Application of Life Cycle Assessment to a Wool Sweater: A Case Study

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Abstract: This work aims at developing an application of the life cycle assessment methodology (LCA) to evaluate the environmental impact of a product by a leading company in the textile sector.

This study will demonstrate that, in the textile sector, the main footprint effect is provided by the electrical and thermal energy used and by the transportation (since, in the case study, the different production phases are delocalized in different countries such as South Africa, Italy, Romania and all around the world at from the distribution centre to the stores).

Keywords: Life cycle assessment (LCA), carbon footprint, environmental supply chain, textile sector.

1. INTRODUCTION

The textile sector is one of the biggest sources of greenhouse gases, due to the number of processes and products that are necessary to produce any kind of clothing. Wiedmann and Mix (2007) calculated textiles and clothing are responsible for around four percent of the secondary carbon footprint of an individual in the developed world. The problem has been largely addressed at European level, the EU COST Action 628 (2007) was established to produce first hand, industrial environmental data of textiles in Europe, as well as to suggest tools for comparisons of present technologies and practices with cleaner applications, including the economic effects. Unique, first-hand industrial data were collected from five European textile industries. Many industries in the textile chain addressed the question connected to the environmental impacts associated with the production chain. Turunen and van der Werf (2006) detailed the impact of the production of yarn from hemp and flax using Life Cycle Assessment (LCA).

The main aim of this work is to evaluate the application of the LCA methodology in order to obtain a tool to support the company environmental policy. The object of the analysis is the evaluation of the basic items produced a company. A simple wool sweater without buttons, laces, zippers or other accessories, with standard production processes for the yarn, weaving and finishing treatments was taken into account. This particular model had not been produced in the past and, at the moment of the study, it had still to be commercialized and only selling previsions were available.

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2. RELATED RESEARCH WORKS

Proto *et al*. (2000) analyzed the development opportunities in agricultural and manufacturing processes in view of new trends that are characterized by sustainable life-cycle assessments.

They described the relation between agricultural resources, industrial activities and the environment and assessed that among the sectors that are showing a certain environmental sensitivity, there is the textile one, and particularly the cotton sector.

DuPont, the US based chemicals major, that revolutionized the fiber industry with the introduction of man-made fibers like nylon, rayon and spandex now offer Sorona, a polymer which is made with agricultural feedstocks. Fabrics made with Sorona provide a 30% carbon dioxide reduction while the Sorona manufacturing process reduces greenhouse gas emissions by 63%, compared to conventional nylon made from petroleum.

BASF, the German chemicals major, has launched a number of eco-efficient solutions that are environmentally friendly and contribute to saving resources.

J. W. Mc Curry (2009) described a study about future trend in textile industries carried out from Freedonia Group, an Ohio-based consultancy firm. It reveals that the textile chemical's world demand will show an increase of 2.8% per year to $19 million in 2012, with colorants and auxiliaries as the largest segment and that textile industry will encourage the

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use of nanotechnology to enhance fiber properties, and the use of inexpensive, man-made fibers especially polyester fibers can limit the use of reactive, vat, and direct dyes as well as sizing preparation chemicals that are generally used in processing of natural fibers.

According to Woodings (2009), the textile industry needs to shift its focus towards recycling of synthetic fibers and to develop novel natural fibers to combat the economic recession and credit crisis. Lenzizng's man-made cellulosic fibers are manufactured by energy neutral process solar powered polymerization, offering low carbon footprint that consumers are increasingly demanding. Also, these nature-based fibers, which are obtained from wood, straw, and grass, are recyclable. The industry should also encourage plastic recycling for the recovery of oil-based polymers and fibers, and fibers like polyester, which have no alternative, need to pay attention to recycling. The industry needs to move towards price indexing systems allowing fast responses to the fluctuating raw materials market.

An ecological footprint study in the textile field has been proposed by Herva *et al*. (2008). They analyzed a textile tailoring plant with the overall purpose of developing a tool for evaluating the environmental impact evolution due to the performance of the plant. The selected data were those from the manufacturing work. Data were divided into three main categories: energy, resources and waste. The principal contribution to the final EF (expressed in hectares of land) was the resources category, mainly due to the high value associated with the cloth. Results were divided by the production rates in order to obtain a comparable relative index useful for different stakeholders. This is of special importance for a Company involved in Corporate Social Responsibility and thus meant to have a general communication strategy.

3. MATERIAL AND METHODS

The application of the LCA methodology was carried out according to the international standards (ISO14040 series) and by using the Simaprò software and the Ecoinvent database. In accordance with ISO 14041 the stage of life cycle inventory (LCI) involves the collection of the data related to the processes and the various calculation procedures. The relationship between the item produced and the environment are defined. We focused our attention on the calculation of carbon footprint, measured as CO_2 equivalent. IMPACT2002+ method was selected:

The Characterisation factors for Human Toxicity and Aquatic & Terrestrial Ecotoxicity are taken from the methodology IMPACT 2002 - IMPact Assessment of Chemical Toxics. It allows evaluating the other indexes of the environmental impact: human toxicity, respiratory effects, ionizing radiation, land occupation, ozone layer depletion. It also normalizes the index and groups them into a single global indicator.

4. CASE STUDY

The LCA methodology has been used to define the carbon footprint of a wool sweater made by a leader company in the textile industry. The entire production chain has been analysed and all single contributions to the environmental impact have been evaluated. The idea with which many decisions were made was to maintain a quite generic point of view since the main goal was to assess if the LCA methodology can be applied continuously and systematically to entire garments collection.

4.1. System Boundaries

It was decided to define the boundaries of the system starting from sheep breeding at the farms in South Africa, from which the greasy wool is obtained, then considering the other production phases, the distribution to the final stores all around the world and, finally the user phase (washing and final disposal) as shown in Figure **1**.

Those boundaries take into consideration all phases related to sweater production, distribution and use: wool scouring, dyeing, spinning, knitwear, transportation to the distribution centers and then to the selling stores, washing and final disposal.

The English guidelines (PAS 2050:2008)[1] were taken into consideration for the following aspects of the boundaries definition:

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[1] "Where products are distributed to different points of sale (i.e. different locations within a country), emissions associated with transport will vary from store to store due to different transport requirements. Where this occurs, organizations should calculate the average release of GHGs associated with transporting the product based in the average distribution of the product within each country, unless more specific data is available" (publicly available specification PAS 2050:2008, par. 6.4.6, note 4).

"The GHG emissions arising from the production of capital goods used in the life cycle of the product shall be excluded from the assessment of the GHG emissions of the life cycle of the product" (publicly available specification PAS 2050:2008, par. 6.4.3).

"CO2 emissions arising from biogenic carbon sources shall be excluded from the calculation of ghg emission from the life cycle of product, except where the CO2 arises from land use change" (PAS 20050:2008, par 5.3).

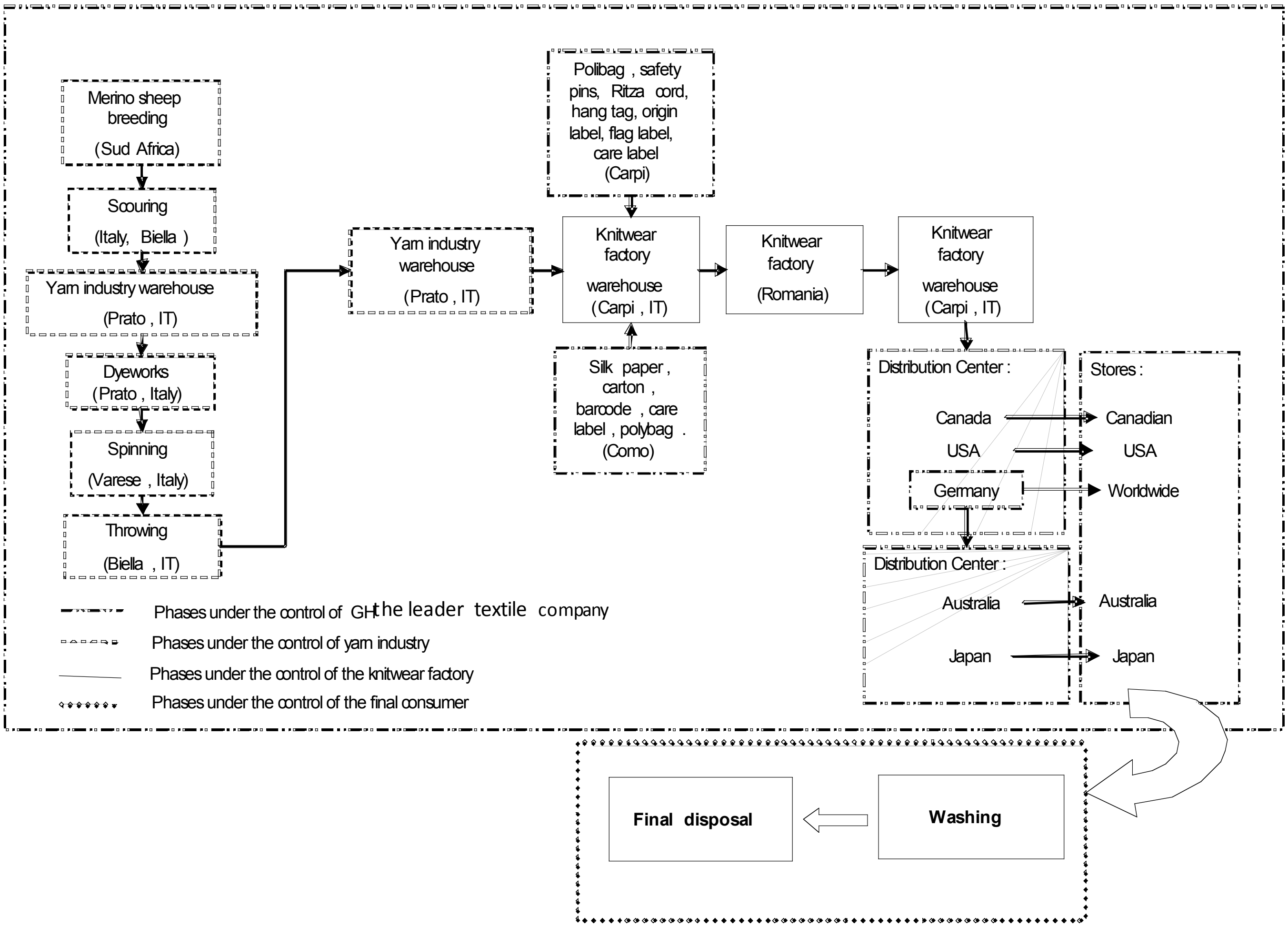

Figure 1: System boundaries (source Bevilacqua *et al*., 2011).

- The modeling of the transportation phase to the stores was taken into account and an average transportation model was used;
- The exclusion of the capital goods from the analysis;
- The exclusion of the CO_2 emissions arising from biogenic carbon sources for the sheep breading modeling.

The last assumption has changed the final results significantly in terms of GWP, as it will be presented in the following discussions.

All the packaging, especially the ones used for sending the sweater from the production site to the store were considered.

Regarding the environment boundaries, it was decided to consider the agricultural systems as part of the environment this means, for example, that pesticides are view as emissions.

4.2. Functional Unit

According to ISO standard, it is necessary to define the objective function and the functional unit related. All different characteristics were included in the functional unit.

The sweater chose a case study had the following characteristics:

- 100% Merinos wool;
- 4 color;
- Winter 2009 collection.

To calculate the average sweater the medium weight method was used: the data used were deduced from the selling previsions,

The parameters included in the average sweater, representative of the functional unit were:

- Size distribution: each size assumes a different weight as shown in table **1**.

Table 1: Percentage Distribution for each Size

	S	M	L	XL	XXL	XXXL	Tot
Distribution Pieces-Size	4,71%	20,59%	25,29%	24,71%	17,65%	7,06%	100%
Pieces for Size (n)	141,18	617,65	758,82	741,18	529,41	211,76	3000
Weight Tot for Sizes (g)	**32654,12**	**150798,53**	**195017,65**	**201911,29**	**151025,29**	**63131,29**	**794538,18**

- Color: each color has a slightly different dyeing process. Based on the color distribution for the examined sweater in the entire winter 2009 collection, it was possible to calculate the contribution of each color in the medium sweater in terms of weight.

The medium sweater has the following characteristics (Table **2**):

Table 2: Average Sweater Characteristics

1	Main label (regular fit)	0.31 g
1	Flag Label	0.11g
1	Origin label	0.11g
1	Hangtag	1.83g
1	Safety pins (hantag)	0.2g
1	Cord ritza (hang tag)	0.3g
1	Care label	0.3g
2	Barcode	0.1g
1	Silk Paper	4.25g
1	Polybag	15.65g

Net weight: 264.85 g (without accessories),

Color:

Color	001	032	038	521	522	Tot kg
Weight distribution %	111,81	3,22	82,25	32,00	35,58	264,85

Accessories.

4.3. Life Cycle Inventory Analysis (LCIA)

The second stage of the LCA investigation is the Life Cycle Inventory Analysis in which a model, that contains the amounts of all inputs and outputs of processes that occur during the life cycle of the sweater has been created.

The data collected have been divided into two different group: primary and secondary data as is shown in Table **3**.

The primary data were collected directly from the company involved in the different phases of the production process by a questionnaire. Secondary data that were extracted from:

- The software models (Yarn production bast fibers/ IN U, 2007).
- The “BREF”(Best available technology reference document) of the European Community (2003). This document provides information about the best techniques for the textile sector.
- The “Analysis of the production cycle in the textile and wool sector” of the Arpa of Piemonte Region (2005).

For the final phases of the life cycle: use and final disposal, data were obtained from the literature, market analyses, company data and ENEA database.

The sweater life cycle provides a contribution to all the environmental impact categories (Ecosystem Quality, Human Health, Resources, Climate Change).

Table 3: Data Sources

Supplying company	Production processes	Primary data	Secondary data		
			Software model	BREF	ARPA
A	Sheep breeding	X	X		
B	Scouring			X	X
C	Dyeing	X		X	X
D	Spinning	X	X		X
E	Trowing e vaporizing	X			X
F	knitwear factory	X	X		

The main environmental effects are due to the water volumes utilized (since they are predominant in the textile industry) and to the chemicals used.

Moreover, electrical and thermal energy is widely used in several phases of the production. Important contributions come also from waste production (mud deriving from the depuration of some processes, and packaging) and from smelling emissions.

Liquid waste management plays a key role in the environmental impact reduction in the textile sector: the flows coming from the different processes are mixed together and create a combination that changes depending on several factors (chemicals used, fiber produced, processing techniques, season, production program, etc.).

The processes described so far give a great contribution to the environmental impact in terms of Ecosystem Quality, Human Health, Resources, but they are not very important in terms of carbon footprint. In fact, the research carried on demonstrated that the CO_2 production related to the chosen sweater depends mostly on the complexity of the supply chain and the distribution management.

4.3.1. The Production Process

In textile manufacturing system is possible to distinguish two main different processes: mechanical (spinning and weaving) and chemical (washing, dyeing and finishing).

The complete processing cycle of the analyzed item involves several steps. First comes shearing, followed by sorting and grading, making yarn, dyeing, finishing, making fabrics, making up the sweater and distributing.

All the production processes of the selected item are executed by external companies. The main company is directly linked only to two of them: one that provides the finished yarn and another that from the finished yarn produces the sweater.

In synthesis 7 companies are involved in the production of the analyzed item with 17 transportation phases for a total of more than 10.000 km, 5 kWh of electrical energy, 18 MJ of thermal energy, 60 g chemicals and detergents, 200 g of packaging and 350 g of waste.

Regarding the use of the sweater, data were obtained from the company literature database and from ENEA guidelines (2003). A medium life of 5 years with 15 washing per year was considered, 30°C of washing temperature, 10 l of water for each cycle, 130 ml of chemicals[2] (soap and conditioner).

For the last life phase, the final disposal, from literature data it was established that 49% was disposed of 49% was burned and the last 2% was reused.

The transportation scheme for the distribution centers and the relative percentage are shown in the following figure **2**.

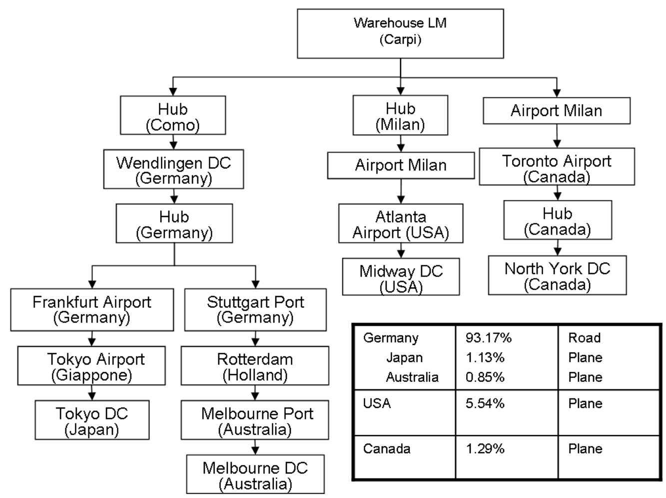

Figure 2: Scheme of the transportation from the warehouse to the DC (source Bevilacqua *et al.*, 2011).

4.4. Impact Calculated by IMPACT 2002+

In the following Table **4**, the impacts of the Midpoint Categories and the comparison between different boundaries definition are reported. The boundaries were set in three different ways: by considering only the sweater production phase that ends at the warehouse in Carpi (GARMENT PRODUCTION); by considering also the transportation to the stores (GARMENT SHOPS); and by considering all the life cycle of the sweater including washing and final disposal (GARMENT LIFE CYCLE).

The results obtained in terms of Midpoint categories for the entire analysis can be expressed as the

[2] Data obtained from ENEA.

Table 4: Impacts Midpoint Categories and Comparison between Different Boundaries

Impact categories	Unit	Garment production		Garment Shops		Garment life cycle	
Carcinogens	kg $C_2H_3Cl_{eq}$	0,001164	51%	0,001379	60%	0,002302	100%
Non-carcinogens	kg $C_2H_3Cl_{eq}$	-0,47882	104%	-0,4783	104%	-0,46141	100%
Respiratory inorganics	kg $PM_{2.5\ eq}$	0,000948	59%	0,001422	89%	0,001596	100%
Ionizing radiation	Bq C-14 $_{eq}$	9,666948	4%	16,6939	8%	222,5458	100%
Ozone layer depletion	kg CFC-11 $_{eq}$	5,65E-07	50%	7,63E-07	68%	1,13E-06	100%
Respiratory organics	kg $C_2H_{4\ eq}$	0,000178	43%	0,000309	74%	0,000415	100%
Aquatic ecotoxicity	kg TEG water	70,8688	53%	74,38199	56%	133,3963	100%
Terrestrial ecotoxicity	kg TEG soil	23,94951	55%	27,36658	62%	43,83981	100%
Terrestrial acid/nutri	kg $SO_{2\ eq}$	0,033399	58%	0,051734	89%	0,057834	100%
Land occupation	$m_2$org.arable	0,091095	11%	0,094252	12%	0,811925	100%
Aquatic acidification	kg $SO_{2\ eq}$	0,004384	53%	0,006894	83%	0,008278	100%
Aquatic eutrophication	kg PO_4 P-lim	1,95E-05	30%	4,05E-05	62%	6,57E-05	100%
Global warming	kg CO_2 eq	0,694237	40%	1,384873	79%	1,754337	100%
Non-renewable energy	MJ primary	82,02989	32%	106,0451	42%	255,0609	100%
Mineral extraction	MJ surplus	0,005392	76%	0,005441	77%	0,007051	100%

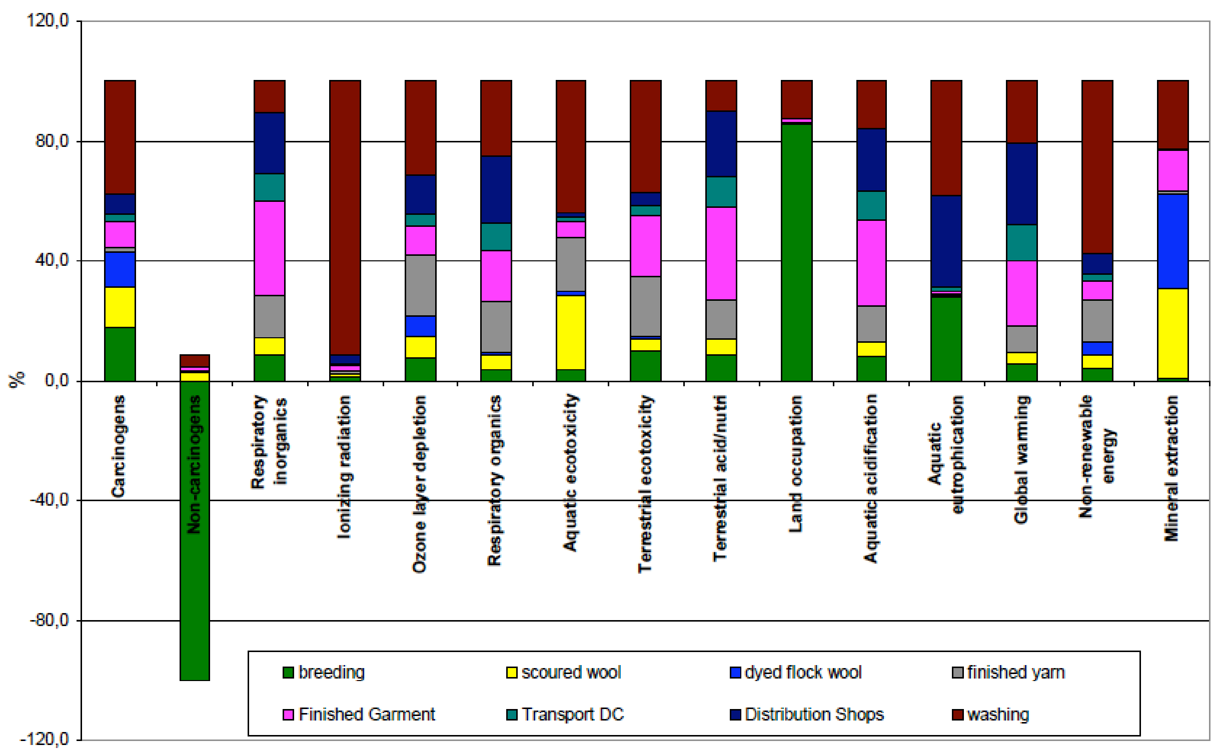

Figure 3: Percentage contribution to the single damage categories.

percentage contribution of each phase for the single damage category as shown in figure **3**.

Final results of the impacts distribution in the different phases (midpoint categories) are shown in figure **4**:

- The weight of CO_2 is about 9% of global impact on the life cycle from breeding to shops.
- The washing phase by itself contribute to the 64% of global impact, and 20% of CO_2.

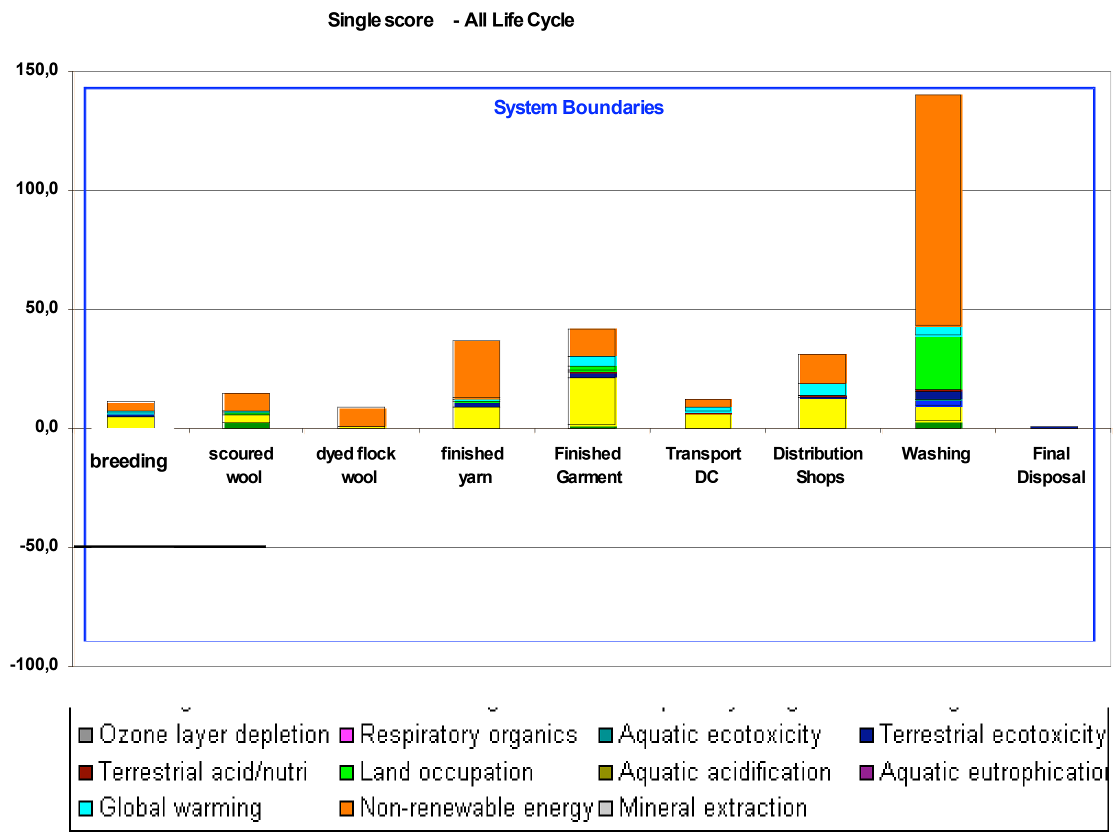

Figure 4: Midpoint categories contribution in each phase.

CONCLUSIONS

In the last few years, life cycle thinking has been the focal point in the environmental policy development that is standardized by the IPP (Integrated Product Policy) in the European community. Many other standards are utilized in other countries.

In this scenario, LCA provides the scientific reference for all the activities related to the Corporate Sustainability Report that is a tool that more than 500 of the major companies all around the world use to communicate to the market their environmental policies.

The use of LCA methodology allows company to assess and disseminate the environmental impact of their processes and products. Moreover, it is a useful way to increase the environmental consciousness of the employees and of the supply chain operator involved in the production process.

The LCA can be also used to evaluate the suppliers and to improve the entire supply chain and as support for the eco-design in order to realize green products.

The aim of this paper was to assess the environmental impact associated with a particular product of a leading textile company. The selected item has been utilized as a case study: average characteristic was chosen in order to define the input for the LCA model. With the use of LCA, it is possible to face the environmental analysis at different levels. The "damage category" was addressed by specific indicators like ecosystem quality, human health, resources; the "midpoint category" by evaluating ozone depletion, carcinogens, aquatic ecotoxicity, etc.

The use of LCA methods in this work was a good choice. This technique is a powerful tool to address the eco-efficiency promotion and it provides several benefits to the company as:

- Competitive advantage to show to customer that the product is environmentally sound;
- Market access possibilities: the EU is the key region of concern as it leads the way in requiring demonstration of sustainable practices and is a significant market for the company[3].

[3] The EU-EcoLabel criteria are based on LCA principles.

- Assistance on quantifying risks and opportunities to avoid threatening to market access.
- Improve production performances in terms of effectively managing and use of resources.

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