IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 14, Issue 11 Ser. II (November 2020), PP 19-27
www.iosrjournals.org

Life cycle assessment of manufacturing processes of a cable harness in Morocco

Hanaa ABOULJALIL[1], Mahacine AMRANI[2]
[1,2,](Laboratory of Chemical Engineering and Resource Valorisation, Faculty of Sciences and Technology /AbdelmalekEssaadi University, Faculty of Sciences and Technology Tangier, Morocco)

Abstract:
***Background**: Growing concerns over energy and environmental sustainability have lately sparked worldwide interest in more efficient and cleaner transportation systems and industrial activities. Today's automotive wire harness manufacturing process faces huge challenges in term of competitiveness, quality and responsiveness. The most important is related to environmental issues and how manufactures can produce a sustainable and profitable industry through adopting more environmentally friendly technologies.*
***Materials and Methods**: In this article, we emphasize the life cycle assessment (LCA) of a wiring harness in Morocco. An inventory of materials inputs and environmental releases from gate to gate (cutting and assembly processes) was fixed.*
***Results**: The assembly manufacturing was found to be the main contributor process, mainly due to the utilization of bronze and copper materials. Similarly, the potential environmental impact was evaluated in term of human health by 37% and ecosystem quality by 19%.*
***Conclusion:** Finally, the LCA of this product was decisively influenced by the consumption of raw materials and, therefore, the reduction of these raw materials makes the cable considerably more sustainable from an environmental point of view.*

***Key Word**: Life Cycle Assessment; Wiring Harness; Automotive industry; Impact assessment; Environmental impact; ISO 14040.*

Date of Submission: 12-11-2020 Date of Acceptance: 28-11-2020

I. Introduction

Year after year, the world car production is increasing in an evident way. Around 2.9 cars are being produced and sold every second [1]. Conscious of the economic and environmental stakes, Morocco tries to reconcile durably the economic development and the climate protection. The Moroccan automotive industry has risen to sustained levels of growth over the last decade. The 2014-2020 Acceleration Plan and the new ecosystem approach which it introduces bases to a steady and long-lasting development of the companies of the sector. Eight ecosystems were set up, to date, in the automotive industry. They concern the sectors of "automotive wiring", "Vehicle interior and seats", "Metal pressing"," automotive batteries", "heavy goods vehicles and industrial bodywork" , "Motors and transmission" and two car manufacturers ecosystems, "Renault" and "PSA" . [3] The Moroccan automotive sector is increasingly differentiated by its industrial wiring business. The automotive wiring segment represents approximately 50% of the national automotive fabric and its exports reached DH 17.2 billion (€ 1.6 billion) in 2014. The sector has more than 150 equipment manufacturers in three main regions: Tangier (43%), Casablanca (39%) and Kenitra (7%), which makes possible to cover the main trades with the aim of generating high value-added vehicle equipment. [4].

Therefore, solid waste management is one of the major environmental problems threatening the Mediterranean Kingdom of Morocco. More than 5 million tons of solid waste is generated across the country with annual waste generation growth rate touching 3 percent [5].

In order to reduce the environmental impacts, improve the product image and identify the appropriate performance indicators, the Life Cycle Assessment is mostly used to support business strategy. The Life Cycle Assessment (LCA) methodology is an efficient tool for studying, assessing and quantifying the environmental impacts of products (whether they are goods, services or manufacturing processes) in their life cycles.

In this context, our study made a life-cycle assessment of a wiring harness in its manufacturing in Morocco. Life cycle assessment (LCA) methodology was adopted through the production stages of a cable, which starts with the reception of the raw material, subsequently the cutting, assembly process.

II. Material And Methods

A. Overview of Life Cycle Assessment

Life Cycle Assessment (LCA) provides a rigorous framework to assess a product against a range of environmental impact categories from the 'cradle to the grave', or a subset of production stages.

Defined by ISO: 14040:2006 and 14044:2006, LCA sets out a clear method for analysis, including goal and scope definition, Life Cycle Inventory (LCI) development, Life Cycle Impact Assessment (LCIA) and interpretation (Fig. 1) [6] . The principles set out in the ISO standard (14040:2006b) [7] state that an LCA is to have: a life cycle perspective, an environmental focus, a relative approach and functional unit, an iterative approach, transparency, comprehensiveness, and priority of scientific approach [8]. The method can be utilized by industry, government bodies and academia (often in collaboration) for strategic planning, product improvement and marketing.

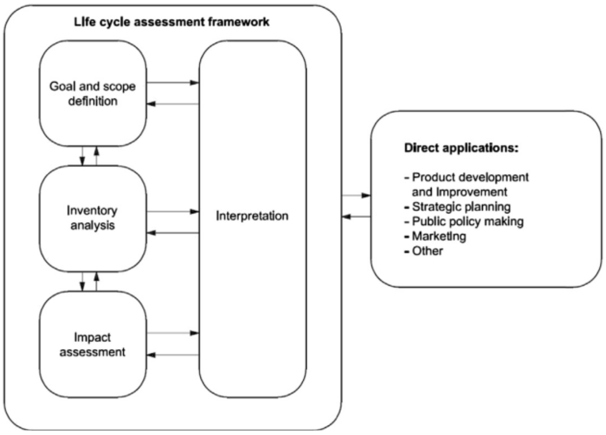

Figure No 1 : Phases in the Life Cycle Assessment Framework. Source: NEN-EN-ISO 14040:2006 (en) reproduced with permission from NEN, Delft,www.nen.nl.

The Life Cycle Assessment framework can be traced back to Resource and Environmental Profile Analysis methods conducted in the 1960s. The basis for the modern day LCA was then formalized in the early 1990s by the Society of Environmental Toxicology and Chemistry (SETAC), culminating in the SETAC code of practice in 1993 – defining terminology, framework and methods. The

SETAC code of practice was superseded by a series of standards from the International Standards Organization (ISO) over the course of 1997 to 2000. These standards were categorized under the environmental management standards – the 14000 series. In 2006 these standards were revised to the form that is utilized currently, where ISO 14040:2006 provides the principles and framework and ISO 14044:2006 details all steps of an LCA in one standard [9] .

B. Goal definition and scope

The ISO standards for LCA require practitioners to provide clear goals and a well-defined scope. The specified goals influence decisions related to all phases of the LCA method. Goals are determined by the research questions asked (why the assessment is to be carried out), intended application (what) and target audience (who) of an assessment; all of which are interrelated. Research questions are defined based on the reasons and decision context of an assessment. Intended applications can be a combination of: policy development, benchmarking, 'hotspot' identification, developing product 'footprints', product comparison, trade-off analysis, scenario analysis and methodological developments (e.g. improving metrics for water use). Target audiences can be a combination of policy makers, decision makers in industry, customers or academics. Goal definition must also incorporate details on limitations, whether will be used for a comparative assertion that will be disclosed to the public, and which organization commissioned/supported the LCA [8].

The purpose of FU is to lay the groundwork for providing a reference unit to which the inventory data is standardized [10]. The choice of functional unit can have a significant impact on the resulting impact assessment [11].

The system boundary of an assessment sets out what stages of a life cycle will be incorporated, as well as the temporal and geographical bounds. An LCA of a full life cycle will include all production stages from raw materials (referred to as the cradle) to disposal (the grave), whereas other LCAs may include a limited range of production stages.

C. Life Cycle Inventory Analysis (LCI)

It is considered as the most intensive phase in comparison to other phases in a Life Cycle Analysis (LCA), mainly by virtue of data collection. The life cycle inventory points out the identification and quantification of the inputs and outputs of each elementary process according to the reference flow. In consequence, it is an inventory of elementary flows (energy and materials) and emissions (pollutants, waste, water discharges, etc. [12].

The Life Cycle Inventory (LCI) phase of an LCA involves the compilation of data to quantify resource use and emissions for each process in the defined system. A Life Cycle Inventory can be compiled in a spreadsheet, statistical package, dedicated LCA software (such as openLCA, SimaPro and Gabi). The LCI is often designed to allow a sensitivity analysis to be carried out in the Life Cycle Impact Assessment (LCIA) stage.

An LCI can draw upon multiple sources, including: primary data, academic literature, LCI databases and expert opinion. The source used will depend on the specificity required for the assessment.

D. Impacts Assessment (or Life Cycle Impacts Assessment (LCIA))

The Life Cycle Impacts Assessment (LCIA) is designed to understand and assess all potential environmental impacts, which are based on inventory analysis, within the scope and objective of the study. In this phase, the results of the inventory are attributed to different categories of impact, in relation to the types of impacts expected on the environment. The impact assessment of LCA consists of the following elements: classification and characterization, and optional elements: standardization, weighting grouping and data quality analysis [13].

Assessing the sensitivity of data and modelling choices on the estimated environmental impacts is an important aspect of the transparency principle of LCA. A sensitivity analysis will quantify the extent to which an LCI entry or modelling choice influences LCIA results. The uncertainties characterized in the LCI phase are important inputs into this process.

E. Interpretation

The interpretive stage is composed of making various analyses at different levels that can back up a decision or can provide an easily understandable result of a Life Cycle Assessment (LCA). It must meet the objectives of the study identified in the first step with the intention of proposing recommendations. At this stage, it is also of paramount significance to identify the relevant solutions for redesigning the product according to the quality of the data. It is therefore about analyzing the results; complete control, sensitivity check and consistency check [13].

The utility of a Life Cycle Assessment depends on the interpretation and communication of results. The communication of results must also be accompanied with a summary of the goal and scope, Life Cycle Inventory and Life Cycle Impact Assessment phases. The target audience will influence how results are presented.

III. Result

A. Goal definition and scope

The objective of the study was to evaluate the environmental impacts of the manufacturing industry of IP wiring cable’s restraints in Morocco, to compare the associated impacts with sub-processes and to distinguish the most polluting category. In our studies, the functional unit is a production of one instrument panel IP cable (RHD).

The instrument panel (IP) is a control panel located directly ahead of a vehicle's driver, displaying instrumentation and controls for the vehicle's operation (figure 2). This cable harness is an assembly of electrical cable or wires, which transmit signals or electrical power.

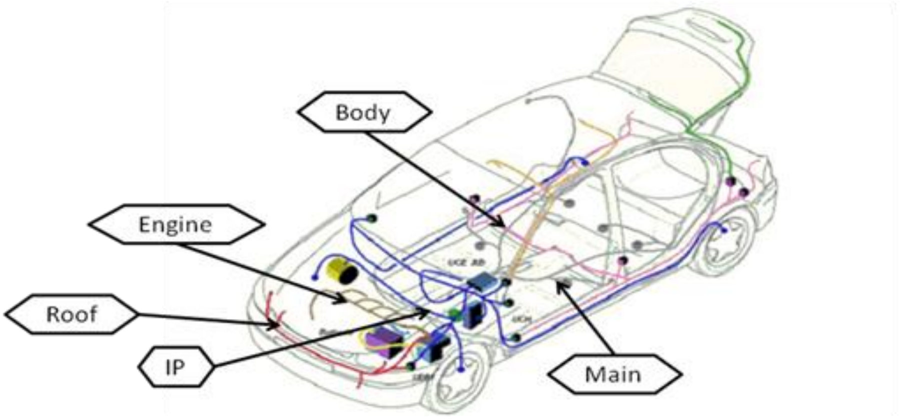

Figure No 2: Wiring Harnesses of a vehicle

As depicted in figure 3, the system boundary of the products relies on a gate-to-gate approach, starting with the receipt of the raw material, the stages of production up to the point where the product is ready to be distributed to automobile wire harness makers. Regarding manufacturing wastes, the system boundary doesn't include waste processing up to the end of waste state or the disposal of final residues.

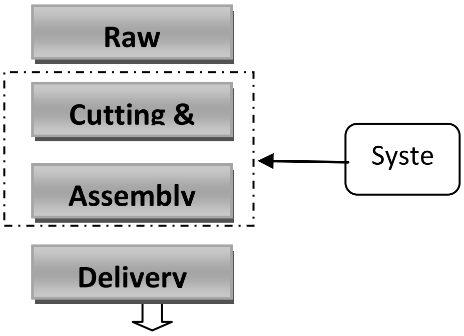

Figure No3: Production diagram of a cable

The manufacturing process was divided to two stages: 1) Cutting and lead prep, 2) Manufacturing & Wiring Assembly.

Stage 1 comprises the following process:

- Cutting individual wires, to the desired length
- Marking wires with a special machine
- Crimping terminals into one or both sides of the wire
- Soldering of wire ends
- Partial plugging of wires profited with terminals into connector housings
- Twisting wires

Stage 2 includes the processes of manufacturing, as briefly described below:

- UCAB & Ultrasonic splicing welding applied to work pieces being held together under pressure to create a solid waste weld.
- Plug terminals in connectors, used to join terminations and create an electrical circuit.
- Special cable assembly and wires distribution in boards.
- Manual taping.
- Body clips and cable channel assemblies and electrical test.
- Electrical control process.
- Labelling and packing.

A functions diagram explains the process of IP's cable, each block in the figure (figure 4) represents the operations involved in manufacturing from receiving through finish goods.

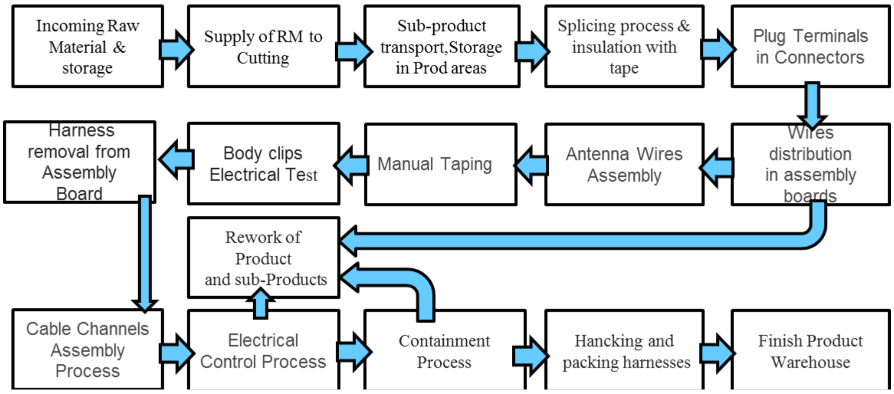

Figure No 4: Process flow diagram PFD of instrument panel (IP) cable

Data regarding the cable manufacturing processes was provided by the manufacturing company, including the consumption of raw materials as well as the information concerning the production of finished product and wastes. The data were collected by direct measures, mass balances or through annual accounting data of the company. For reasons of confidentiality, the manufacturing company name cannot be disclosed.

B. Life Cycle Inventory Analysis (LCI)

In this phase, all the inputs and outputs occurring in the life cycle of the systems previously defined are inventoried to perform a quantitative description of all flows of materials across the system boundary either into or out of the system itself.

Inventory table for RHD IP cable is provided in table 1, representing the quantity of each material that made up a wiring harness and the nature of each composition.

Type	Quantity (per category)	UoM (only P, M, G, R)	Material Specification (only P, M, G, R)	Quantity of MS (per category)	UoM (only P, M, G, R)
Connector	26	P	Polybutylene terephthalate PBTP GF30	606,35	g
Clip	54	P	Polyamide PA	4,3	g
Bracket	1	P	Polyamide PA66 GF30	19	g
Subassembly	1	P	DACAR 535/536 : Cu tinned /PVC-AL/C-shield	70	g
Eyelet	6	P	ALLOY CuSn4	30,66	g
Tape	41,692	M	Polyvinyl chloride PVC	41,692	m
Wire	231,315	M	small size (0,13;0,35;0,5;0,75)	214,94	m
Wire		M	big size (1;1,5;2;4;6)	16,375	m
Terminal	8	P	Tin	35,2	g
Conduit	0,23	M	POLYPROPYLENE PP	0,230000	m

Table No1: Composition of instrument panel (IP) cable

Figure 5 shows the life cycle diagram of the cable. The elementary products and generated waste were considered in the following life cycle phases.

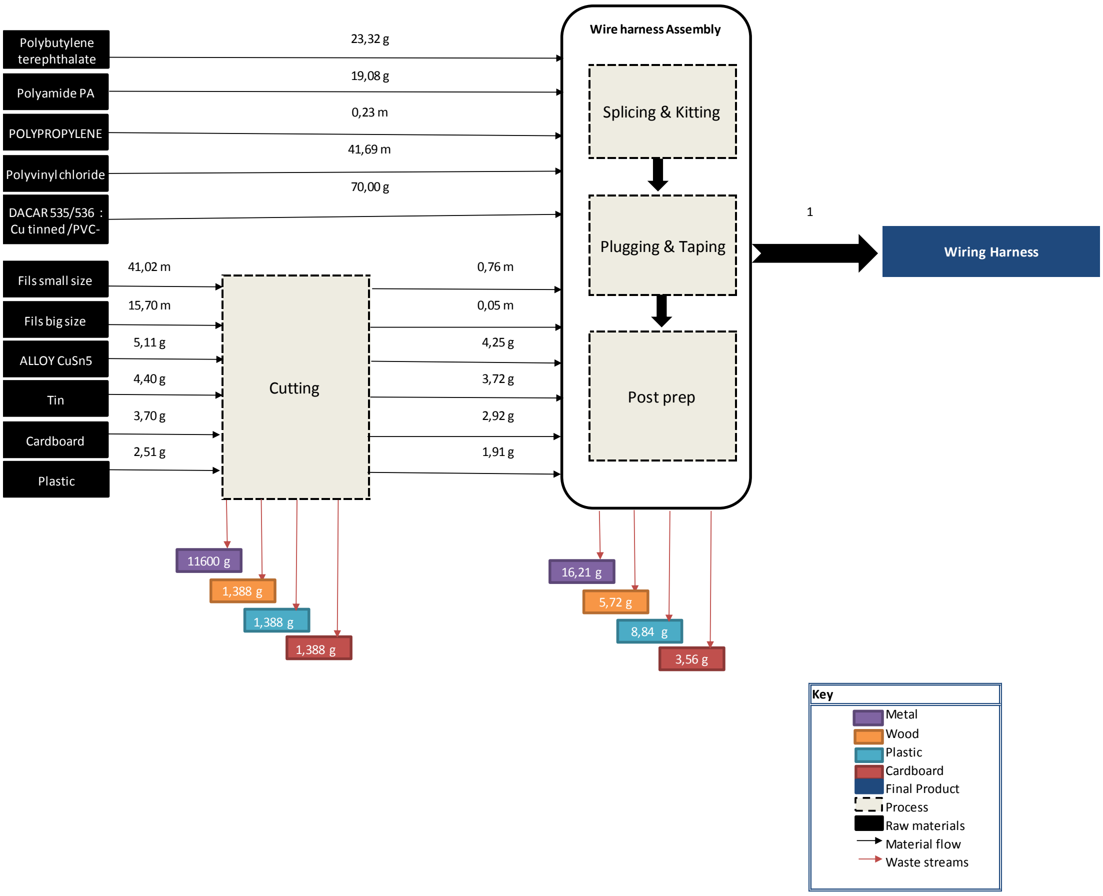

Figure No5:Life cycle flow chart and inventory data of instrument panel (IP) cable, expressed per FU

According to ISO guidelines (ISO,2006b), allocation should be avoided by dividing unit processes into one or more sub-processes in order to obtain data related to them. Hence, this procedure was applied to the manufacturing process, in particular for the raw materials, packaging materials, as well as the scraps produced. Nevertheless, it should be noted that the transportation of these wastes until the recycling site wasn't included.

C. Impacts Assessment (or Life Cycle Impacts Assessment (LCIA))

There are differences in the way methods define them. Some distinguish between various detailed impact subcategories like CML, which considers five impact subcategories according to different reference environmental compartments: soil, fresh- and marine water, freshwater and marine water sediments; some other methods, like Ecoindicator 99 or TRACI consider only one single, more general, impact category: "eco-toxicity".

The CML method [14] developed by the Centrum foorMilieukunde in Leiden, Netherlands (CML) was chosen to assess inventory flows for the impact categories: global warming potential, acidification potential, eutrophication potential and photochemical ozone creation potential, which restrict quantitative modelling to relatively early stages in the cause-effect chain.

Background data for the wiring harness system as well as the reference system were taken from the ECO-Invent integrated database. Wiring harness system modeling, data administration, classification, characterization, analyzing and weighting were done with OPEN LCA software.

In our framework, the list of the selected impacts in the study is the following: climate change, human toxicity, terrestrial ecotoxicity, respiratory effects, depletion resources mineral extraction and non-renewable energy. The results of the simulation show in figure 6 and figure 7 respectively.

Figure 6 shows the impact and characterization results for each process of fabrication.

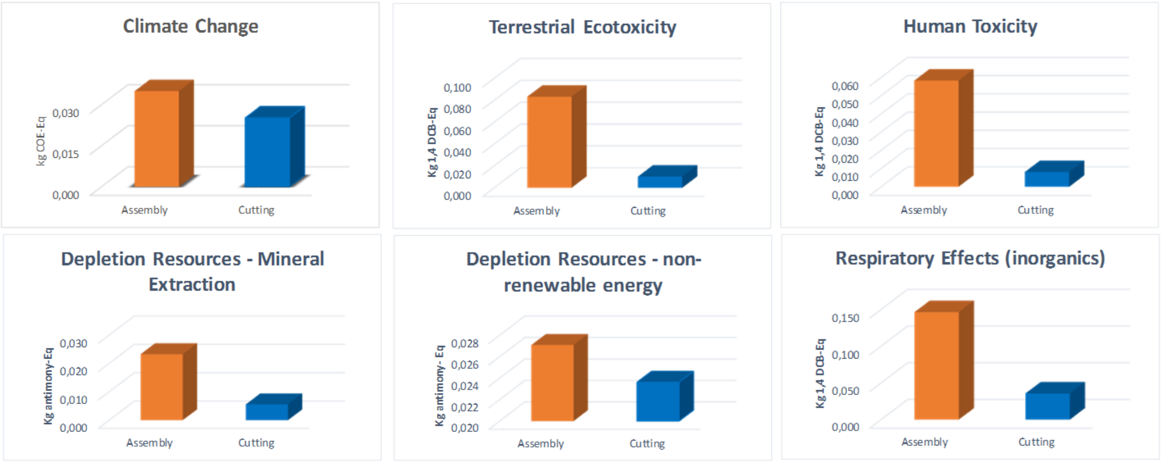

Figure No 6: The Environmental Impacts in manufacturing process of a wiring harness

Figure 7 shows the hot spot category impact of the input elements that is included in system boundary.

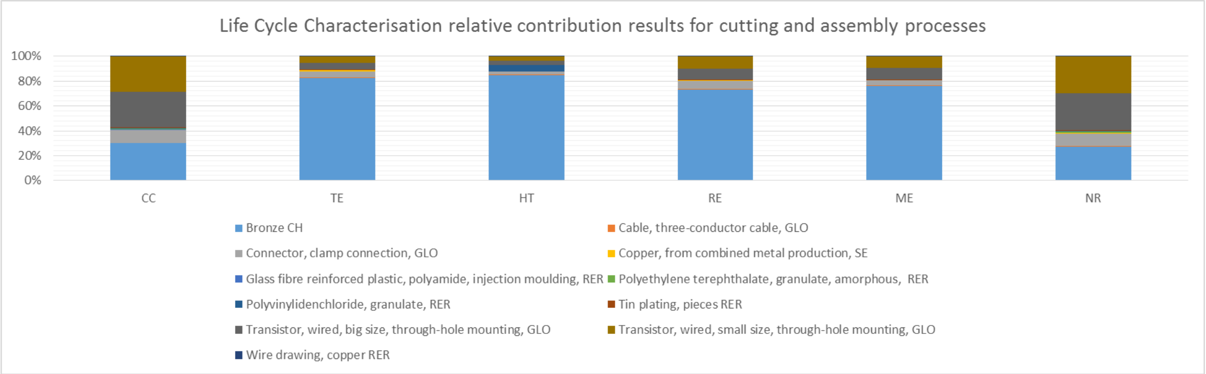

Figure No 7: The hot spots category impact in assembly process of a wiring harness

IV. Discussion

As presented in Figure 6, the cutting process was almost negligible in all impacts categories. However, the assembly process was the stage with the largest environmental burdens for all impact categories, such as:

- Climate change (CC) has an impact of about 0.035 Kg CO2-Eq,
- Resource depletion – mineral extraction (ME): 0.023 kg antimony-Eq,
- Resource depletion – non-renewable energy (NR): 0.027 antimony-Eq,
- Toxicity (HT) : 0.058 kg 1,4-DCB-Eq,
- Respiratory effects (RE):0.146 kg 1,4-DCB-Eq,
- Terrestrial Ecotoxicity (TE): 0.083 kg 1,4-DCB-Eq,

The impacts from the assembly process are dominated by bronze consumption, accounting for 25% (CC), 80% (TE), 85% (HT), 70% (RE), 77% (ME), 23% (NR), in term of relative impact contribution as mentioned in figure 7. Furthermore, the cooper and transistor utilization presented also significantimpact contribution. The remaining materials (Polyethylene, polyvinylidenchloride, polyamide, connector,tin plating) were not relevant, as they accounted for less than 5% on average.

As far as the other manufacturing processes are concerned, the cutting process express approximately the same values of the environmental impacts in the different categories. The most important impact in the considered system boundary are the bronze and the cooper.

This study has reached the intended aim as it allows to fully understand the environmental impacts at each stage of production and manufacture of a harness wiring and to specify the most important stressors. On top of that, it was possible to observe that:

- The most impacting process for a harness production that is the assembly because of the use of metal materials.
- The important impact generated by the input/output elements included in the assembly process, is the bronze, the cooper followed by plastics.
- The most significant categories of impacts are climate change, ecotoxicity and toxicity.

The figure 8 shows the global impacts of a harness manufacturing from the receipt of the raw materials to the final product (gate to gate). It turns out that the automotive industry has a set of impacts on the environment in the production and manufacturing phase.

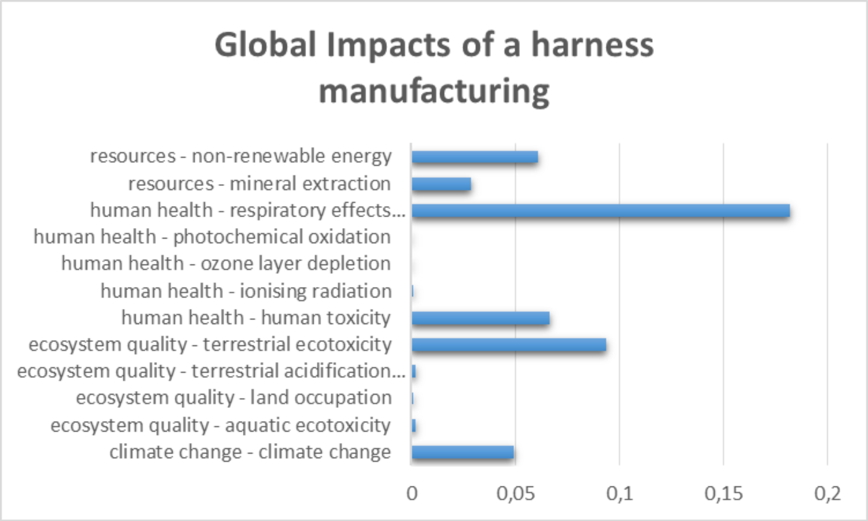

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Figure No 8: Global impact of manufacturing a wiring harness

V. Conclusion

This study allowed the evaluation of the environmental impacts related to wiring harness manufacturing, applying the Life Cycle Assessment (LCA) methodology.

The selected functional unit is one instel panel harness. A fixed composition for right hand harness was chosen. The results obtained from the impact assessment phase, carried out according to the CML method, clearly show the impacts categories such as climate change, resource depletion, ecotoxicity and human health.

LCA allowed us to compare between the different manufacturing processes and shows which is mainly stressing the whole production.

The assembly process of wiring harness was found as the main contributor, followed by cutting process. The effective impacts of assembly stage are mostly due to the bronze use, then to the utilization of cooper and to the plastics losses.

Despite the results obtained for the wiring harness, there is still possible to reduce the impact for manufacturing stage. While there is pressure on the environment there will be an ongoing need to conduct LCAs to inform decision making. The snapshots and scenarios of today will need to be revisited and extended to suit future contexts and a wider geographical scope.

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Hanaa ABOULJALIL, et. al. "Life cycle assessment of manufacturing processes of a cable harness in Morocco." *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 14(11), (2020): pp 19-27.