j \text{ and } a_{ji} = \frac{1}{a_{ij}} \tag{2}$$

Step 2 Calculation of relative normalised weight (w_i) for each criterion.

This can be done by calculating the geometric mean of i^{th} row and normalising the geometric mean of rows in the comparison matrix.

$$GM_i = \left(\prod_{j=1}^{M} a_{ij}\right)^{\frac{1}{M}} \tag{3}$$

and

$$W_i = \frac{GM_i}{\sum_{j=1}^{M} GM_i} \tag{4}$$

Step 3 Consistency check for pairwise comparisons.

The consistency check can be performed using following sub steps:

Step 3a Calculate matrix A_3 and A_4 such as:

$$A_3 = A_1 \times A_2 \;\text{ and }\; A_4 = A_3 / A_2 \tag{5}$$

where

$$A_2 = [W_1, W_2, \ldots, W_i, W_N]^T \tag{6}$$

Step 3b Find out the maximum Eigen value which is the average of matrix A_4.

Step 3c Calculate the consistency index (C.I.).

$$C.I. = (\lambda_{\max} - M)/(M - 1) \tag{7}$$

The smaller the value of C.I., the smaller is the deviation from the consistency.

Step 3d Calculate the consistency ratio,

$$C.R. = C.I./R.I. \tag{8}$$

where R.I. = random index for the number of criteria used in decision making obtained from Saaty's RI for N criterion as shown in Table 4.

Table 4 Saaty's R.I. value for the number of criterion N

N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

According to Saaty's boundary condition for the consistency of pairwise comparison, if the calculated value of consistency ratio comes out to be less than 0.1, then the comparison made are consistency and the calculated weights for the criteria can be acceptable for proceeding the further calculations.

4.2 Technique for order preference by similarity to ideal solution approach

Likewise, the AHP method, TOPSIS technique also categorised as a multi-criteria/alternative decision analysis tool, which was originally developed by

Hwang and Yoon in 1981. Due to its simplicity and lessen calculation, the TOPSIS technique has been most extensively used by the researchers and decision makers to select the best one among a set of possible solutions or alternatives (Hsieh et al., 2006). In addition to its simplicity and robustness, the TOPSIS technique enables the decision makers and the researchers to make the decision that implicate the monotony of both beneficial (increasing) and non-beneficial (decreasing) requirements of the objective (Joshi et al., 2011). In TOPSIS, the ranking for the alternatives is based on the principle of distance from the ideal solution. The TOPSIS method aims to find out the alternative that is closest to positive ideal solution (PIS) and farthest from negative ideal solution (NIS) (Lin et al., 2008). The PIS is that which provides maximum benefit and minimum cost among all the solutions. Opposite to the nature of PIS, NIS cost maximum and minimum profit to the objective function.

In the presented research work, the TOPSIS has been used to obtain the ranking for the proposed alternatives and to select best among them. In order to acquire the ranking for alternatives through TOPSIS method, at first a questionnaire was constructed asking for the alternative importance rating relative to each criteria on a scale of 1 to 9 (1 for least preferred and 9 for most preferred alternative) and send to 85 experts. Out of which 33 responses were received (response rate 36.47%) and analysed the entire in systematic manner before analysing to implement to the TOPSIS. The stepwise procedure to implement the TOPSIS technique to acquire the ranking for a set of alternatives based on criteria weights is as follows:

To explain the procedural steps involved in the TOPSIS, it is presumed that there are '**n**' alternatives (option) and '**m**' criterion (attributes). It is also assumed that the priority weights for each criterion have been calculated using AHP or any other MCDM technique and each alternative have the weights with respect to each criterion.

Step 1 Construction of pairwise evaluation matrix. An evaluation matrix $(d_{ij})_{n\times m}$ assuming d_{ij} be the score of alternative (option) i with respect to criterion j

$$A = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ d_{31} & d_{32} & \cdots & d_{3m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{m2} & \cdots & d_{nm} \end{bmatrix} \end{array} \tag{9}$$

Step 2 Normalisation of the pairwise evaluation matrix.

The matrix $(d_{ij})_{n\times m}$ is normalised to form the matrix $R = (r_{ij})_{n\times m}$, using the normalisation method using equation (10) as given below:

$$r_{ij} = \frac{d_{ij}}{\sqrt{\sum_{i=1}^{m} d_{ij}^2}} \tag{10}$$

For, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$.

Step 3 Construction of the weighted normalised decision matrix.

$$U = \left(u_{ij}\right)_{n\times m} = \left(w_j r_{ij}\right)_{n\times m}, \qquad \{i = 1, 2, \ldots, n \text{ and } j = 1, 2, \ldots, m\} \tag{11}$$

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1j} & \cdots & u_{1m} \\ \vdots & \vdots & \ddots & \vdots & \cdots & \vdots \\ u_{i1} & u_{i2} & \cdots & u_{ij} & \cdots & u_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \cdots & u_{nj} & \cdots & u_{nm} \end{bmatrix}$$

Step 4 Determination of the positive ideal and negative ideal solutions.

$$\begin{aligned} S^+ &= \left\{\left(\max_i u_{ij} \,\middle|\, j \in J\right), \left(\min_i u_{ij} \,\middle|\, j \in J'\right) \text{ for } i = 1, 2, \ldots, n\right\} \\ &= \left\{u_1^+, u_2^+, \ldots, u_j^+, \ldots, u_n^+\right\} \end{aligned} \tag{12}$$

$$\begin{aligned} S^- &= \left\{\left(\min_i u_{ij} \,\middle|\, j \in J\right), \left(\max_i u_{ij} \,\middle|\, j \in J'\right) \text{ for } i = 1, 2, \ldots, n\right\} \\ &= \left\{u_1^-, u_2^-, \ldots, u_j^-, \ldots, u_n^-\right\} \end{aligned} \tag{13}$$

where

{$J = 1, 2, \ldots m|j$ associated with benefit criteria}

{$J' = 1, 2, \ldots, m|j$ associated with the cost criteria}.

Step 5 Calculate the separation measure:

Positive ideal separation:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} \left(u_{ij} - u_j^+\right)^2} \qquad i = 1, 2, \ldots, n \tag{14}$$

Negative ideal separation:

$$D_i^- = \sqrt{\sum_{j=1}^{n} \left(u_{ij} - u_j^-\right)^2} \qquad i = 1, 2, \ldots, n \tag{15}$$

Step 6 Calculate the relative closeness to the ideal solution.

$$C_i^* = \frac{D_i^-}{\left(D_i^- + D_i^-\right)}, \qquad 0 < C_i^* < 1, i = 1, 2, \ldots, n \tag{16}$$

$$\begin{aligned} C_i^* &= 1 \qquad \textit{if } A_i = A^+ \\ C_i^* &= 0 \qquad \textit{if } A_i = A^- \end{aligned}$$

The ranking for the alternatives using TOPSIS method depends upon the calculated value of relative closeness coefficient (C_i^*). The alternative having highest C_i^* is considered as the best alternative among all and given rank one and the same with lowest C_i^* value is least preferred and given rank last.

5 Implementation of the proposed methodology

In the current research work, it is aimed to identify and analyse the critical factors (criteria) responsible for higher emissions from the cold chain and recommend the best possible alternatives in terms of technological practices. For the same, based on literature review and opinions obtained from the experts, eight most critical criteria and five best possible alternatives have been selected. The selected criteria are analysed using AHP approach. To provide the ranking and proposed best among them, TOPSIS method has been used as discussed in the research methodology section. The experts summary and data collection was done according to discussed summary in research methodology section.

5.1 Criteria analysis using AHP

In the current segment of the presented work, AHP method is used to obtain the criticality weights for the identified criteria. Stepwise procedure to achieve the research objective is as follows:

At first, following the steps (1 and 2) of AHP research methodology, a pairwise comparison matrix was constructed (using averaged of the all responses received from the experts, using equations (1) and (2) and normalised weights for the criteria were calculated [using equations (3) and (4)]. The summary of the pairwise comparison matrix and the criteria weights is given in Table 5.

Table 5 Weightage matrix for criteria

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*Priority weightage*
C1	1	4	2	5	2	1	4	4	0.25496
C2	0.25	1	0.33	0.33	0.2	0.5	2	5	0.06644
C3	0.5	3	1	3	0.25	0.5	4	1	0.11537
C4	0.2	3	0.33	1	0.33	0.33	3	2	0.08073
C5	0.5	5	4	3	1	1	2	3	0.19952
C6	1	2	2	3	1	1	3	4	0.19403
C7	0.25	0.5	0.25	0.33	0.5	0.33	1	1	0.04698
C8	0.25	0.2	1	0.5	0.33	0.25	1	1	0.04812

After formulating the pairwise comparison matrix and calculating the normalised criteria weights, it is very essential to know about the consistency of matrix, whether it is consistent or not. To check the consistency, consistency ratio (CR) that shows the mathematical demonstration of consistency for the comparisons made was calculated following the step 3 as discussed in AHP methodology. Following the steps (3a to 3d) and using equations (5), (6), (7) and (8), the C.R. value for the pairwise comparisons has been calculated as 0.09972, which is within the empirical upper limit of Saaty's upper boundary of consistency (according to Saaty, C.R. should be less than 0.1 for the consistency to exist). Therefore, from the above analysis, it can be said that the comparisons made for criteria weights calculation are consistent and can be accepted for the further calculations.

5.2 Determination of the alternatives raking using TOPSIS

After finding the severity weights for each criterion, it is needed to assess the weight value of considered alternatives with respect to the criteria and recommend the best one among them. For the same, TOPSIS approach has been applied following the steps as discussed in research methodology section and an evaluation matrix for five alternatives and eight criteria [using step 1 and equation (9) for TOPSIS methodology] has been developed. The matrix was constructed using the averaged of all the responses received for preference rating of the alternative relative to each criterion (as discussed in research methodology section for TOPSIS) and the same is shown in Table 6.

Table 6 Evaluation matrix for alternatives with respect to criteria

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	6	5	6	5	9	5	8	8
A2	8	9	9	8	7	4	7	2
A3	9	7	8	7	8	6	8	6
A4	6	4	8	6	5	4	4	4
A5	6	6	6	5	6	8	7	6

In the next step, in order to reduce the variability among the data in row and column, normalisation of the evaluation matrix has been performed [using equation (10)] and a normalised evaluation matrix has been constructed as shown in Table 7.

Table 7 Normalised decision matrix

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	0.3772	0.3475	0.3579	0.3544	0.5636	0.3990	0.5143	0.6405
A2	0.5030	0.6255	0.5364	0.5671	0.3192	0.3192	0.4500	0.1601
A3	0.5658	0.4865	0.4772	0.4962	0.5010	0.4789	0.5143	0.4804
A4	0.3772	0.2780	0.4772	0.4253	0.3131	0.3192	0.2571	0.3203
A5	0.3772	0.4170	0.3579	0.3579	0.3757	0.6385	0.4500	0.4804

Table 8 Weightage normalised matrix

Criteria weights, u_{ij}	*0.25496*	*0.06644*	*0.11537*	*0.08073*	*0.19952*	*0.19403*	*0.04698*	*0.04812*
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	0.0962	0.0231	0.0413	0.0286	0.1124	0.0774	0.0242	0.0308
A2	0.1282	0.0416	0.0619	0.0458	0.0875	0.0619	0.0211	0.0071
A3	0.1443	0.0323	0.0551	0.0401	0.1000	0.0929	0.0242	0.0231
A4	0.0962	0.0185	0.0551	0.0343	0.0625	0.0619	0.0121	0.0154
A5	0.0962	0.0277	0.0413	0.0286	0.0750	0.1239	0.0211	0.0231
$S_i^+ =$	0.1443	0.0416	0.0619	0.0458	0.1124	0.1239	0.0242	0.0308
$S_i^- =$	0.0962	0.0185	0.0413	0.0286	0.0625	0.0619	0.0121	0.0077

After constructing the normalised evaluation matrix, a weightage-normalised matrix was developed [using equation (11)] and positive ideal and negative ideal solutions were determined by using equations (12) and (13), the summary of the same is given in Table 8.

When the positive ideal and negative ideal solutions formed, next, the separations for each alternative from the positive ideal and negative ideal solutions (i.e., D_i^+ and D_i^-) were calculated using equations (14) and (15). The separations from PIS and NIS are summarised in Tables 9 and 10, respectively.

Table 9 Matrix for separation from positive ideal solution

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	Σ *row*	D_i^+
A1	0.0023	0.0003	0.0004	0.0003	0.0000	0.0022	0.0000	0.0000	0.0055	0.0744
A2	0.0003	0.0000	0.0000	0.0000	0.0006	0.0038	0.0000	0.0005	0.0053	0.0725
A3	0.0000	0.0001	0.0000	0.0000	0.0002	0.0010	0.0000	0.0001	0.0013	0.0366
A4	0.0023	0.0005	0.0000	0.0001	0.0025	0.0038	0.0001	0.0002	0.0097	0.0987
A5	0.0023	0.0002	0.0004	0.0003	0.0014	0.0000	0.0000	0.0001	0.0047	0.0685

Table 10 Matrix for separation from negative ideal solution

	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	Σ *row*	D_i^-
A1	0.0000	0.0000	0.0000	0.0000	0.0025	0.0002	0.0001	0.0005	0.0034	0.0586
A2	0.0010	0.0005	0.0004	0.0003	0.0006	0.0000	0.0001	0.0000	0.0030	0.0547
A3	0.0023	0.0002	0.0002	0.0001	0.0014	0.0010	0.0001	0.0002	0.0056	0.0746
A4	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0003	0.0168
A5	0.0000	0.0001	0.0000	0.0000	0.0002	0.0038	0.0001	0.0002	0.0044	0.0663

The preference order or ranking for alternatives using TOPSIS technique depends upon relative closeness of the alternative from the positive ideal solutions. Therefore, it is required to know the relative closeness of each alternative from the ideal solution. In order to calculate the relative closeness coefficient (C_i^*), equation (16) has been used. The summary of the relative closeness coefficient (C_i^*) is given in Table 11.

Table 11 Relative closeness for alternatives

	$C_i^* = \frac{D_i^-}{\left(D_i^+ + D_i^-\right)}$
A1	0.4408
A2	0.4298
A3	0.6710
A4	0.1453
A5	0.4917

The final step of the TOPSIS method is to provide ranking for the alternatives. The ranking and preference order obtained from TOPSIS analysis depend upon the value of relative closeness coefficient (C_i^*). The alternative that attains the highest relative closeness coefficient is most prefer alternative and given rank first while the same with least C_i^* value considered as the least preferable and given rank last. Accordingly the other alternatives are ranked based on their C_i^* value.

6 Results and discussion

The objective of the presented work was to identify and analyse the most critical criteria responsible for higher negative emissions from the cold supply chain and propose best possible alternatives to improve the performance of the same from environmental perspective. To achieve the objective, based on literature review and discussion with experts, eight criteria were identified as most critical and selected for their severity analysis performed using AHP method. The results obtained from AHP are summarised in Table 5. To check the consistency of the decisions made for pairwise comparison, consistency check has been performed. From the consistency test, it has been found that the value of C.R. is 0.09972, which fulfils Saaty's requirement of the consistency of the decisions made for pairwise comparison (according to Saaty, C.R. should be less than 0.1 for the consistency to exist). Therefore, it can be whispered that the decisions made by the experts are consistent and the criteria weights as summarised in Table 5 can be accepted for further analysis.

Table 5 demonstrates that the criterion C1 (level of energy consumption) having eigenvalue 0.25496 attains the highest priority weight and is most severe criterion from the environmental as well as economic point of view. On the other hand, the criterion C7 (uneven distribution of cold stores) attains the least priority weight 0.04698 and is least influencing criteria to the negative emissions of the cold supply chain. The reason behind the 'level of energy consumption' as the highest influencing criterion to the environment is that as the energy consumption in cold chain rises, it significantly escalates the GHG emissions and operational cost of the refrigeration (Ferretti et al., 2018). In addition, if the consumed energy comes from the coal or other primary fuels operated thermal power plants, the condition becomes more worsen as it causes to degradation of natural energy resources, a dangerous negative impact on the environment (for, e.g., CO_2 emission), and a significant rise in the operational economy of the cold chain. Therefore, for a cold chain management and decision makers, it should be the prime focus to reduce the energy consumption in all stages of the chain so that the environmental cost and other energy related costs can be minimised up to a least possible level.

In continuation of the results, the criterion C5 (lack of implementation of advance technologies) attains the second highest priority weight ($W_5 = 0.19952$) and become the second most severe criteria responsible for higher GHG emissions and energy consumption in cold supply chain. Therefore, after emphasising energy consumption throughout the cold chain, the decision makers and management must focus on the technology used for the refrigeration and other cold chain operations. The application of traditional and outdated technology often leads to higher energy consumption; poor efficiency and coefficient of performance, refrigeration leakage, and higher energy consumption that significantly raise the GHG emission form the cold chain.

Followed by the level of energy consumption and lack of implementation of advance technologies, other criteria C6 (cost of rotten waste, W6 = 0.19403), C3 (leakage of refrigerants and their contribution to global warming, W3 = 0.11537), C4 (reverse impact of climate change on cold supply chain operations and GHG emission, W4 = 0.08073), C2 (level of carbon emission, W2 = 0.06644), C8 (lack of logistical support, W8 = 0.04812), and C7 (uneven distribution of cold stores, W7 = 0.04698) attain the highest severity weight accordingly. The severity sequence of criteria can be summarised as: C1 > C5 > C6 > C3 > C4 > C2 > C8 > C7. To visualise the severity order of the criteria in one view, a pie chart has been constructed and shown in Figure 3.

Figure 3 Pie chart for the severity weights of the criteria (see online version for colours)

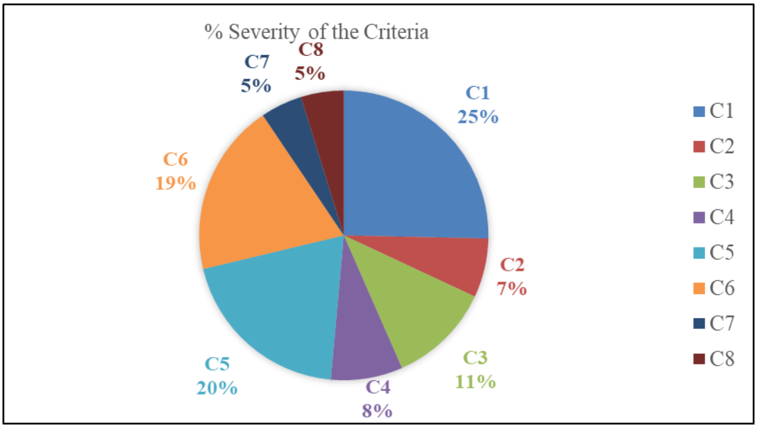
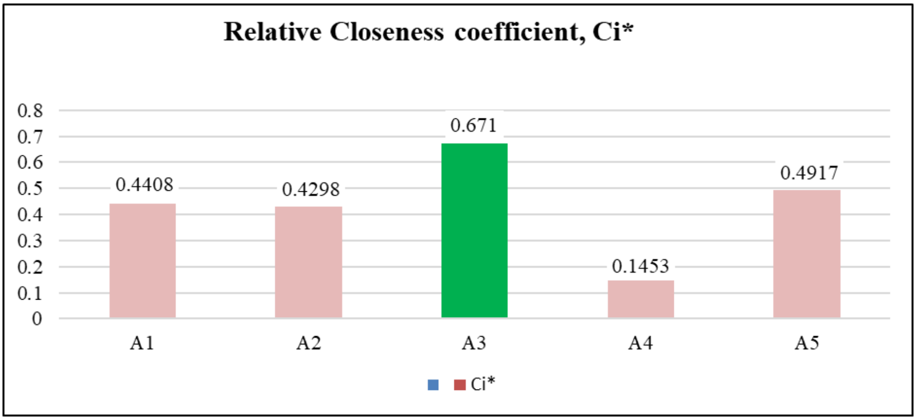


Figure 4 Bar diagram for relative closeness coefficient (see online version for colours)



In order to improve the performance of the cold chain and mitigate the influence of the above-discussed criteria on the environment, the research work proposed five best possible alternatives (in terms of technological practices). To acquire the ranking for the alternatives and suggest best among them, TOPSIS method has been used. To rank the alternatives, relative closeness coefficient (C_i^* shows the closeness of the alternative from the PIS or separation from NIS) for each alternatives was calculated as discussed in ‘implementation of research methodology’ section and summarised in Table 11. Based on C_i^* value, priority/ranking of alternatives has been decided. The alternative, for which C_i^* value was highest, given rank one and considered as the most preferred alternative and the same with least C_i^* value, given rank eight and preferred at last. The one sight view of the alternative preference weights based on relative closeness (C_i^*) is shown in Figure 4.

Analysis of the results as acquired from the TOPSIS method (Table 11 and Figure 4) demonstrates that alternative A3 (implementation of solar energy system on large scale refrigeration) realises the highest value of relative closeness coefficient (C_3^* = 0.6710), thus reflected as the most important from environmental perspective and ranked as one. Solar energy is a very imperative and available in abundant quantity with lower installations cost compare to other form of energy resources. In addition to this, a solar energy driven refrigeration system not only tackles the challenges of non-renewable energy resources (e.g., fossil fuel and nuclear material) such as unreliable power supply and power short falls but also facilitate an environmental friendly refrigeration with almost zero GWP. The key factors that inspire to uptake the solar energy driven refrigeration systems at first priority among all the alternatives are:

- very low or no electrical or primary energy consumption
- very low GHG emission as it utilises the solar energy as the energy source for refrigeration processes
- most suitable refrigeration technique for the case of vaccines supply chain and the regions where frequent power short falls occur
- reduces the overall cost of operation including environmental cost

A solar energy driven tri-generation refrigeration technology facilitates the cold chain both from economic and environmental perception. The foremost rewards facilitated by implementing the solar operated tri-generation refrigeration technology are (Dabwan et al., 2020):

- facilitate cooling, heating and power effect at the same time with higher efficiency in comparison to traditional ones
- robust applicability
- lesser environmental impact as the units are driven from solar energy.

From the above discussion it can be said that the implementation of solar energy driven refrigeration system on large scale not only reduce the cost of cold chain but reduces the GHG emission on large scale. Therefore, in order to improve the performance of the cold chain both from economic and environmental perspective, the cold chain management must implement the solar energy for the refrigeration process on large scale.

Followed by the alternative A3 (implementation of solar energy system on large scale refrigeration), alternative A5 (automated temperature monitoring storage) acquired the second highest value of relative closeness coefficient $(C_5^* = 0.6710)$ and therefore, considered as the second most preferred alternative provided as rank two. The key advantages which stands automated temperature monitoring over the other three alternatives (excluding first ranked alternative) are: better control over working temperature, higher shelf-life of the products, mitigate the risk of the products getting waste, lesser labour required, make cold highly efficient , and lower the negative impact of cold chain emissions on the environment. Followed by the alternatives A3 and A5, the other alternatives A1 (tri-generation technology embedded with absorption refrigeration system), A2 [thermo-acoustic (TA) and air cycle refrigeration (ACR) system], and A4 (replacement of high GWP and OLDP refrigerants with alternative environmental friendly refrigerants) received the relative closeness coefficient 0.4408, 0.4298, and 0.1453 respectively and acquire rank three, four, and five respectively. Thus, above analysis shows that the alternative A1 analysed as the third, A2 as the fourth and A4 fifth most important alternative from environmental point of view. The preference order of the alternatives based on their relative closeness coefficient can be summarised as A3 > A5 > A1 > A2 > A4.

7 Managerial and theoretical implications

Due to the increasing concerns of the governmental and environmental welfares, and public awareness towards the environmental issues, cold chain management, as a major contributor to the GHG emissions, comes under a mounting pressure to reduce their negative emissions (such as CO_2 emission). Thus, from the management perspective, it become vital to identify and analyse the critical responsible factors that significantly rises the amount of cold chain emissions and take the corrective decisions so that the overall cost of the cold chain (including environmental and operating cost) can be minimised to the optimum level. To the best of author's knowledge, no work has been present yet that dictate the theoretical and mathematical analysis of various factors contributing directly or indirectly to higher GHG emissions with solutions to tackle them.

The present work aims to provide a systematic analysis of the most critical criteria that directly or indirectly contribute to negative environmental impact. In continuation, the research work aims to facilitate a guide map that helps the management to understand how the various factors such as energy consumption, types of technology used for refrigeration and temperature monitoring, volume of waste, types of infrastructure of the chain affect the emissions level from the cold. Analysis of the results for the criteria helps the management to establish the benchmark for the emissions from their cold chain. In addition, to mitigate the effect of the considered criteria, the presented work also propose five best possible alternatives in terms of technological practices. The implementation of the research findings in terms of alternatives such as solar energy driven refrigeration system, solar driven tri-generation refrigeration, automated temperature monitoring helps the management to reduce the negative emissions and improving the performance of the cold chain. In addition to the wide managerial implications, by enriching the literature in a well-structured way, the presented work also acquires broad subjective implications.

8 Conclusions

The objective of presented research work was to identify and analyse the most critical criteria responsible for higher rate of negative emissions (such as GHG emission) from the cold chain and to mitigate the same, propose best possible alternatives with their preference order. To achieve the objective, based on an extensive literature review and expert's opinions, eight most critical criteria and five most suitable alternatives were identified and selected for their severity and importance analysis. The severity analysis of the criteria was performed using AHP technique. To analyse the severity of the criteria using AHP, at first the eigenvalues for each criteria were calculated according the steps involved in AHP research methodology section. Then, to check the consistency of the data used for the analysis, consistency test was performed. From the consistency test, it can be noticed that the value of consistency ratio (that shows a mathematical indicator of the consistency) was 0.09972, which fulfilled the Saaty's requirement of the consistency of the decisions made for pairwise comparison (according to Saaty, C.R. should be less than 0.1 for the consistency to exist) and thus the weights obtained using AHP were accepted. Analysis of the results obtained from the AHP reveals that the criteria 'level of energy consumption' is the most critical criterion among all, followed by 'lack of implementation of advance technologies', 'cost of rotten waste', 'leakage of refrigerants and their contribution to global warming', 'reverse impact of climate change on cold supply chain operations and GHG emission', 'level of carbon emission', 'lack of logistical support', and 'uneven distribution of cold stores', attain the severity weight accordingly.

To obtain the preference order/ranking of the proposed alternatives, TOPSIS method was used. The preference ranking of the alternatives from TOPSIS method was obtained using the principle based on the separation distance of the alternative from the ideal solutions for which the relative closeness coefficient for each were calculated using the steps discussed in TOPSIS methodology section. The alternative with highest relative closeness coefficient was provided rank first and considered as the most suitable alternative to mitigate the effect of the identified criteria on the environment. On the other hand, the alternative with least relative closeness coefficient was given rank eight and suggested to be preferred at last. The results obtained from the TOPSIS method show that the alternative A3 'implementation of solar energy system on large scale refrigeration' is the most suitable alternative and provided as rank one. Followed by the A3, alternative A5 'automated temperature monitoring storage' obtained as second highest preference priority and ranked two. The other alternatives A1 'tri-generation technology embedded with absorption refrigeration system', A2 'thermo-acoustic (TA) and air cycle refrigeration (ACR) system', and A4 'replacement of high GWP and OLDP refrigerants with alternative environmental friendly refrigerants' acquired the ranks as three, four and five respectively.

The priority order of alternatives can be summarised as 1 – A_3, 2 – A_5, 3 – A_1, 4 – A_2 and 5 – A_4. Hence, it can be concluded that to improve the performance of cold supply chain system in respect of its operating cost and global warming impact of emissions, 'implementation of solar energy system on large scale refrigeration' the implementation of solar direct drive on large scale refrigeration is required.

Although, the present work has various significant contributions to improve performance of cold supply chain from environmental as well as economic point of view, in spite of that, also have some limitations in the form of collected data, considered criteria and alternatives. Such as for the data collection, the experts were selected from India only, therefore, for some geographical regions, the results of the analysis may vary according to expert's perception. However, best attempt has been made to avoid the biasness of the data, vagueness may exist. Interested researchers may consider more number of criteria and their sub criteria, integrating the fuzzy system for the data analysis. In the current research, a hybrid approach using AHP-TOPSIS methodology is used for the analysis but in future; extension may exist for the validation of the results using other MCDM approaches such as fuzzy-AHP, fuzzy-TOPSIS, (DEMATEL), ELCTRE, SWARA, multi attribute utility theory and simple multi attribute rating technique, etc.

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