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Assessment of the economic and environmental sustainability of a food cold supply chain

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Abstract: Based on environmental and economic factors, reverse logistics (RL) issues have attracted attention among both academia and practitioners. This study investigates the issue of economic and environmental sustainability evaluation in a food cold supply chain (FCSC), which carries out four main different processes, i.e. product collection, backroom storage, products delivery and RL. For the RL process, which is taken as an example, we have detailed the equations implemented in an analytic model to carry out the computation of the economic and environmental sustainability, while for the remaining processes, we present and discuss only the main results obtained. The model was developed under Microsoft Excel™ and is intended to assess the total cost and CO_2 emissions of an important company operating as a cold chain logistics service provider. Results of the model show that the highest total cost and environmental impact are due to the product delivery process. Moreover, the results proposed indicate quite clearly the specific activity component where the FCSC managers should intervene to remove or decrease possible inefficiencies and optimize or increase the sustainability of a FCSC.

Keywords**:** Sustainability, food cold supply chains, reverse logistics, case study, economic and environmental assessment, analytic model.

1. INTRODUCTION

"Sustainable development" is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Keeble, 1988). Sustainability has become a higly relevant factor for companies, economies and societies (Oelze, et al., 2018). Sustainable operations are needed to create value and customer care, and these may be implemented by focusing on social development, environmental protection, and economic development (Lin, Madu, Kuei, Tsai, & Wang, 2015).

Understanding different aspects of sustainability, supply chain (SC) operations, and decision making policies and relating them to performance measurement have been increasingly investigated in the last decade (Tajbakhsh & Hassini, 2015). A SC, in its classical form (forward SC), is a combination of processes to fulfil customers' requests and includes all possible entities like suppliers, manufacturers, transporters, warehouses, retailers, and customers themselves (Chopra & Meindl, 2010).

Economic and environmental issues are the major driving forces behind development of closed-loop SC systems like RL (Vijayan, Kamarulzaman, Mohamed, & Mahir, 2014). Rogers & Tibben-Lembke (1998) based on the definition proposed by the American RL Executive Council, define RL as "the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or paper disposal" (Ndhaief, et al., 2017).

In recent years, the economic benefits from waste reuse and recycling, environmental concern from the public, and positive social impacts have become the most important motivations for the implementation of RL in order to achieve sustainable development (Yu & Solvang, 2016). In the most recent literature, Gallo, et al. (2017) have proposed a mixed integer linear programming model to minimize the total energy consumption associated with the cold oprations experienced by perishable products, including harvesting, production, packaging, storage, and transport activities. Moreover, Meneghetti, et al. (2018) have developed an optimisation model applied to a local network of supermarkets requiring pallettized frozen bread deliveries from a central refrigerated warehouse. This model was effective in identifying the best route taking into account energy consumptions in the refrigerated food transport, either to move the vehicle while reaching different customers or to maintain the correct temperature during transportation.

In line with the considerations above, this paper focuses on the evaluation of the economic and environmental sustainability of a food cold supply chain (FCSC). To be more precise, we illustrate the evaluation of the total cost and CO_2 emissions of the FCSC by means of an analytic model developed under Microsoft Excel™. The application of the model is presented for a reference process (i.e. the RL

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process), while for the remaining processes, we present and discuss only the main results obtained.

The remainder of the paper is organized as follows. The next section describes the methodology adopted to develop the model. The application of the model to the case of a FCSC is described in section 3. Discussion of the key results obtained is proposed in section 4, while the implications, limitations and future research directions of study are reported in the last section.

2. METHODOLOGY

2.1 FCSC processes

This study takes into account the key SC process of a real FCSC, i.e. product collection, backroom storage, product delivery and RL. In particular, Company A is an important company operating as a cold chain logistics service provider. As far as the logistics processes of the FCSC are concerned, by product collection we mean the goods transport from suppliers to Company A, while backroom storage describes the material handling within the warehouse and the preservation of goods. By product delivery, we mean the transport of goods from Company A to the retail stores. Finally, RL is the process of managing the return flow of goods from the retailers to Company A and the expired product's flow from the retailers to disposal of in landfill sites.

2.2 Model overview

An evaluation model was developed under Microsoft Excel™ to support the assessment of the economic and environmental sustainability of the FCSC. This model consists of four spreadsheets and each of them reproduces one of the FCSC processes and computes the relating economic and environmental impact.

For the sake of brevity, in the following we will illustrate in detail the application of the model for a representative FCSC process (i.e. the RL process) with the aim to detail the computational steps for the assessment of both the economic and environmental sustainability. For the remaining FCSC processes, we will present the results obtained from the application of the model, omitting the detailed steps.

The model developed takes several data as input. The relevant data was collected from Company A. Then, a careful bibliographic analysis was conducted with the support of the Scopus database to identify the models available in literature for sustainability evaluation as well as to obtain further data not directly available at Company A.

The notation used in the analysis and the full list of input data relevant to the reverse logisitcs process are shown in Table 1.

Table 1. Nomenclature and input data - RL process

Symbol	Description	Numerical value (source)	Unit of measurement
$C_{u,t,d}$, $C_{u,t,i}$	Cost of expired product's transport per disposal and incineration	0.00875; 0.014 (Company A)	[€/kg]
$C_{u,t,ret}$	Cost of returned product's transport	0.0163 (Company A)	[€/kg]
Q_d, Q_i	Quantity of expired products disposed and incinerated	68,052.82; 10,8884.5 (Company A)	[kg/year]
Q_{ret}	Quantity of returned product	1,536,459.36 (Company A)	[kg/year]
$C_{u,d}$, $C_{u,i}$	Cost of expired product's disposal and incineration	0.02625; 0.126 (Company A)	[€/kg]
FC_{truck}	Fuel consumption for a refrigerated truck	2.25 (Tassou, De-Lille, & Lewis, 2018)	[l/h]
$\%T_i$	Percentage of ignition time of the refrigerator unit of the truck	60% (Company A)	-
$t_{trip,ex}$, $t_{trip,ret}$	Duration of the trip for expired and returned product	1.50; 5.00 (Company A)	[h/trip]
$N_{trip/year,ex}$ $N_{trip/year,ret}$	Amount of expired and returned product's trips per year	60.00 3656.00 (Company A)	[trip/year]
$C_{u,litre}$	Fuel cost	1.282 (Trasporti-Italia, 2018)	[€/l]
d_{diesel}	Density of diesel fuel at normal environmental condition	850.00 (Wang & Economides, 2009)	[kg/m^3]
I_{truck}	Environmental impact of a truck per km	$6.22*10^{-4}$ (Ciccarello & Caserini, 2018)	[$tonCO_2/km$]
D_{ex}	Average distance from retailers to disposal of in landfill	95.30 (Company A)	[km/trip]
D_{ret}	Average distance from retailers to company's DC	48.00 (Company A)	[km/trip]
$I_{u,k,landfill}$	CO_2 emissions to the k "fresh" products	See Table 2	[$kgCO_2/kg$]

2.3 Preliminary assumptions

Since the products handled at the RS are of different nature, the logistics service provider (Company A) has grouped them into two categories, i.e. "fresh" and "dry" products. Both categories are transported at the same temperature, i.e. T = [0, +4] °C. This categorization is relevant because only "fresh" products are taken into consideration in the process of expired product disposal of in landfill sites; in fact, this kind of product is more subject to expiration due to the short shelf life.

3. MODEL APPLICATION

In the following, we describe the application of the computational model to a reference process, which is taken as a case study, for Company A.

3.1 RL process

In this subsection, we describe the computational procedure applied to quantify the costs and emissions arising from the management of RL process. As the analysis focuses mainly on transport activity, it is important to mention that 33-pallet lorries are assumed as the type of vehicles considered for transport. In addition, products processed in RL activities can be either "expired" or simply "returned". In particular, expired products may be disposed of or incinerated; on the contrary, returned product involve a return flow from retailers to the site of Company A due to unsold products or possible delivery errors.

3.1.1 Expired products analysis

To compute the relevant costs of the RL process for expired products, the first step is to calculate the transport costs for two possible destinations of the expired products, i.e. disposal $(C_{t,d})$ and incineration $(C_{t,i})$, as follows:

$$C_{t,d} = C_{u,t,d} * Q_d \tag{1}$$

$$C_{t,i} = C_{u,t,i} * Q_i \tag{2}$$

The total economic impact caused by the transport of expired products to disposal and incineration $(C_{tot,t,ex})$ in RL accounts for:

$$C_{tot,t,ex} = C_{t,d} + C_{t,i} \tag{3}$$

Another cost component is the cost of disposal (C_d) and incineration (C_i) and the following equations can be used:

$$C_d = C_{u,d} * Q_d \tag{4}$$

$$C_i = C_{u,i} * Q_i \tag{5}$$

An important characteristic of many food distribution systems is temperature control. Indeed, for a wide variety of products, temperature control is essential for controlling food quality and food safety. It does, however, lead to additional energy consumption (Akkerman, et al., 2010). Because the transport of fresh product requires refrigerated trucks, the economic impact of fuel consumption $(C_{E,ex})$ should be computed as follows:

$$C_{E,ex} = FC_{truck} * \%T_i * t_{trip,ex} * N_{trip/year,ex} * C_{u,litre} \tag{6}$$

Total economic impact for the expired products in RL process in the cold supply chain $(C_{tot,ex})$ can finally be computed by adding up the contributions listed above:

$$C_{tot,ex} = C_{tot,t,ex} + C_d + C_i + C_{E,ex} \tag{7}$$

Besides the economic performance, the environmental sustainability of the RL process for expired products was evaluated taking into account different contributions relating the transport phase and the disposal.

Using the following conversion factors:

$$1\ litre = 1dm^3 = 0.001m^3 \tag{8}$$

$1tonCO_2 = 42.621GJ$ (Minambiente, 2016) (9)

$$1kWh = 3.6 * 10^6 J \tag{10}$$

$1kWh = 2{,}65 * 10^{-4} tonCO_2$ (Emilia Romagna, 2015) (11)

the environmental contribution for the transport of expired products can be calculated as follows:

$$I_{t,ex} = \frac{FC_{truck} * \%T_i * t_{trip,ex} * N_{trip/year,ex} * 0.001 * d_{diesel} * 42.621 * 2{,}65 * 10^{-4}}{3.6 * 10^6} \tag{12}$$

The environmental impact of truck used to collect the expired products from the retailer to the disposal of in landfill $(I_{truck,ex})$ is finally obtained taking into account the transport distance, according to the following formula:

$$I_{truck,ex} = I_{truck} * D_{ex} * N_{trip/year,ex} \tag{13}$$

Another impact component for the expired products is the emission due to disposal of in landfill $(I_{landfill})$. As already mentioned in the assumptions (Section 2.2), only "fresh" products are taken into consideration for this specify process. The first step is to compute the CO_2 emissions of four types of products (k=A, B, C, D), which are assumed to represent the vast majority of the total expired products. To do this, we use the Environmental Product Declaration (EPD), i.e. a document that includes certified, transparent and comparable information about the life-cycle environmental impact of products (EPD International, 2018). The CO_2 emissions of the "fresh" products $(I_{u,k,landfill})$ considered as examples are provided in Table 3.

Knowing Q_d and Q_i, it is possible to calculate the total emissions of the individual products $(I_{k,landfill})$ as follows:

$$I_{k,landfill} = \frac{I_{u,k,landfill} * (Q_d + Q_i)}{1000} \tag{14}$$

Finally, by averaging the emissions of the k-th "fresh" products, we can obtained the emissions due to disposal of in landfill $(I_{landfill})$.

Finally, the total environmental impact for the expired products in the FCSC $(I_{tot,ex})$ was derived by adding up the contributions listed above:

$$I_{tot,ex} = I_{t,ex} + I_{truck,ex} + I_{landfill} \tag{15}$$

Table 2. EPD for four "fresh" products (EPD International, 2018)

Product	$(I_{u,k,landfill})$ [kgCO₂/kg]
A - salad	2.02
B – yogurt	4.07

C - milk	1.39
D - mozzarella	9.72

3.1.2 Return products analysis

To compute the relevant costs of the RL process for returned product, the first step is to calculate the transport costs $(C_{t,ret})$, as follows:

$$C_{t,ret} = C_{u,t,ret} * Q_{ret} \quad (16)$$

As in the case of expired products, a further cost component is generated by the fuel consumption $(C_{E,ret})$ and can be computed as follows:

$$C_{E,ret} = FC_{truck} * \%T_i * t_{trip,ret} * N_{trip/year,ret} * C_{u,litre} \quad (17)$$

Total economic impact for the returned product in the FCSC $(C_{tot,ret})$ can finally be computed by adding up the contributions listed above:

$$C_{tot,ret} = C_{t,ret} + C_{E,ret} \quad (18)$$

As per the economic performance, the environmental sustainability of RL activities of returned product should be evaluated taking into account different contributions.

Using the conversion factors proposed in equations (8)-(11), the environmental contribution of the transport of returned product $(I_{t,ret})$ can be calculated as follows:

$$I_{t,ret} = \frac{FC_{truck} * \%T_i * t_{trip,ret} * N_{trip/year,ret} * 0.001 * d_{diesel} * 42.621 * 2,65 * 10^{-4}}{3.6 * 10^6} \quad (19)$$

The environmental impact of the trucks used to collect the returned product from the retailers to Company A $(I_{truck,ret})$ is finally obtained taking into account the transport distance, according to the following formula:

$$I_{truck,ret} = I_{truck} * D_{ret} * N_{trip/year,ret} \quad (20)$$

The total environmental impact $(I_{tot,ret})$ for the returned product in RL process in the FCSC can be derived by adding up the contributions listed above:

$$I_{tot,ret} = I_{t,ret} + I_{truck,ret} \quad (21)$$

4. RESULTS AND DISCUSSION

4.1 RL process

We now report the main results of the assessment for the RL process, in terms of the economic and the environmental contribute, with the purpose of evaluating the sustainability of FCSC. Table 3, Figure 1 and Figure 2 summarise the finding for this process. In particular, Table 3 shows a summary of the economic and environmental values that characterise the process.

Table 3. Cost and emissions - RL process

Product	Activity	Cost [€/year]	Emission [$tonCO_2$/year]
Expired	Transport	2,119.85	3.56
Expired	Fuel consumption	155.76	0.32
Expired	Disposal	1,786.39	737.43
Expired	Incineration	13,719.45	
EXPIRED	***TOTAL***	***17,781.44***	***741.31***
Returned	Transport	25,091.97	109.95
Returned	Fuel consumption	31,637.20	65.81
RETURNED	***TOTAL***	***56,729.16***	***175.77***
	TOTAL	**74,510.60**	**917.08**

As shown in table 3, the most relevant cost component is the cost of fuel consumption of the returned product (31,637.20 €/year), followed by the transport cost (25,091.97 €/year) for the same type of product. It is interesting to note that same activities have a much lower impact on the total cost for expired products than for returned products (e.g. fuel consumption: 155.76 €/year vs. 31,637.20 €/year). The most relevant emissions of this process are due to disposal of in landfill of expired products (737.42 $tonCO_2$/year). Figures 1 and 2 show the share of costs and emissions of individual activities, regardless of the type of products (expired or returned).

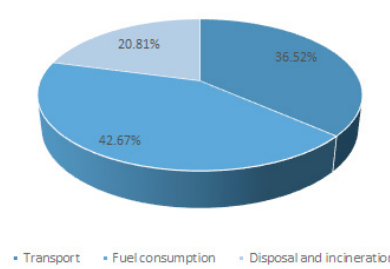

Fig. 1. Share of the costs – RL process

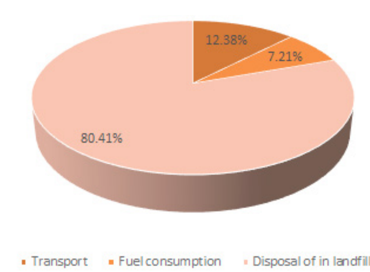

Fig. 2. Share of the emissions – RL process

As can be seen from these figures, the greatest impact on the total costs of the RL process is due to fuel consumption (42.67%); conversely, the activity that had the greatest impact on emissions is disposal of in landfill (80.41%).

Figures 3 and 4 compare the costs and emissions for expired and returned products. As shown in these figures, expired products generate lower costs than returned products, but cause greater emissions.

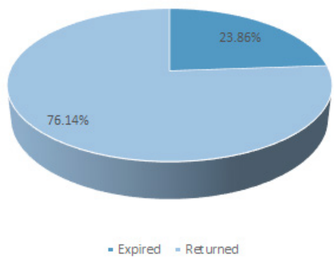

Fig. 3. Comparison of the costs for expired and returned products.

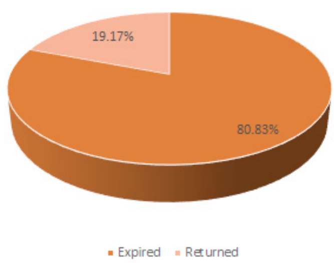

Fig. 4. Comparison of the emissions for expired and returned products.

4.2 Product collection process

The main results obtained by applying the evaluation model to the product collection process are shown in Table 4, for both the economic and environmental aspects of sustainability. As this table shows, the activity that entails the greatest cost and emission in product collection is the transport (233,325.12 €/year and 394.81 tonCO_2/year).

Table 4. Cost and emissions - product collection process

Activity	Cost [€/year]	Emission [tonCO_2/year]
Transport	233,325.12	394.81
Fuel consumption	38,187.90	79.44
TOTAL	**271,513.02**	**474.25**

4.3 Backroom storage process

In a real FCSC, the storage area is typically used only for handling and storage of fresh products.

The main results obtained by applying the evaluation model to the backroom storage process are shown in Table 5, for both the economic and environmental aspects of sustainability. As this table shows, the activity that generates the highest cost in the backroom storage is the inventory (2,372,602.80 €/year). From an environmental perspective, CO_2 emissions are mainly due to energy consumption of refrigeration plants (1,782.88 tonCO_2/year).

Table 5. Cost and emissions for the backroom storage process

Activity	Cost [€/year]	Emission [tonCO_2/year]
Inventory	2,372,602.80	-
Installation refrigeration systems	778.58	-
Energy consumption refrigeration plants	942,914.20	1,782.88
Energy consumption of the warehouse	-	262.02
Maintenance of fork lift trucks	865,036.50	917.47
Emissions of HFC gas	-	350.00
TOTAL	**4,181,332.08**	**3,312.37**

4.4 Product delivery process

By product delivery we mean the goods transport from Company A to the retail stores. Table 6 provides the results of economic and environmental assessment of this process. As shown in this table, the most onerous cost component is the cost of transport activities (8,334,976.42 €/year), which also generate the greatest emissions (3,985.23 tonCO_2/year).

Table 6. Cost and emissions - product delivery process

Activity	Cost [€/year]	Emission [tonCO_2/year]
Transport	8,334,976.42	3,985.23
Fuel consumption	378,708.89	787.775
TOTAL	**8,713,685.31**	**4,773.005**

5. CONCLUSIONS

This paper has proposed an assessment of the economic and environmental sustainability of a FCSC with Microsoft Excel™. The analysis take into account the key SC processes of the FCSC, i.e. product collection, backroom storage, product delivey and RL. The ultimate aim of the model was to determine the costs and emissions of the processes under consideration.

Starting from the consideration that sustainability, SC and RL have been increasingly investigated in the last decade, we have detailed the equations implemented in the model to carry out the computation only for this reference process, while for the remaining processes, the detailed computational procedure is omitted, for brevity, and only the main results are presented.

The comparison of the economic and environmental outcomes obtained for the four FCSC processes analysed is shown in table 7.

Table 7. Comparison of the costs and emissions - FCSC processes

Process	Cost [€/year]	%	Emission [tonCO_2/year]	%
Product collection	271,513.02	2.05	474.25	5.00
Backroom storage	4,181,332.08	31.58	3,312.37	34.95
Product delivery	8,713,685.31	65.81	4,773.005	50.37
RL	74,510.62	0.56	917.07	9.68

TOTAL	**13,241,041.03**	**100.00**	**9,476.695**	**100.00**

As can be seen from table 7, the process with the highest cost and emission is the product delivery (65.81% and 50.37%, respectively) followed by the backroom storage (31.58% and 34.95%, respectively).

The results of this study provide an idea of the total cost and environmental impact of a FCSC. The outcomes can be used by FCSC managers, retail managers and logistics practitioners to identify the processes on which to focus with the aim to reduce the cost and environmentally effective FCSC process. Moreover, the study also indicates the specific activity or component on which to intervene to remove possible inefficiencies, to optimize sustainability.

From a technical perspective, the development of an evaluation model to quantify the economic and environmental sustainability of a FCSC represent an interesting additionto the literature. The fact that the model developed can be implemented in Microsoft Excel™ is also interesting, because this general purpose software is known and widespread. This is expected to encourage the application of the model in practical cases. Nonetheless, some limitations of the analysis should be mentioned. The choice of the activities may be modified, depending on the case study analysed, including further activities in the evaluation.

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