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A model for assessing economic and environmental sustainability dimensions of a fashion supply chain and a case study

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Abstract: Due to the recent attention gained by sustainability issues in the context of supply chains, the aim of this study is to present a model developed under Microsoft Excel™ for the assessment of the economic and environmental dimensions of a fashion supply chain, sector that deserves particular attention being one of the most polluting in the world. The assessment of the economic dimension is made through the evaluation of the total cost incurred in each process of the supply chain, while the environmental aspect is evaluated in terms of the carbon dioxide emissions generated. Specifically, in this paper the modelling of the warehouse function is detailed. To test the effectiveness of the model a case study is carried out on a fashion company based in the North of Italy; the key results are reported in the manuscript, showing where the majority of costs and emissions are generated. Information obtained from this tool can support the company's management in their operational decisions and show where to focus their attention to enhance the economic and environmental sustainability.

Keywords: fashion supply chain; sustainability; case study; economic and environmental assessment; modeling.

1. INTRODUCTION

Sustainability has nowadays become a fundamental issue as important for society as it is for the business context and for the environment itself. The realities of climate change, depletion of resources, increasing in pollution and the various accidents occurred in the past make it necessary for companies to adopt major innovations so that they can operate in a responsible way, satisfy consumers' growing demand for eco-friendly products and services and comply with regulations (Hojnik et al., 2018).

Supply chain models were traditionally designed in order to minimize total costs without taking into account their harmful emissions; in recent studies this last issue has been included (Elhedhli & Merrik, 2012) due to the trend of the last years towards the study of the effects of supply chains on environmental questions (Von der Gracht & Darkow, 2016). This also led to introduce the term sustainable supply chain management (SSCM), i.e. *the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development into account which are derived from customer and stakeholder requirements* (Seuring & Müller, 2008).

Sustainable solutions can be achieved through integrating the economic, environmental and social dimensions, the so-called triple bottom line (TBL) approach which has overcome the previous single bottom line perspective that only focused on financial objectives (Oelze at al., 2018). The economic sustainability is defined as the ability to generate durable growth of economic indicators, notably the ability to generate income and employment for the population livelihood; the environmental sustainability refers to preserving the natural ecosystem by reducing polluting emissions and waste production, and the social sustainability is defined as the ability to ensure equity in quality of life and human well-being conditions, regardless of class and gender (Capone et al., 2016). The challenge is to achieve a balance between these dimensions.

Sustainability in the fashion industry has recently gained attention but, even so, has not yet been properly deepen (Yang et al., 2017). Achieving sustainable practices in the fashion and textile industries is difficult since they are made up of long supply chains (Shim et al., 2018), but at the same time it is essential, being considered among the world's most polluting industries (Boström & Micheletti, 2016). There is little doubt that considering the three aforementioned pillars of sustainability is critical to their success (Choi et al., 2018). Interesting issues are given by Karaosman et al. (2016), who reviewed the existing literature on the integration of sustainability in fashion operations including the supply chain level confirming that the implementation of sustainability positively influence supply chain itself and firms' performance. Desore & Narula (2018) also gave an overview on corporate response towards sustainability issues in this context, showing that companies are taking active steps to improve their environmental performance, even if this mainly happens in developed countries.

In line with the considerations above, this study proposes an analytic model developed under Microsoft Excel™ for the quantitative assessment of the economic and environmental sustainability dimensions of a fashion supply chain. The main processes were identified and included according to the sector in question, i.e. supply, warehousing, production, distribution and reverse logistics. For the sake of brevity, only the model

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for the automated warehouse is presented in detail in this paper. In order to test its effectiveness, the whole model is then applied to all the processes of a company based in the North of Italy, called Company A.

The remainder of the manuscript is as follows: in section 2 the methodology is described, while section 3 deals with the modelling for the assessment of the warehouse area. The case study results are reported in section 4, followed by discussion, conclusions and suggestions for future research directions (section 5).

2. METHODOLOGY

This study deals with the development of a model for the quantitative assessment of the economic and environmental dimensions of a fashion supply chain. After having analysed the existing literature and the existing models for sustainability assessments, five key processes were identified for the supply chain in question, namely: (1) supply, (2) warehousing, (3) production, (4) distribution and (5) reverse logistics.

The economic sustainability is evaluated in terms of the total costs incurred in each process expressed in thousands of euros yearly i.e. TEUR/year, while for the environmental perspective, tons of carbon dioxide (CO_2) emitted were determined; appropriate conversion factors were used where different data (e.g. kWh) were available.

The evaluation model was developed under Microsoft Excel™ and consists of six spreadsheets; each of them represents one of the five supply chain processes and evaluate both the economic and environmental aspects. A final spreadsheet shows the aggregated results.

To test its effectiveness, the model was applied to the case study of an Italian company producing medium-high level ladieswear. Data were collected through interviews with the management, and if not available were deduced from literature and previous studies. Specifically, since only the warehouse process has been detailed in the following, only input data dealing with it will be provided.

3. MODELLING FOR THE ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF THE WAREHOUSE PROCESSES

In this section the modelling for the assessment of the economic and environmental sustainability of the warehouse processes is presented. The model is designed for an automated warehouse (AS/RS); therefore, workers' contribution is not considered.

Several activities are carried out in this process: receiving, storage, picking and finally organization for shipment.

The two dimensions are evaluated on the basis of the total cost incurred and the carbon dioxide emissions generated from the following activities:

- Storage of goods;
- Facilities heating, cooling and lighting;
- Electricity consumption of material handling equipment.

The Microsoft Excel™ spreadsheet can be thought as composed of three tables, each of which dedicated to the three abovementioned activities responsible for costs and emissions; the only exception is the storage of goods, which does not involve emissions and therefore is not taken into account in the relating computation. In the table dedicated to the storage of goods, costs can be divided depending on products' location in the storage area. Table reporting results derived from facilities heating, cooling and lighting shows in detail data from the three elements. The third table, instead, includes the different types of equipment effectively used. A fourth, final table can be added in order to synthesize obtained values of economic and environmental results.

As far as the computational procedure to quantify costs and emissions is concerned, the notation used is shown in Table 1.

Table 1 - Nomenclature for the economic and environmental modelling of the warehouse process.

SYMBOL	DESCRIPTION	UNIT OF MEASUREMENT
C_{SK}	Storage of goods cost	TEUR/year
c_{sk}	Storage of goods unitary cost	€/m^2/year
A	Total warehouse area	m^2
a_s	% of storage area in the warehouse	%
$C_{H/C}$	Heating and cooling cost	TEUR/year
c_e	Electricity consumption unit cost	€/kWh
$f_{h/c}$	Heating and cooling factor	kWh/ m^2/year
C_L	Lighting cost	TEUR/year
f_l	Lighting factor	kWh/ m^2/year
C_{MMHE}	Mobile material handling equipment cost	TEUR/year
me	Mobile material handling equipment (1,..,ME)	-
c_{me}	MMHE hourly cost	€/h
h_{me}	MMHE operating hours	h/year
C_{FMHE}	Fixed material handling equipment cost	TEUR/year
fe	Fixed material handling equipment (1,..,FE)	-
c_{fe}	FMHE hourly cost	€/kWh
h_{fe}	FMHE operating hours	h/year
C_W	Total cost of the Warehouse area	TEUR/year
$E_{H/C}$	Heating and cooling emissions	tCO_2/year

E	Conversion factor kWh → kgCO2	tCO_2/kWh
E_L	Lighting emissions	tCO_2/year
E_{MMHE}	MMHE emissions	tCO_2/year
k_{me}	MMHE hourly energy consumption	kWh/h
E_{FMHE}	FMHE emissions	tCO_2/year
k_{fe}	FMHE hourly energy consumption	kWh/h
E_W	Total emissions of the warehouse area	tCO_2/year

3.1 Economic model

The economic dimension is evaluated in terms of the total costs incurred for the three abovementioned components.

The first cost item i.e. the storage of goods, is computed using a coefficient that takes into account the area/volume dedicated to the storage. Heating, cooling and lighting costs can be calculated as well through a coefficient expressing the electricity consumption per unit of warehouse area; usually heating and cooling are evaluated together. Regarding the cost for the material handling equipment, it is firstly necessary to distinguish between Mobile Material Handling Equipment (MMHE), e.g. forklift trucks or AGVs, and Fixed Material Handling Equipment (FMHE), e.g. sorters or conveyor belts (Tompkins, et al., 2010). In both cases, one may think to a cost coefficient taking into account the energy consumption and maintenance, if any.

According to the considerations above, the following formulae are used in the computation:

- cost for the storage of goods

$$C_{SK} = c_{sk} \cdot A \cdot a_S \text{ [TEUR/year]} \quad (1)$$

- cost for heating/cooling

$$C_{H/C} = c_e \cdot f_{h/c} \cdot A \text{ [TEUR/year]} \quad (2)$$

- cost for lighting

$$C_L = c_e \cdot f_l \cdot A \text{ [TEUR/year]} \quad (3)$$

- cost for MMHE

$$C_{MMHE} = \sum_{me=1}^{ME} c_{me} \cdot h_{me} \text{ [TEUR/year]} \quad (4)$$

- cost for FMHE

$$C_{FMHE} = \sum_{fe=1}^{FE} c_{fe} \cdot h_{fe} \text{ [TEUR/year]} \quad (5)$$

The total cost of the warehouse area consists in the sum of the single contributions of cost items listed above:

$$C_W = C_{SK} + C_{H/C} + C_L + C_{MMHE} + C_{FMHE} \text{ [TEUR/year]} \quad (6)$$

3.2 Environmental model

The environmental dimension, instead, is evaluated through the tons of carbon dioxide generated by the three elements mentioned in the economic analysis; the only exception is the activity of good storage, which is not considered in the computation. Emissions from heating and cooling as well as those resulting from lighting are computed based on a factor considering consumptions per unit area, while for the material handling equipment, the operating hours and unitary energy consumption are considered. Relating formulae are listed in the following:

- emissions from heating/cooling

$$E_{H/C} = E \cdot f_{h/c} \cdot A \text{ [tCO}_2\text{/year]} \quad (7)$$

- emissions from lighting

$$E_L = E \cdot f_l \cdot A \text{ [tCO}_2\text{/year]} \quad (8)$$

- emissions from MMHE

$$E_{MMHE} = \sum_{me=1}^{ME} k_{me} \cdot h_{me} \cdot E \text{ [tCO}_2\text{/year]} \quad (9)$$

- emissions from FMHE

$$E_{FMHE} = \sum_{fe=1}^{FE} k_{fe} \cdot h_{fe} \cdot E \text{ [tCO}_2\text{/year]} \quad (10)$$

The total emissions are obtained as the sum of the single contributions, i.e.:

$$E_W = E_{H/C} + E_L + E_{MMHE} + E_{FMHE} \text{ [tCO}_2\text{/year]} \quad (11)$$

The same procedure described for the warehousing activities has been followed for the remaining processes of the fashion supply chain, taking into account their specific features. The different activities and cost/emission components were firstly identified for each activity; then, formulae were determined in order to obtain the two final outcomes investigated.

4. CASE STUDY

This section presents the results of the application of the whole model to a case study company, called Company A. This company is located in northern Italy and acts as the *focal company* of its supply chain; it is set within the context of medium-high level ladieswear and production is planned based on orders received from the various point of sales, after they have sight of the new seasonal collection i.e. it is a demand driven supply chain (Iannone et al., 2015). There are two main types of finished products i.e. knitting and jersey, for which different chains are involved due to the substantial difference of raw materials and processes between the two. Only in the distribution phase this difference disappears since all products are shipped together. Around 2,000,000 items per category are produced in one year.

The product flow starts with the procurement of raw materials (supply); these latter can come from Turkey, India, Poland, Egypt and Italy. Once goods are received at the Italian warehouse, they are shipped to the production plants. A key characteristic of Company A is that production is carried out by third parties situated abroad (typically in the Far East), in line with the common trend due to globalization of shifting production sites to emerging markets and developing countries (Warasthe & Brandenburg, 2018). Once the items have been manufactured, they are shipped back to the Italian warehouse, and finally they are delivered to the shippers' logistic platforms; at this point the company's control ends. This is the reason why no reverse logistics activities are managed by Company A: once finished products reach the different points of sales, these last are responsible for their sale or for managing return flows.

For the sake of consistency with the model developed, the analysis has been conducted on all the relevant supply chain processes, namely supply, warehouse, production and distribution; reverse logistics has been excluded from the evaluation as it is of marginal interest for Company A.

Results from economic and environmental analysis are shown in the subsections below and, where possible, shared among the knitting and jersey product categories. Since in the previous section the modelling for the assessment of the warehouse area has been explained in detail, only this area will be detailed step by step and input data will be provided.

4.1 Supply

Once suppliers were identified as well as their geographical location, means of transport used namely road or ship, quantities ordered and purchase costs for each raw material, the results in Table 2 were obtained:

Table 2 - Results from supply function.

Product type	Cost [TEUR/year]		Emissions [tCO_2/year]	
	Raw materials	Transport	Raw materials	Transport
Knitting	1,677.16	20.17	-	17.12
Jersey	1,049.3	16.7	-	13.61
Total	2,763.32		30.73	

Costs for the supply are mostly due to the knitting product category. The reason is the very high unitary cost of the yarn used for these items, which is imported from India and shipped by sea.

Emissions as well are mainly generated by the knitting product category, since its raw materials have a greater number of deliveries.

4.2 Warehousing

Taking as starting point the model described in section 3 for the assessment of the economic and environmental sustainability of the warehouse, results are provided below, step by step. The first activity generating cost is the storage of goods. Input data for its calculation are listed in Table 3.

Table 3 - Input data for the storage of goods cost.

Parameter	Numerical value	Measurement unit	Source
c_{sk}	142	€/m^2/year	Company A
A	5,200.00	m^2	Company A
a_s	13	%	Company A

The storage of goods cost C_{SK} is easy to calculate, and totals around 96 TEUR/year.

Furthermore, thanks to the detailed subdivision of the storage area between finished products/raw materials and knitting/jersey, it is also possible to determine exactly the costs related to each category using the same formula; detailed results are shown in Table 4. Note that costs are the same for the two categories since each of the two owns exactly 50% of the area dedicated to raw materials and of the one meant to finished product.

Table 4 - Storage of goods costs.

Cost component	Knitting	Jersey
Raw Material storage cost [TEUR/year]	16	16
Finished Product storage cost [TEUR/year]	32	32
Total cost per product category [TEUR/year]	48	48
Total cost [TEUR/year]	96	

The second element generating both costs and emissions is the energy consumption for facilities heating/cooling and lighting, which depends on the warehouse total area. Input data and the relating sources are given in Table 5.

Table 5 - Input data for heating, cooling and lighting costs and emissions.

	Numerical value	Measurement unit	Source
c_e	0.174	€/kWh	Ricciardi (2015)
$f_{h/c}$	200	kWh/ m^2/year	Fichtinger et al. (2015)
f_l	36	kWh/ m^2/year	Fichtinger et al. (2015)
A	5,200.00	m^2	Company A
E	$4.332 \cdot 10^{-4}$	tCO_2/kWh	Emilia-Romagna (2015)

In view of the abovementioned values, results are immediate: costs incurred for heating/cooling and lighting of facilities account, respectively, for 180.96 TEUR/year and 32.57 TEUR/year, and total 213.53 TEUR/year. Emissions, instead, amount to 531.62 tCO_2/year (450.53 from heating/cooling and 81.09 from lighting). It is clear that most of the expenses and emissions are held for heating and cooling the facilities.

Finally, costs and emissions related to the material handling equipment need to be determined. The warehouse activities require 5 stacker cranes and 4 fork trucks (MMHE), plus a sorter and a roller conveyor (FMHE). Data for the mobile equipment refers separately to stacker cranes and fork lift trucks; accordingly, we have two components called MMHE1 and MMHE2 respectively. For the fixed equipment, values refer to both elements. The required data are listed in Table 6.

Table 6 - Input data for material handling equipment costs and emissions.

Parameter	Numerical value	Measurement unit	Source
c_{me} MMHE$_1$	3.30	€/h	Company A
c_{me} MMHE$_2$	1.40	€/h	Company A
c_{fe}	5.57	€/h	Company A
h_{me} MMHE$_1$	1,399.50	h/year	Company A
h_{me} MMHE$_2$	1,866.00	h/year	Company A
h_{fe}	2,332.50	h/year	Company A
k_{me} MMHE$_1$	20.00	kWh/h	Company A
k_{me} MMHE$_2$	6.39	kWh/h	Company A
k_{fe}	27.87	kWh/h	Fichtinger, et al., 2015
E	$4.332 \cdot 10^{-4}$	tCO_2/kWh	Emilia-Romagna, 2015

The final results show that the total cost for the MMHE corresponds to 7.23 TEUR/year each year, while the cost for FMHE is 12.99 TEUR/year. Emissions, instead, amount to 17.3 tCO_2 for the mobile equipment each year, and 28.16 tCO_2 for the fixed equipment.

More generally, the costs observed in the warehouse amount to 329.74 TEUR/year and the emissions to 577.07 tCO_2 each year. The worthiest component for both economic and environmental analysis is the maintenance of facilities, specifically for heating and cooling.

4.3 Production

Since Company A outsources production, the evaluation is not based on the manufacturing processes themselves, but rather on forward flows (FF), i.e. the shipment of raw materials from the Italian warehouse to the production plants abroad, and backward flows (BF), i.e. the product flow from the production plant abroad to the Italian warehouse. Volumes in the backward flow phase are, of course, higher. Results are depicted in Table 7.

Table 7 - Results from production function.

Type of product	Cost [TEUR/year]		Emissions [tCO_2/year]	
	FF	BF	FF	BF
Knitting	28.97	758.14	16.50	661.07
Jersey	11.29	749.34	8.42	623.84
Total	1,547.75		1,309.84	

The cost for the forward flow is definitely lower than the backward flow, since finished products are more numerous.

Foreign countries involved are China, Romania, Tunisia, Morocco, Portugal, Turkey and Croatia. Despite the air transport is involved only with China, this is the highest cost and emissions component.

4.4 Distribution

The last process analysed is the distribution, which, for the case under examination, is the shipment of the finished items to the transporters, which will then serve the point of sales. Shipment is carried out only by road, and logistic platforms are all located in northern Italy not far from the main warehouse of Company A.

The results obtained are shown in Table 8. Note that the distinction between knitwear and jersey disappears at this stage as well, since both product categories are distributed jointly.

Table 8 - Results from distribution process.

Cost [TEUR/year]	Emissions [tCO_2/year]
34.8	25.94

5. DISCUSSION AND CONCLUSIONS

This paper aimed at presenting the economic and environmental sustainability modelling of a fashion supply chain. Total costs were considered as the key performance indicator for evaluating the economic aspect, while carbon dioxide emissions was used to evaluate the environmental dimension.

The model, developed under Microsoft Excel^{TM}, takes into account all the typical processes of a fashion supply chain, from raw material procurement up to the shipment of the finished product to the stores. For the sake of brevity, the paper has detailed the warehouse process only, to provide the reader with an idea of the computational procedure followed for the evaluation of the economic and environmental sustainability.

The whole model has subsequently been applied to an Italian company operating in the fashion industry, for the evaluation of four supply chain processes. The aggregated results of the economic and environmental evaluation are presented in Table 9, including the percentage share of costs and emissions among the different supply chain processes.

Table 9 - Aggregated results from the economic and environmental analysis of the case study.

Process	Cost [TEUR/year]	%	Emissions [tCO_2/year]	%
Supply	2,763.32	59.1	30.73	1.6
Warehouse	329.74	7.1	577.07	29.7
Production	1,547.75	33.1	1,309.84	67.3
Distribution	34.8	0.7	25.94	1.4
TOTAL	4,675,607.19	100	1,943.6	100

For the tested supply chain, most of the economic impact is generated at the supply stage; the second cost item impacting the total cost to the greatest extent is the production process.

The production process turns out to be responsible for most of the emissions despite the fact that the relating evaluation only took into account the logistics processes (i.e. the flows from the main Italian warehouse to the production plant and vice versa), as Company A outsources the true production activity. This result was somehow unexpected, since the emissions of this process are more than forty times higher than those related to the supply, despite the logistics aspect (i.e. transport) only was taken into account for the environmental evaluation of both processes. Of course, it should be mentioned that supply considers only one-way transports (i.e. from the supplier to the company's warehouse), while for production round trips are involved (i.e. from/to the warehouse to/from the production plants); result is anyway noteworthy. Emissions due to the supply process are as well significantly lower than those due to the warehouse, which are especially generated from the heating and cooling systems. To be more precise, it emerges that air transport, used to cover great distances (i.e. for the relationship with China), has a major impact on both costs and emissions.

This set of information may be useful to the management by highlighting those processes where the attention should be addressed and can support operational decisions aimed at decreasing the environmental impact of the company. For instance, in our case study, managers might consider other suppliers or other raw materials, since the majority of costs occurs for their purchase. Similarly, to reduce the emissions, they could reconsider transport to/from production plants or evaluate renewable energy sources to be used in the warehouse. More in general, the model developed in this paper can be taken as a starting point for similar evaluations in other supply chains and can be adapted to scenarios different from the fashion industry, e.g. by changing processes or including other activities, depending on the particular context. Moreover, it can be implemented in companies of different size in order to identify any contingency factors.

Among the limitations of this paper, we have to mention that the specific case study could be more thorough if data about the true production process were available and included in the analysis. Moreover, the social dimension of sustainability has been neglected in this study due to the difficulties in its quantitative assessment; nonetheless, its evaluation could be deepened. These aspects form interesting issues for future research activities.

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