

## Article

# An Analytic Model for Estimating the Economic and Environmental Impact of Food Cold Supply Chain

Eleonora Bottani <sup>1,\*</sup>, Giorgia Casella <sup>1</sup>, Majcol Nobili <sup>2</sup> and Letizia Tebaldi <sup>1</sup>

<sup>1</sup> Department of Engineering and Architecture, University of Parma, Viale G.P.Usberti 181/A, 43124 Parma, Emilia-Romagna, Italy; giorgia.casella@unipr.it (G.C.); letizia.tebaldi@unipr.it (L.T.)

<sup>2</sup> VERCOS FRIGO s.r.l., Viale Kennedy 82/A, 42035 Castelnovo ne' Monti, Reggio Emilia, Italy; majcol.nobili@studenti.unipr.it

\* Correspondence: eleonora.bottani@unipr.it; Tel.: +39-0521-905872

**Abstract:** Cold chain management has gained increasing interest among practitioners, researchers and academics; similarly, sustainability is also proving to be an increasingly critical topic in all supply chains and in cold chains in particular. In line with this, this study proposes a model to estimate the economic and environmental impacts in a food cold supply chain (FCSC). The model intended to estimate the total cost and CO<sub>2</sub> emissions of a company operating in the cold supply chain, was carried out in Microsoft Excel™. Specifically, the model reproduces the main FCSC processes, i.e., Product collection, Backroom storage, Product delivery and Reverse logistics. For each process, we have exposed the implemented equations. Results show that the product delivery process is the most critical in both economic and environmental terms. Conversely, product collection and reverse logistics process contribute to the total cost and emission to a limited extent. The results obtained provide useful guidelines for supply chain managers to undertake operation decisions aimed at decreasing the economic and/or environmental impact of a FCSC.

**Keywords:** food cold supply chains (FCSCs); case study; sustainability; analytic model



**Citation:** Bottani, E.; Casella, G.; Nobili, M.; Tebaldi, L. An Analytic Model for Estimating the Economic and Environmental Impact of Food Cold Supply Chain. *Sustainability* **2022**, *14*, 4771. <https://doi.org/10.3390/su14084771>

Academic Editors: Claudia Colicchia and Sara Perotti

Received: 1 March 2022

Accepted: 13 April 2022

Published: 15 April 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 1. Introduction

The notion of “sustainability” emerged in The Ecologist’s A Blueprint for Survival, in 1972 [1]. In recent years, incorporating sustainability practices into a supply chain network (SCN) has attracted wide attention from both academics and practitioners [2,3] defined sustainability in supply chain management (SCM) as “strategic, transparent integration and achievement of an organization’s social, environmental and economic goals in the systematic coordination of critical interorganizational business processes for improving the long-term financial performance of the individual and its supply chain (SC) [4]. With the publication of the Brundtland Report “Our Common Future”, the concept of sustainable development has spread since 1987 [5,6]. When considering the complexity of sustainable development in the context of SCM, it is a management concept extending beyond a SC’s performance metrics of cost, time, and flexibility [7]. Indeed, the triple bottom-line (TBL) indicates that in order to achieve sustainable development, firms should take into account social and environmental performance in addition to economic considerations [8]. The TBL has continuously gained relevance for managerial decision making in general and for SCM and operations management in particular [9].

The equipment and processes used to protect, store, and transport temperature sensitive items along a SC and the logistical planning to protect the integrity of these shipment are referred to as the cold chain [10]. Food cold supply chain (FCSC) can also be defined as a set of comprehensive facilities and management means that use certain technological means to make fresh food kept incessantly under suitable conditions and furthest keep the quality of fresh food during the whole process of harvest, processing, packaging, storage, transportation and sales and the logistics system formed by all logistics links under

complete low temperature environment is called food cold chain logistics [11]. Besides the general characteristics of SCs, FCSC needs specialized refrigeration equipment, namely, refrigerated trucks and cold storage facilities during the cold chain food's processing, storing, distribution, sales and other links [12]. In fact, refrigerated systems and refrigeration in general, impact not only the economic aspects of the distribution chain, i.e., its costs, but also the attention to environmental performance of the system [13]. A few studies related to sustainability in food SCs have been conducted, which majorly include food SC, agri-retail SC, cold chains and agri-SC [14]. Optimization of cost, time and storage conditions of fresh food during transportation has a significant practical value and has received great attention in the research [15]. Moreover, the adoption of mathematical models to support the design and management of the different phases of food SCs is widely diffused in the literature [16].

In line with these considerations, this study aims to evaluate the economic and environmental sustainability of the FCSC by presenting a mathematical model that takes into account transport and storage activities. This paper builds upon the study by [17] and represents the second part of a wider research project, whose general aim is to model and optimize the sustainability of FCSC. A mathematical model based on costs and environmental impacts has been developed to this end. Starting from the previous study, which has focused on evaluating the economic and environmental performance of the reverse logistics process only, this paper goes ahead by analyzing and optimizing the sustainability of the remaining processes in the same FCSC, by means of an analytic approach developed under Microsoft Excel™. The approach follows the typical logistics processes of a FCSC (i.e., product collection, backroom storage, product delivery and reverse logistics). Moreover, a case study is presented for showing the usefulness and effectiveness of the model proposed.

This paper is organized as follows. Section 2 presents a literature review about sustainability in the context of FCSCs. The next section defines the methodology used for the model and presents the assumptions useful in its development. Section 4 shows the computation of the total cost and emission and also presents the application to the case study of an FCSC. Section 5 presents the primary outcomes obtained for each process analyzed. Finally, in the last section the implications, limitations and suggestion for further research activities are discussed.

## 2. Theoretical Overview

Sustainability, in terms of the consideration of environmental factors and economic aspects in SCM, has become a highly relevant topic for researchers and practitioners, with a relevant number of papers published on the subject [9]. In line with the aim of this study, the analysis of the literature was focused on those papers that dealt with the issue of evaluating the sustainability of FCSCs.

Ref. [18] has applied safety and reliability concepts to establish fresh food distribution routing optimization model with time windows and solved the model using MAX-MIN Ant System (MMAS) in a real FCSC. To be more precise, the problem was how the distribution center needs to arrange its distribution route and priority order so as to generate the lowest distribution costs, at the same time satisfying the constraints of arrival time windows.

Ref. [19] has examined an inventory model for cold items that considered temperature-controlled unit capacities associated with holding and transporting the cold items in a SC. In addition, both the cost and emission functions for such an environment are analyzed.

In the attempt to improve the efficiency of FCSC network, shorten the logistic time of food and reduce the logistics cost of food, [11] analyzed the optimization strategy and various cost factors of the supply network of FCSC and established a logistics network model suitable for the food cold chain logistics. A genetic operator was designed and an improved genetic algorithm was used to solve the model, through adaptive crossover probability and mutation probability.

Ref. [20] has recognized a strong need of a cold SC performance measurement model for the upward mobility of this sector. Measuring SC performance is a key complex

managerial task which encompasses a variety of activities. Structural equation modelling was used to develop and validate a confirmatory model for evaluating the performance of a cold SC.

Ref. [15] has developed a method to assist logistics managers upstream in the fresh food SC in making cost optimized decisions regarding transportation, with the objective of minimizing the total cost while maintaining the quality of food products above acceptable levels. The practical application of the model was illustrated by using various computational intelligence approaches.

Ref. [21] has studied the cold SC design problem and have provided a mathematical model to represent its economic and environmental effects. The authors have formulated the problem as a concave mixed-integer programming problem, where the objective was to minimize the expected total cost of the SC, including capacity, transportation and inventory costs, besides costs associated with the global warming impact due to greenhouse gas (GHG) emissions. The environmental effects of both CO<sub>2</sub> emissions due to energy consumption and leakage of refrigerant gas in warehouse and vehicles were considered.

Ref. [22] has assessed the impact of accounting for carbon emissions, resulting from transportation and storage activities of a cold item, in the context of a multi-stage SC including a plant/warehouse, a distribution center (DC) and a retailer. The authors presented a cost minimization model, a carbon footprint minimization model and a hybrid economic and environmental minimization model.

Ref. [23] has investigated GHG emissions from the Traditional Multi-Vehicle Distribution (TMVD) and Multi-Temperature Joint Distribution (MTJD) systems by formulating mathematical models that consider delivery scheduling for time dependent demand of multi-temperature foods. The authors suggested that carriers should use the MTJD system to reduce routing distances and emissions simultaneously.

Ref. [24] made a specific study of the terminal problem and established a joint distribution node. Different distribution schemes were adopted for individual, medium, and large customers. The authors found that the semi-trailer was used to carry out the transportation of jammers by using mathematical modelling and time window constraint analysis, which could effectively integrate cold chain logistics resources, save logistics space and human resources, and improve terminal logistics distribution capacity.

Ref. [13] has presented a model for evaluating the environmental impacts associated with the management of cold SC, considering transport and storage activities. A novel portable refrigerated unit (PRU) for the management of goods along the cold chain was presented, and its performance, in term of emissions at different distribution stages, was compared to that of traditional cold chain equipment. Environmental benefits and efficiency of the new equipment were considered, as well as energy consumption reduction.

A decision theory-based framework was adopted by [14], where a prescriptive decision analysis methodology was used to generate preferences among the challenges to sustainability in perishable food SC. An integrated interpretive structural modelling-analytic network process (ISM-ANP) decision framework was formulated to identify and model key challenges to sustainability in perishable food SCs.

Ref. [25] has investigated the impact of carbon emissions arising from storage and transportation in the cold SC in the presence of carbon tax regulation, and under uncertain demand. A two-stage stochastic programming model was developed by the authors to determine optimal replenishment policies and transportation schedules to minimize both operational and emissions costs, while a metaheuristic algorithm based on the iterated local search algorithm and a mixed integer programming was developed to solve the problem in realistic sizes.

To identify the driving factors towards the sustainable cold chain supplier, in the first phase of their study, [26] have utilized an ISM approach, while in the next phase, the authors have conducted the selection of cold chain supplier in the context of Pakistan. For this purpose, fuzzy VIKOR, a multi-criteria decision-making (MCDM) technique, was used for analyzing eight suppliers based on the criteria found in the first phase.

Ref. [27] has studied a bi-objective green hub location problem where several perishable products can be distributed concurrently in a cold supply chain. This study aimed to minimize the total cost of the system and maximize the quality of the delivered product.

The study developed by [28] have identified all potential factors that influence cold supply chain performance in the food industry. This paper has proven to be useful for managers, food suppliers, and logistics parties for sustainable cold chain management. The main results are to identify potential criteria that influence cold supply chain performance.

None of the reviewed articles focused on all the key SC processes, although many of them dealt with sustainability. Moreover, in general, the topic of assessing economic and environmental sustainability in food SC is little explored in the literature, especially in the Italian scenario, where it is not assessed. This paper tries to contribute to the literature by addressing these gaps, in that it proposes a detailed evaluation of the economic and environmental sustainability of a FCSC with a focus on the Italian context.

### 3. Methodology

As mentioned earlier in the manuscript, this study aims to evaluate the economic and environmental sustainability of the FCSC. The research questions of the study therefore refer to:

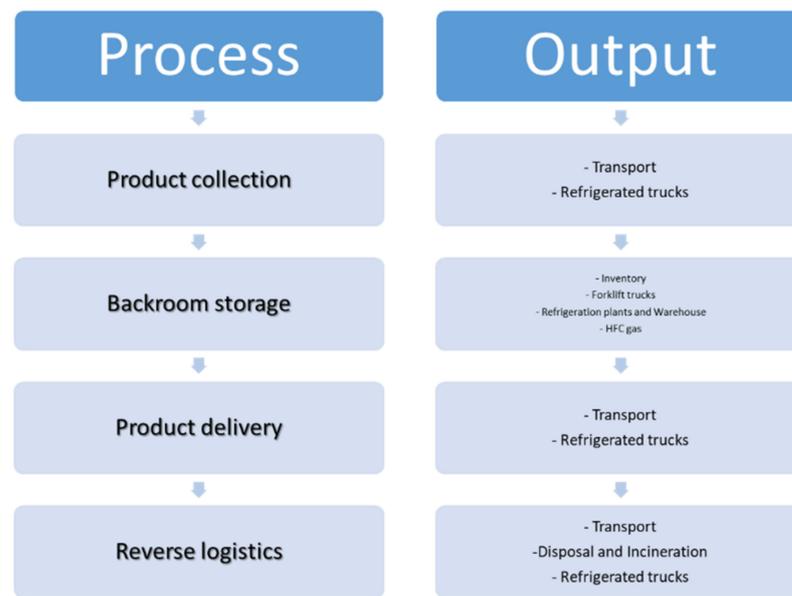
1. the identification of the most impactful process of a FCSC in economic and environmental terms; and
2. the identification of possible strategies to reduce cost and environmental impact of a FCSC.

The methodological approach adopted to answer the above questions is a mathematical model, developed under Microsoft Excel™, that reproduces the key processes of a FCSC and evaluates the cost and environmental impact of each process.

These processes and the relating mathematical equations are listed and described in the sub-sections that follow. The last subsections lists the input data required for an evaluation of the economic and environmental impact of a FCSC in practice.

#### 3.1. Logistics Processes

As mentioned, this paper builds upon the study by [17] and focuses on the same FCSC, which includes the typical processes, i.e., product collection, backroom storage, product delivery and reverse logistics. The chosen company, called Company A for the sake of confidentiality, is an important Italian company operating as a cold chain logistics service provider. As far as the logistics processes of the FCSC are concerned (see Figure 1), “product collection” is the process of collecting, cooling and transporting goods from the suppliers to Company A, immediately after production. Transport is carried out using refrigerated trucks that make it possible to maintain a certain temperature within them. “Backroom storage” describes the material handling within the depot and the conservation of properties. The storage of cold products is an energy intensive process, in which energy costs associated with keeping the products at given temperature account for a significant portion of the storage costs [22]. Indeed, whether it is a plant in which the product remains in the warehouse for a few days, or a structure in which the product is placed in the refrigerated warehouse only for a very short time, it is essential that the cold chain is not interrupted. “Product delivery” reflects the shipping of products from Company A to the retail stores (RSs). Lastly, “reverse logistics” is a type of SC management that moves goods from RSs back to the Company A or to the disposal of in landfill sites. In general forms, this process starts from the end users where used products are collected and attempts to manage the product’s end of life through different decisions, such as recycling, remanufacturing, repairing, and finally, disposing of some used parts [29].



**Figure 1.** Structure of the model.

The processes described above causes economic and environmental impacts because of transport activities from suppliers to Company A (product collection), from Company A to the RSs (product delivery) and from the retailers to Company A (reverse logistics). Moreover, the storage activities generate a further economic and environmental impact, because produce a significant contribution of emissions and an important source of financial losses.

Our analytic model was built with Microsoft Excel™, a software program created by Microsoft that uses spreadsheets to organize numbers and data with formulas and functions, and almost available at any company, which is expected to enhance the application potentials of the model itself. Also, MS Excel™ is it is recognized as a powerful software package frequently used for small and medium scale quantitative analyses (Hesse and Scerno, 2009). Its usage also allows for a process to be designed in a flexible (parametrized) way, so that virtually any real situation can be reproduced.

The model developed in our study consists of five spreadsheets, where the key FCSC processes are reproduced. The purpose is it to calculate the total costs and emissions. A final spreadsheet shows the aggregated results. The key outputs of the model are listed in Figure 1.

### 3.2. Model Assumptions

Company A has two different warehouses, called Beta and Gamma respectively. Warehouse Beta deals mainly with storage—the products can remain inside the warehouse even for a few days –, while warehouse Gamma deals with consolidation/sorting, without, however, considering storage (transit point)—qualitative/quantitative displacement of the goods. However, taking into account a FCSC, the products must always be stored in refrigerated plant, even if for a short time only. Therefore, warehouse Beta deals with all four processes taken into consideration in this study, while warehouse Gamma deals with backroom storage and product delivery activities only. Therefore, from now on, if this distinction is not mentioned, we will be implicitly talking about warehouse Beta, as it covers all logistics processes of Company A.

Company A's trips are performed via road transport, using 33-pallet lorries. Given the different nature of the products handled by the RS, the company has classified them into two types, "fresh" and "dry". The transport temperature for both categories is  $T = [0, +4]$  °C. in the reverse logistics, only "fresh" products are considered, i.e., products with a short shelf life.

Another relevant consideration for the purposes of this analysis concerns the refrigeration installations inside the warehouse. In particular, in the construction of large industrial refrigeration plants, especially for the food sector, glycol water (a mixture between water and glycol) is used. This is to prevent the water from freezing at temperatures below 0 °C.

### 3.3. Data Collection

For each process evaluated, the relevant flow data were collected by means of a direct examination of the company's processes and interviews with logistics and supply chain managers. The data collection phase took from June to December 2021. Other, more general, data, such as the fuel consumption or CO<sub>2</sub> emissions of trucks, were taken from available sources.

## 4. Model Formulation and Application

This section describes the computational procedure followed to model the key aspect of the FCSC processes and to evaluate their economic and environmental performance in quantitative terms, taking Company A as a representative case study. Both the economic and environmental component are calculated for each process. The input data used in the model to each process are available in the Supplementary Materials of this paper.

### 4.1. Product Collection

In this subsection, we present the computational procedure assigned to evaluate the economic and environmental performance from the product collection process. In this process, the focus is on the transport activity, i.e., the collection of products from the customers to bring them to their own facility, in order to carry out the storage and consolidation/sorting activities of the goods themselves. As related to refrigerated goods transport, vehicle consumption is not limited to fuel requirements, but it involves also other aspects, related to the special transport conditions requirements, as the case of refrigerants consumption [13].

The notation used in the analysis to the product collection process are presented in Table 1.

**Table 1.** Nomenclature—product collection process.

Symbol	Explanation
$q_{(\frac{c}{year}),C}$	Amount of products collected per year
$C_{u,C}$	Unit cost of a transport truck per kg collected
$FC_{truck}$	Fuel consumption for a refrigerated truck [30]
$\%T_{i,C}$	Percentage of ignition time of the refrigerator unit of the truck
$t_{trip,C}$	Travel time for product collection
$N_{(\frac{trip}{year}),C}$	Amount of collected product's trips per year
$C_{u,litre}$	Fuel cost [31]
$d_{diesel}$	Density of diesel fuel at normal environmental condition [32]
$I_{truck}$	Emissions of a truck per km [33]

- Economic component of the product collection process:

$$\text{Total cost of transport } C_{(t,TOT),C} = C_{u,C} * q_{(\frac{c}{year}),C} \text{ [€/year]} \quad (1)$$

$$\text{Refrigerated trucks fuel consumption } C_{E,C} = FC_{truck} * \%T_{i,C} * t_{trip,C} * N_{(\frac{trip}{year}),C} * C_{u,litre} \text{ [€/year]} \quad (2)$$

$$\text{Total economic impact } C_{tot,C} = C_{(t,TOT),C} + C_{E,C} \text{ [€/year]} \quad (3)$$

The following conversion factors (taken from [34,35]) have been used for the environmental component:

$$1 \text{ litre} = 1 \text{ dm}^3 = 0.001 \text{ m}^3 \quad (4)$$

$$1 \text{ tonCO}_2 = 42.621 \text{ GJ} \quad (5)$$

$$1 \text{ kWh} = 3.6 * 10^6 \text{ J} \quad (6)$$

$$1 \text{ kWh} = 2.65 * 10^{-4} \text{ tonCO}_2 \quad (7)$$

- Environmental component of the product collection process:

$$\text{Energy consumption refrigeration plants } I_{t,C} = \frac{FC_{\text{truck}} * \%T_{i,C} * t_{\text{trip},C} * N_{(\text{year}),C} * 0.001 * d_{\text{diesel}} * 42.621 * 2.65 * 10^{-4}}{3.6 * 10^6} \quad (8)$$

[tonCO<sub>2</sub>/year]

$$\text{Energy consumption of the warehouse } I_{\text{truck},C} = I_{\text{truck}} * D_C * N_{(\text{year}),C} \quad (9)$$

[tonCO<sub>2</sub>/year]

$$\text{Total environmental impact } I_{\text{tot},C} = I_{t,C} + I_{\text{truck},C} \quad (10)$$

[tonCO<sub>2</sub>/year]

#### 4.2. Backroom Storage

On the basis of the description above, this process is carried out in both warehouses, Beta and Gamma, which are, therefore, both taken into account. Nonetheless, for the sake of brevity, the detailed presentation of the model will be limited to a representative warehouse, while for the remaining one, only the key results will be presented, omitting the detailed steps. This is because the model has the same structure for both warehouses and its application follows the same steps. In this subsection, we present the computational procedure assigned to evaluate the economic and environmental performance in the Company's own plant, i.e., all activities that range from the unloading of trucks to the storage of products in refrigeration systems. The installation and use of these refrigeration plants cause both economic and environmental complications. In the first instance, their installation contributes to increasing the total cost of the process, but also contributes significantly to energy consumption. Another important role, in both dimensions, is played by the fork lift trucks.

The table below shows the notation useful to the evaluation for the backroom storage process.

The list in Table 2 encompasses all the elements useful to compute the outcomes requested for evaluating the economic and environmental impacts generated by this process.

**Table 2.** Nomenclature—backroom storage process.

Symbol	Explanation
$i = 1, 2, 3$	Type of forklift (1 = small, 2 = medium, 3 = big)
$EC_{u,p}$	Energy consumption of plants
$C_{u,m}$	Unitary plants cost
$A$	Storage area
$Year_p$	Number of years of plant operation
$h_{\text{day}}$	Number of hours per working day
$N_{\text{days/year}}$	Working days per year
$m_{\text{year}}$	Month per year
$C_{u,p}$	Unitary installation plants cost
$C_{u,e}$	Unitary energy plant cost
$C_{h,i}$	Hourly cost of maintenance of forklift trucks
$V$	Storage volume
$F_W$	Water factor
$F_L$	Lighting factor [36]
$EC_{h,i}$	Hourly energy consumption of forklift trucks
$EC_{\text{warehouse}}$	Energy consumption of warehouse

- Economic component of the backroom storage process:

$$\text{Inventory cost } C_{(\text{inv,TOT}),BS} = C_{u,m} * A \quad (11)$$

[€/year]

$$\text{Annual rate installation refrigeration systems } C_{(\text{inst},\text{TOT}),\text{BS}} = \frac{EC_{u,p} * 1000 * C_{u,p} * 0.001}{h_{\text{day}} * N_{\text{days/year}}} \text{ [€/year]} \quad (12)$$

$$\text{Energy consumption refrigeration plants } C_{(\text{EC},\text{TOT}),\text{BS}} = C_{u,e} * m_{\text{year}} \text{ [€/year]} \quad (13)$$

$$\text{Maintenance of forklift trucks } C_{(\text{forklift},\text{TOT}),\text{BS}} = h_{\text{day}} * N_{\text{days/year}} * (\sum C_{h,i}) \text{ [€/year]} \quad (14)$$

$$\text{Total economic impact } C_{\text{TOT},\text{BS}} = C_{(\text{inv},\text{TOT}),\text{BS}} + C_{(\text{inst},\text{TOT}),\text{BS}} + C_{(\text{EC},\text{TOT}),\text{BS}} + C_{(\text{forklift},\text{TOT}),\text{BS}} \text{ [€/year]} \quad (15)$$

- Environmental component of the backroom storage process:

$$\text{Energy consumption refrigeration plants } I_{(\text{EC},\text{TOT}),\text{BS}} = EC_{u,p} * V * 2.65 * 10^{-4} * 0.001 \text{ [tonCO}_2\text{/year]} \quad (16)$$

$$\text{Energy consumption of the warehouse } I_{(\text{warehouse},\text{TOT}),\text{BS}} = \frac{EC_{\text{warehouse}} * 2.65 * 10^{-4}}{1000} \text{ [tonCO}_2\text{/year]} \quad (17)$$

$$\text{Maintenance of forklift trucks } I_{(\text{forklift},\text{TOT}),\text{BS}} = h_{\text{day}} * N_{\text{days/year}} * (\sum EC_{h,i}) * 2.65 * 10^{-4} * 0.001 \text{ [tonCO}_2\text{/year]} \quad (18)$$

$$\text{Emissions of HFC gas } I_{(\text{HFC},\text{TOT}),\text{BS}} = h_{\text{day}} * N_{\text{days/year}} * (\sum C_{h,i}) \text{ [tonCO}_2\text{/year]} \quad (19)$$

$$\text{Total environmental impact } I_{\text{TOT},\text{BS}} = I_{(\text{EC},\text{TOT}),\text{BS}} + I_{(\text{warehouse},\text{TOT}),\text{BS}} + I_{(\text{forklift},\text{TOT}),\text{BS}} + I_{(\text{HFC},\text{TOT}),\text{BS}} \text{ [tonCO}_2\text{/year]} \quad (20)$$

#### 4.3. Product Delivery

In this process, as in the product collection process, the focus is on the transport, i.e., the delivery of products from the company to the RSs. As mentioned above, refrigerated transport requirements, and refrigeration in general affects both the cost and environmental performance of the FCSC [13].

Table 3 below shows the nomenclature used in the analysis of the economic and environmental dimensions considered to the product delivery process.

**Table 3.** Nomenclature—product delivery process.

Symbol	Explanation
k = 1, 2	Type of product (1 = fresh, 2 = dry)
km <sub>year,k</sub>	Amount of km travelled per year
C <sub>u,km,D</sub>	Unitary economic impact of a transport truck per km travelled
N <sub>(<math>\frac{\text{trip}}{\text{year}}</math>),D</sub>	Amount of delivery product's trips per year
%T <sub>i,D</sub>	Percentage of ignition time of the refrigerator unit of the truck
t <sub>trip,D</sub>	Travel time for product delivery

The environmental impact can be estimated using the conversions [4–7] presented in Section 4.1.

- Economic component of the product delivery process:

$$\text{Total cost of transport } C_{(t,\text{TOT}),D} = C_{u,\text{km},D} * \text{km}_{\text{year},k} \text{ [€/year]} \quad (21)$$

$$\text{Refrigerated trucks fuel consumption } C_{E,D} = FC_{\text{truck}} * \%T_{i,D} * t_{\text{trip},D} * N_{(\frac{\text{trip}}{\text{year}}),D} * C_{u,\text{litre}} \text{ [€/year]} \quad (22)$$

$$\text{Total economic impact } C_{\text{tot},D} = C_{(t,\text{TOT}),D} + C_{E,D} \text{ [€/year]} \quad (23)$$

- Environmental component of the product delivery process:

$$\text{Transport of product delivered } I_{t,D} = \frac{FC_{\text{truck}} * \%T_{i,D} * t_{\text{trip},D} * N_{\left(\frac{\text{trip}}{\text{year}}\right),D} * 0.001 * d_{\text{diesel}} * 42.621 * 2.65 * 10^{-4}}{3.6 * 10^6} \quad [\text{tonCO}_2/\text{year}] \quad (24)$$

$$\text{Environmental component of truck } I_{\text{truck},D} = I_{\text{truck}} * \sum_k \text{km}_{\text{year},k} \quad [\text{tonCO}_2/\text{year}] \quad (25)$$

$$\text{Total environmental impact } I_{\text{tot},D} = I_{t,D} + I_{\text{truck},D} \quad [\text{tonCO}_2/\text{year}] \quad (26)$$

#### 4.4. Reverse Logistics

In this paragraph, we present the procedure for calculating the total costs and emissions for the reverse logistics process. The main activity of this process is transport, so it is essential to specify that 33-pallet lorries have been considered in the analysis. Moreover, as already mentioned, the products handled in this process are either “expired” or “returned.”

As far as the environmental impact is concerned, Company A handles various categories of products and typically, different products have a different environmental impact, because of the inherent differences in the production process and raw materials involved. Analyzing the whole set of products handled by Company A is almost unfeasible; however, from an analysis of the company’s data, it emerged that four categories of products are responsible for most of the return flows, as the relating products are particularly subject to expiry and need to be retrieved for being disposed of. These categories are salads, yogurt, milk and mozzarella cheese, and are indicated in Table 4 as  $w = 1, \dots, 4$ . Because of their relevant role in driving reverse logistics activities, the analysis has been limited to these product categories. The relating environmental impact has been derived from an available source.

**Table 4.** Nomenclature—reverse logistics process.

Symbol	Explanation
$w = 1, 2$	Type of “fresh” products (1 = salad, 2 = yogurt, 3 = milk, 4 = mozzarella)
$C_{u,t,d}$	Cost of expired product’s transport per disposal and incineration
$C_{u,t,i}$	
$C_{u,t,ret}$	Cost of returned product’s transport
$Q_d, Q_i$	Quantity of expired products disposed and incinerated
$Q_{ret}$	Quantity of returned product
$C_{u,d}$	Cost of expired product’s disposal and incineration
$C_{u,i}$	
$\%T_{i,RL}$	Percentage of ignition time of the refrigerator unit of the truck
$t_{\text{trip},ex}$	Travel time for expired and returned product
$t_{\text{trip},ret}$	
$N_{\left(\frac{\text{trip}}{\text{year}}\right),ex}$	Amount of expired and returned product’s trips per year
$N_{\left(\frac{\text{trip}}{\text{year}}\right),ret}$	
$D_{ex}$	Average distance from retailers to disposal of in landfill
$D_{ret}$	Average distance from retailers to company’s DC
$I_{u,w,landfill}$	CO <sub>2</sub> emissions to the w “fresh” products [37]

Table 4 presents the notation used for the process of reverse logistics.

The environmental component can be estimated using the conversions [4–7] presented in Section 4.1.

- Total economic impact of the reverse logistics process—expired products analysis:

$$\text{Transport cost } C_{\text{tot},t,ex} = (C_{u,t,d} * Q_d) + (C_{u,t,i} * Q_i) \quad [€/year] \quad (27)$$

$$\text{Cost of disposal } C_d = C_{u,d} * Q_d \quad [€/year] \quad (28)$$

$$\text{Cost of incineration } C_i = C_{u,i} * Q_i \text{ [€/year]} \quad (29)$$

$$\text{Fuel consumption } C_{E,ex} = FC_{truck} * \%T_{i,RL} * t_{trip,ex} * N_{(\frac{trip}{year})_{ex}} * C_{u,litre} \text{ [€/year]} \quad (30)$$

$$\text{Total economic impact } C_{TOT,EX} = C_{t,d} + C_{t,i} + C_d + C_i + C_{E,ex} \text{ [€/year]} \quad (31)$$

- Total economic impact of the reverse logistics process—return flows analysis:

$$\text{Transport cost } C_{t,ret} = C_{u,t,ret} * Q_{ret} \text{ [€/year]} \quad (32)$$

$$\text{Fuel consumption } C_{E,ret} = FC_{truck} * \%T_{i,RL} * t_{trip,ret} * N_{(\frac{trip}{year})_{ret}} * C_{u,litre} \text{ [€/year]} \quad (33)$$

$$\text{Total economic impact } C_{TOT,RET} = C_{t,ret} + C_{E,ret} \text{ [€/year]} \quad (34)$$

- Total environmental impact of the reverse logistics process—expired products analysis:

$$\text{Fuel consumption } I_{t,ex} = \frac{FC_{truck} * \%T_{i,RL} * t_{trip,ex} * N_{(\frac{trip}{year})_{ex}} * 0.001 * d_{diesel} * 42.621 * 2.65 * 10^{-4}}{3.6 * 10^6} \text{ [tonCO}_2\text{/year]} \quad (35)$$

$$\text{Transport } I_{truck,ex} = I_{truck} * D_{ex} * N_{(\frac{trip}{year})_{ex}} \text{ [tonCO}_2\text{/year]} \quad (36)$$

$$\text{Total emissions of the individual products } I_{w,landfill} = \frac{I_{u,w,landfill} * (Q_d + Q_i)}{1000} \text{ [tonCO}_2\text{/year]} \quad (37)$$

$$\text{Total environmental impact } I_{TOT,EX} = I_{t,ex} + I_{truck,ex} + I_{landfill} \text{ [tonCO}_2\text{/year]} \quad (38)$$

- Total environmental impact of the reverse logistics process—return flows analysis:

$$\text{Fuel consumption } I_{t,ret} = \frac{FC_{truck} * \%T_{i,RL} * t_{trip,ret} * N_{(\frac{trip}{year})_{ret}} * 0.001 * d_{diesel} * 42.621 * 2.65 * 10^{-4}}{3.6 * 10^6} \text{ [tonCO}_2\text{/year]} \quad (39)$$

$$\text{Transport } I_{truck,ret} = I_{truck} * D_{ret} * N_{(\frac{trip}{year})_{ret}} \text{ [tonCO}_2\text{/year]} \quad (40)$$

## 5. Results and Discussion

### 5.1. Product Collection

By applying the computational procedure described in Section 4.1 with the input data in the Supplementary Material, the model gives back the results shown in Table 5.

**Table 5.** Costs and CO<sub>2</sub> emissions for the product collection process.

Activities	Costs [€/Year]	Emissions [tonCO <sub>2</sub> /Year]
Transport	242,826.40	393.43
Fuel consumption	28,685.60	79.44
Total	271,512.00	472.87

As shown in Table 5, the costs and emissions of the product collection process are mainly caused by transport activities, with 89.43% and 83.20%, respectively.

### 5.2. Backroom Storage

The table below presents the main results in economic and environmental components terms, obtained by applying the mode detailed in Section 4.2.

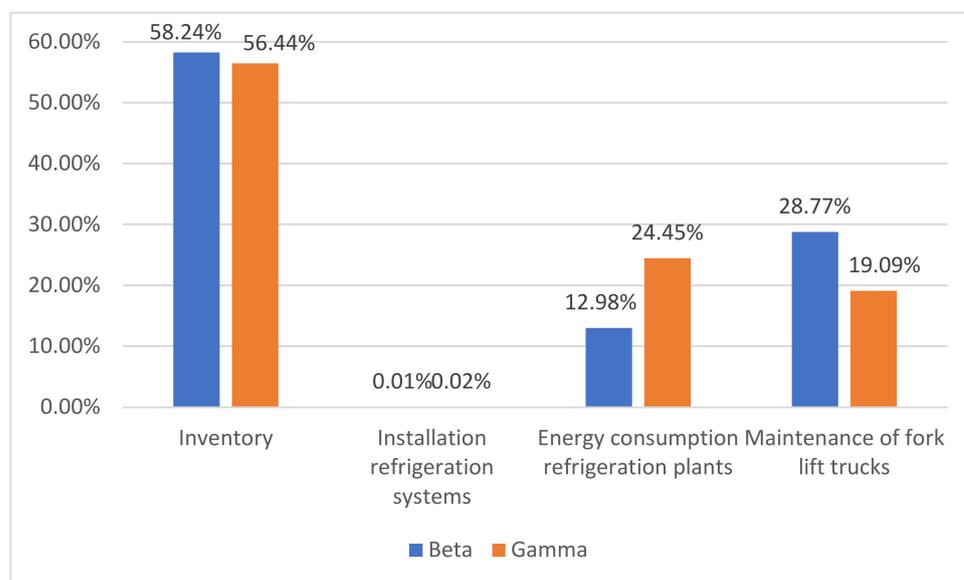
As can be seen from Table 6, the total cost of the backroom storage process, considering both warehouses, amounts to 8,362,664.97 €/year, while the emissions reach 6624.18 tonCO<sub>2</sub>/year. To be more precise, the warehouse that generates the highest cost in

this process is Gamma with 83.45%, compared to 16.55% for Beta. In terms of emissions, Gamma is also the warehouse with the greatest impact (5335.09 tonCO<sub>2</sub>/year, 80.54%). Gamma, as can be seen from the figure above, is the warehouse that has the greatest economic and environmental impact for all the individual activities carried out in the backroom storage process, except for the case of HFC gas emissions (50% and 50%, respectively for Beta and Gamma). In particular, it is interesting to note that the energy consumption for the refrigeration plant impacts mainly on the Gamma warehouse, with 90.47% and 87.02%, respectively for costs and emissions.

**Table 6.** Cost and CO<sub>2</sub> emissions for the backroom storage process.

Activities	Costs [€/Year]		Total Costs [€/Year]	%		Emissions [tonCO <sub>2</sub> /Year]		Total Emission [tonCO <sub>2</sub> /Year]	%	
	Beta	Gamma	Total	Beta	Gamma	Beta	Gamma	Total	Beta	Gamma
Inventory	805,949.60	3,939,255.60	4,745,205.20	16.98	83.02	-	-	-	-	-
Installation refrigeration systems	202.16	1355.21	1557.37	12.98	87.02	-	-	-	-	-
Energy consumption refrigeration plants	179,654.40	1,706,174.40	1,885,828.80	9.53	90.47	462.86	3102.90	3565.76	12.98	87.02
Energy consumption of the warehouse	-	-	-	-	-	72.62	451.43	524.05	13.86	86.14
Maintenance of forklift trucks	398,131.20	1,331,942.40	1,730,073.60	23.01	76.99	403.89	1431.05	1834.94	22.01	77.99
Emissions of HFC gas	-	-	-	-	-	349.72	349.72	699.43	50.00	50.00
Total	1,383,937.36	6,978,727.61	8,362,664.97	16.55	83.45	1289.08	5335.09	6624.18	19.46	80.54

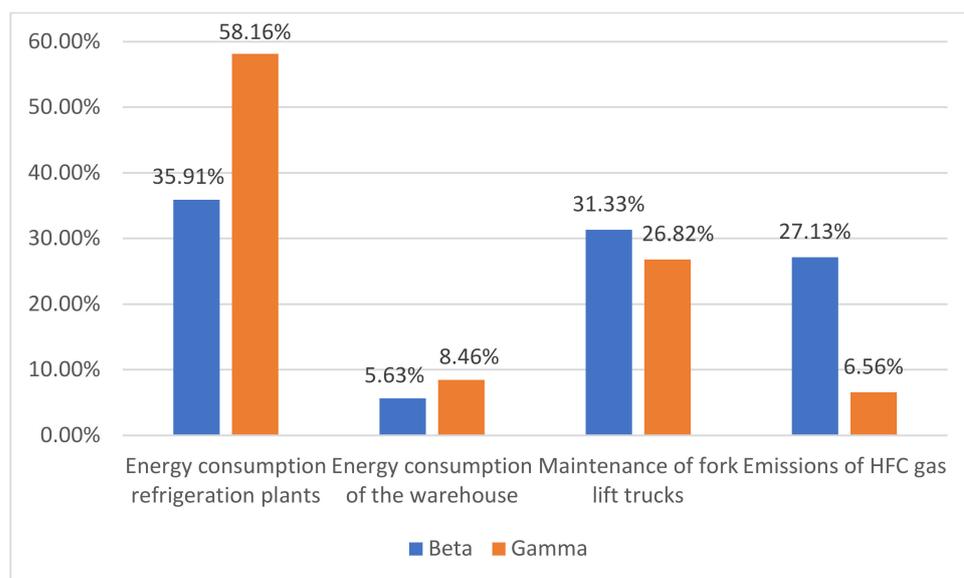
Figure 2 shows the percentage of costs of individual activities, regardless of the type of warehouses (Beta and Gamma), while Figure 3 displays the share of emissions.



**Figure 2.** Percentage share of the costs of individual activities in both warehouses.

The activity that returns the highest cost in this process, as can be seen from Figure 2 is the inventory which accounts for 58.24% and 56.44% (respectively for Beta and Gamma) of the total cost of the warehouses. On the contrary, the cost of installing the refrigeration systems is very limited (0.01% and 0.02% of the total cost of the warehouses, for Beta and Gamma).

In addition, as can be seen from Figure 3, the energy consumption of the refrigeration plants significantly affects the environmental performance of the process (35.91 and 58.16% of the total emission of the warehouse, respectively for Beta and Gamma) and its economic impact—see Figure 2—cannot be neglected either (12.98% and 24.45%).



**Figure 3.** Percentage share of the emissions of individual activities in both warehouses.

### 5.3. Product Delivery

Table 7 provides the results of economic and environmental assessment of the product delivery process.

**Table 7.** Cost and CO<sub>2</sub> emissions for the product delivery process.

Activities	Costs [€/Year]		Emissions [tonCO <sub>2</sub> /Year]	
	Beta	Gamma	Beta	Gamma
Transport	5,961,046.88	10,897,372.69	2814.65	5155.81
Fuel consumption	193,176.16	375,773.39	534.95	1040.60
Total	6,154,223.04	11,273,146.08	3349.60	6196.41
	17,427,369.12		9546.01	

The activity with the highest contribution both economically and environmentally, causing more than 95% of the cost and 80% of the emissions is the transportation activity.

### 5.4. Reverse Logistics

Table 8 below shows the key results in economic and environmental components terms, obtained by applying the model detailed in Section 4.4.

**Table 8.** Cost and CO<sub>2</sub> emissions for the reverse logistics process.

Activities	Costs [€/Year]		Emissions [tonCO <sub>2</sub> /Year]	
	Expired	Returned	Expired	Returned
Transport	2119.85	25,092.00	3.56	109.15
Fuel consumption	117.00	23,764.91	0.32	65.81
Disposal	1786.39	-	737.43	-
Incineration	13,719.45	-	-	-
Total	17,742.68	48,856.91	741.31	174.96
	66,599.60		916.27	

From the table above it can be seen that expired products present lower costs than returned products, while they cause higher emissions. In particular, the activity of trans-

porting the returned product is the most relevant on an economic level (25,092.00 €/year). The same activity, for expired products, has a much lower impact. As far as emissions are concerned, the disposal of in landfill of expired products (737.43 tonCO<sub>2</sub>/year) is the most relevant.

### 5.5. Aggregated Results

The aggregated results of the economic and environmental assessment are shown in Table 9, including the percentage share among the different FCSC processes.

**Table 9.** Cost and CO<sub>2</sub> emissions for the FCSC processes.

Process	Costs [€/Year]	%	Emissions [tonCO <sub>2</sub> /Year]	%
Product collection	271,512.00	1.04	472.87	2.69
Backroom storage	8,362,664.97	32.01	6624.18	37.72
Product delivery	17,427,369.12	66.70	9546.01	54.36
Reverse logistics	66,599.60	0.25	916.27	5.22
Total	26,128,145.69	100.00	17,559.33	100.00

Overall, as can be seen from Table 9, the process with the highest cost and emissions is product delivery (66.70% and 54.36%, respectively) followed by the backroom storage (32.01% and 37.72%, respectively).

### 5.6. Managerial Implications

From a practical perspective, this result clearly highlights that any effort for reducing the economic and environmental impact of the FCSC under examination should start from a restructuring of the product delivery process. This could be obtained, for instance, by optimizing the delivery tours or by reducing the frequency of delivery, so as to enhance the efficiency of the transport means. The other process that impacts FCSC emissions and costs the most is backroom storage. In particular, it can be noticed that the most critical activities concern the refrigeration systems and the energy consumption of the warehouse. Possible solutions for reducing that impact could be, for instance, a decrease in the size of the warehouse, by keeping the storage capacity unchanged; this implies a modified strategy for managing the warehouse itself, making it more efficient in the usage of space. For the product collection and reverse logistics processes, instead, the economic and environmental impacts are significantly lower and contribute to the total impact and cost to a less appreciable extent.

The results of this study, applying the model described in Section 4, provide an assessment of the sustainability of an FCSC, quantifying the total cost and environmental impact. To be more precise, for each process, we determined the key activities, or the warehouse or the type of product which involves the greatest economic and environmental impact. In addition, from a wider perspective, we have also identified the process with the highest cost and emissions, which, in the case under examination, turned out to be the delivery of products. Suggestions can thus be derived for reducing the costs and emissions of the system by focusing on this process. Apart from the specific outcomes of the case study, more generally the results obtained from the model can be used by FCSC managers and logistics practitioners to find and analyze the process, or in more detail the activity on which to focus to improve the cost and reduce the environmental impact of the process under study.

## 6. Conclusions

This paper has investigated the issue of sustainability evaluation in a FCSC, by proposing an analytic framework for estimating the economic and environmental impacts of logistics activities in that system. The analysis was supported by a Microsoft Excel<sup>TM</sup> model, which reproduces the steps for computing the total cost and CO<sub>2</sub> emissions and automates the computational procedure as a function of some input parameters. The model

was designed taking a main company operating as a cold chain logistics service provider (Company A) as a representative example. In particular, the analytic model reproduces the main FCSC processes of that company, namely Product collection, Backroom storage, Product delivery and Reverse logistics. By product collection we mean the process of collecting, cooling and transporting the goods from providers to Company A, while backroom storage describes the material handling within the depot and the conservation of properties. Product delivery reflects the process of moving the goods from Company A to the RSs. Finally, reverse logistics is a type of SC management that moves goods from RSs back to the Company A or to the disposal of in landfill sites. Overall, a set of 40 analytic formulae was structured and implemented in the model for quantifying the CO<sub>2</sub> emissions and total cost of the four FCSC processes. All equations have been detailed in Section 4, facilitating the user to reproduce the procedure.

The results of our study demonstrate that the right managerial decisions about FCSC activities and processes can effectively improve environmental and economic sustainability. In particular, FCSC's most critical processes are product delivery and backroom storage. Similarly, in the study developed by [33] that aimed at an economic and environmental assessment of sustainability in the field of large-scale retail, the sales area, receiving and backroom storage were the processes that had the greatest impact. Furthermore, Ref. [20] have found that the factors that affect cold supply chain performance are, among others, inventory handling cost, transportation, temperature monitoring and shipping errors.

Sustainability assessment is increasingly important nowadays, so from a purely theoretical point of view, the development of our model, which can quantify costs and emissions, is an addition to the literature. Another very important element is the field of application, i.e., SC, which is recognized as a key area for sustainability improvement [2].

Some limitations of the analysis also need to be mentioned. The choice of the activities/processes may be modified, depending on the case study analyzed, including further activities/processes in the evaluation. Similarly, however, another limitation is the particular case study discussed in this paper. To be more precise, the analysis was performed on a certain Italian FCSC company, thus results are difficult to generalize. They may not hold for other FCSCs in other continents or European countries, for example. Also, the social dimension of sustainability is not taken into account in the proposed approach.

Starting from this study, several future research directions could be undertaken. As already recalled, the model developed could be used to analyze other SCs, with the purpose of evaluating the economic and environmental performance of systems different from that investigated. But also, the choice of the processes could be modified, including further activities in the evaluation. Moreover, the social dimension of sustainability could be deepened to identify ways for quantitatively assessing it.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su14084771/s1>.

**Author Contributions:** The corresponding author E.B. was responsible for planning and coordinating the steps of the research. Conceptualization, E.B., G.C., M.N. and L.T.; methodology, E.B., G.C., M.N. and L.T.; formal analysis, G.C. and M.N.; writing—original draft preparation, G.C.; writing—review and editing, E.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the research Grant No. D92I15000210008 (project code RBSI14L97M), called “ESCALATE—Economic and Environmental Sustainability of Supply Chain and Logistics with Advanced Technologies”, funded by the Italian Ministry of University and Research under the SIR (Scientific Independence of young Researchers) 2014 program (decree of 23 January 2014, No. 197) and awarded to the first author.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available in the Supplementary Materials of the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Basiago, A. Methods of defining ‘sustainability’. *Sustain. Dev.* **1995**, *3*, 109–119. [[CrossRef](#)]
2. Rezaei Vandchali, H.; Cahoon, S.; Chen, S.-L. The impact of supply chain network structure on relationship management strategies: An empirical investigation of sustainability practices in retailers. *Sustain. Prod. Consum.* **2021**, *28*, 281–299. [[CrossRef](#)]
3. Carter, C.; Rogers, D. A Framework of Sustainable Supply Chain Management: Moving Toward New Theory. *Int. J. Phys. Distrib. Logist. Manag.* **2008**, *38*, 360–387. [[CrossRef](#)]
4. Shashi, S.; Cerchione, R.; Singh, R.; Centobelli, P.; Shabani, A. Food cold chain management: From a structured literature review to a conceptual framework and research agenda. *Int. J. Logist. Manag.* **2018**, *29*, 792–821. [[CrossRef](#)]
5. World Commission on Environment and Development. *Our Common Future*; Oxford University Press: Oxford, UK, 1987; Volume 2, pp. 4–9.
6. Sadollah, A.; Nasir, M.; Geem, Z. Sustainability and Optimization: From Conceptual Fundamentals to Applications. *Sustainability* **2020**, *12*, 2027. [[CrossRef](#)]
7. Zimon, D.; Tyan, J.; Sroufe, R. Implementing Sustainable Supply Chain Management: Reactive, Cooperative, and Dynamic Models. *Sustainability* **2019**, *11*, 7227. [[CrossRef](#)]
8. Dong, C.; Li, Q.; Shen, B.; Tong, X. Sustainability in Supply Chains with Behavioral Concerns. *Sustainability* **2019**, *11*, 4051. [[CrossRef](#)]
9. Brandenburg, M.; Govindan, K.; Sarkis, J.; Seuring, S. Quantitative models for sustainable supply chain management: Developments and directions. *Eur. J. Oper. Res.* **2014**, *233*, 299–312. [[CrossRef](#)]
10. Bozorgi, A. Multi-product inventory model for cold items with cost and emission consideration. *Int. J. Prod. Econom.* **2016**, *176*, 123–142. [[CrossRef](#)]
11. Jiang, W.; Hu, Z.; Liang, Y.; Chen, Y. Modeling and optimization of food cold-chain intelligent logistics distribution network. *Adv. J. Food Sci. Technol.* **2015**, *7*, 573–578. [[CrossRef](#)]
12. Qiu, Q.; Zhang, Z.; Song, X.; Gui, S. Application research of cross docking logistics in food cold-chain logistics. In Proceedings of the International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII, Washington, DC, USA, 26–27 December 2009.
13. Ferretti, I.; Mazzoldi, L.; Zanoni, S. Environmental impacts of cold chain distribution operations: A novel portable refrigerated unit. *Int. J. Log. Syst. Manag.* **2018**, *31*, 267–297. [[CrossRef](#)]
14. Kumar, A.; Mangla, S.; Kumar, P.; Karamperidis, S. Challenges in perishable food supply chains for sustainability management: A developing economy perspective. *Bus. Strategy Environ.* **2020**, *29*, 1809–1831. [[CrossRef](#)]
15. Nakandala, D.; Lau, H.; Zhang, J. Cost-optimization modelling for fresh food quality and transportation. *Ind. Manag. Data Syst.* **2016**, *116*, 564–583. [[CrossRef](#)]
16. Gallo, A.; Accorsi, R.; Baruffaldi, G.; Manzini, R. Designing sustainable cold chains for long-range food distribution: Energy-effective corridors on the Silk Road Belt. *Sustainability* **2017**, *9*, 2044. [[CrossRef](#)]
17. Bottani, E.; Casella, G.; Nobili, M.; Tebaldi, L. Assessment of the economic and environmental sustainability of a food cold supply chain. *IFAC-PapersOnLine* **2019**, *52*, 367–372. [[CrossRef](#)]
18. Yifeng, Z.; Ruhe, X. Application of cold chain logistics safety reliability in fresh food distribution optimization. *Adv. J. Food Sci. Technol.* **2013**, *5*, 356–360. [[CrossRef](#)]
19. Bozorgi, A.; Pazour, J.; Nazzal, D. A new inventory model for cold items that considers costs and emissions. *Int. J. Prod. Econ.* **2014**, *155*, 114–125. [[CrossRef](#)]
20. Shashi, S.; Singh, R. Modeling cold supply chain environment of organized farm products retailing in India. *Uncertain Supply Chain Manag.* **2015**, *3*, 197–212. [[CrossRef](#)]
21. Saif, A.; Elhedhli, S. Cold supply chain design with environmental considerations: A simulation-optimization approach. *Eur. J. Oper. Res.* **2016**, *251*, 274–287. [[CrossRef](#)]
22. Hariga, M.; As’ad, R.; Shamayleh, A. Integrated economic and environmental models for a multi stage cold supply chain under carbon tax regulation. *J. Clean. Prod.* **2017**, *166*, 1357–1371. [[CrossRef](#)]
23. Chen, W.-T.; Hsu, C.-I. Greenhouse gas emission estimation for temperature-controlled food distribution systems. *J. Clean. Prod.* **2015**, *104*, 139–147. [[CrossRef](#)]
24. Liu, H.; Pretorius, L.; Jiang, D. Optimization of cold chain logistics distribution network terminal. *Eurasip J. Wirel. Commun. Netw.* **2018**, *2018*, 158. [[CrossRef](#)]
25. Babagolzadeh, M.; Shrestha, A.; Abbasi, B.; Zhang, Y.; Woodhead, A.; Zhang, A. Sustainable cold supply chain management under demand uncertainty and carbon tax regulation. *Transp. Res. D* **2020**, *80*, 102245. [[CrossRef](#)]
26. Khan, A.; Ali, Y. Sustainable supplier selection for the cold supply chain (CSC) in the context of a developing country. *Environ. Dev. Sustain.* **2021**, *23*, 13135–13164. [[CrossRef](#)]
27. Golestani, M.; Moosavirad, S.; Asadi, Y.; Biglari, S. A Multi-Objective Green Hub Location Problem with Multi Item-Multi Temperature Joint Distribution for Perishable Products in Cold Supply Chain. *Sustain. Prod. Consum.* **2021**, *27*, 1183–1194. [[CrossRef](#)]

28. Turan, C.; Ozturkoglu, Y. A conceptual framework model for an effective cold food chain management in sustainability environment. *J. Model. Manag.* 2021, *ahead of print*. [[CrossRef](#)]
29. Govindan, K.; Soleimani, H.; Kannan, D. Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *Eur. J. Oper. Res.* **2015**, *240*, 603–626. [[CrossRef](#)]
30. Tassou, S.; Ge, Y.; Hadawey, A.; Marriott, D. Energy consumption and conservation in food retailing. *Appl. Therm. Eng.* **2011**, *31*, 147–156. [[CrossRef](#)]
31. Legacoop Produzione e Servizi. Legacoop Produzione & Servizi. 2021. Available online: <https://legacoop.produzione-servizi.coop/wp-content/uploads/2021/05/costo-Gasolio-APRILE-2021.pdf> (accessed on 17 February 2022).
32. Wang, X.; Economides, M. *Advanced Natural Gas Engineering*; Gulf Publishing Company: Houston, TX, USA, 2009.
33. Bottani, E.; Casella, G.; Arabia, S. Sustainability of retail store processes: An analytic model for economic and environmental evaluation. *Int. J. Simul. Process. Model.* **2019**, *14*, 105–119. [[CrossRef](#)]
34. Minambiente. 2016. Available online: [http://www.minambiente.it/sites/default/files/archivio/allegati/emission\\_trading/Tabella\\_coefficienti\\_standard\\_nazionali\\_2013\\_2015\\_v1.pdf](http://www.minambiente.it/sites/default/files/archivio/allegati/emission_trading/Tabella_coefficienti_standard_nazionali_2013_2015_v1.pdf) (accessed on 18 February 2022).
35. Emilia Romagna. 2015. Available online: [https://energia.regione.emilia-romagna.it/entra-in-regione/norme-e-atti-amministrativi/certificazione-energetica/certificazione-energetica/DOC\\_INDIRIZZO\\_fattoridiconversione\\_2.pdf/at\\_download/file/DOC\\_INDIRIZZO\\_fattori%20di%20conversione\\_2.pdf](https://energia.regione.emilia-romagna.it/entra-in-regione/norme-e-atti-amministrativi/certificazione-energetica/certificazione-energetica/DOC_INDIRIZZO_fattoridiconversione_2.pdf/at_download/file/DOC_INDIRIZZO_fattori%20di%20conversione_2.pdf) (accessed on 22 February 2022).
36. Fichtinger, J.; Ries, J.; Grosse, E.; Baker, P. Assessing the environmental impact of integrated inventory and warehouse management. *Int. J. Prod. Econ.* **2015**, *170*, 717–729. [[CrossRef](#)]
37. EPD International. The International EPD System. 2018. Available online: <https://www.environdec.com/home> (accessed on 25 February 2022).