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EVALUATION OF ENVIRONMENTAL IMPACTS: COMPARATIVE ANALYSIS OF AN ELECTRIC WIRING HARNESS USING DIFFERENT LCA IMPACT METHODS

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ABSTRACT

Green processes have received growing interest by industries, governments, and researchers during the last years, in which the concept of sustainability has become the key point. There are different software tools and methods to perform Life Cycle Assessment (LCA) and results may be different according to which method the user chooses. This paper aims to present how different LCA results can be achieved due to the use of different LCA methods for the same product system. The present study focuses on analyzing three LCA methods on the same software Open LCA: CML9901, Impact 2002 and Eco indicator 90. The results were discussed and compared in terms of modelling principles, hotspots, and impacts for each method. The selected midpoint impact categories were: acidification, climate change, ecotoxicity and human toxicity. In many cases, modelling principles were identical among the software tools or nearby so, but results reveal differences for the implementation of the impact assessment. Some of these differences were so large that they could influence the LCA decisions and conclusions.

Keywords: life cycle assessment, wiring harness, automotive industry, environmental impact, LCA comparative assessment.

1. INTRODUCTION

From an environmental viewpoint, it is becoming increasingly important to analyse the potential impact of products and actions [1-3]. The Moroccan automotive industry has risen to sustained levels of growth over the last decade. Therefore, solid waste management is one of the major environmental problems threatening the Moroccan Kingdom Mediterranean. More than 5 million tons of solid waste is generated across the country with an annual waste generation growth rate touching 3 percent [4]. The problem of solid waste has been interpreted in several ways inside the LCA community, leading to the development of significantly different characterization factors for each LCA impact method.

Consequently, a user's choices of impact method may over- or deemphasize the depletion impact of a particular resource [5]. A significant number of studies have analysed and compared the various impact methods available, to contribute with informed selection, and development of more comprehensive ways to assess resources in LCA, including ([5]; [6]; [7]; [8]; [9]; [10]). Most of these studies state that there is no one single method that can be applicable to all case studies, but rather that there are advantages and disadvantages to all methods, and thus their selection must be done with care, understanding the approach, assumptions, and limitations inherent to each method. Non-specialists and persons with only a passing knowledge of LCA often ask why different results may be obtained when different Life-Cycle Impact Assessment (LCIA) software tools are used, and whether the degree of uncertainty in results is high enough [11] to cast doubt on the scientific arguments put forward. The research described here seeks to examine the differences between various environmental impact assessment tools based on the results obtained when they are applied to a wiring harness.

In this paper, three different LCIA software tools are compared using Open LCA software:

- CML 2001 [12], developed by the Institute of Environmental Sciences of Leiden University.
- Eco-indicator 99 (EI99), the first endpoint impact assessment software tool which allowed the environmental load of a product to be expressed in a single score [13];
- IMPACT2002, which proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results via 14 midpoint categories [14].

For common or skilled LCA practitioners who consider purchasing or applying this type of advanced software to assist in performing a quantitative environmental LCA, a natural question is, "Does it matter which software I choose?" The purpose of this paper is to investigate that question.

2. AIMS AND SCOPE

The ISO standards for LCA require practitioners to provide clear goals and well-defined scope. The specified goals influence decisions related to all phases of the LCA methods.

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.

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The aim of the current study is 1) to identify the environmental hotspots of the production of a cable in three different tools, 2) to evaluate the potential impacts associated with identified inputs and releases, and 3) to clarify how to select the different methods can influence the total results.

3. MATERIALS 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 (Figure-1) [15]. The principles set out in the ISO standard (14040:2006b) [16] 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 [17]. The method can be utilized by industry, government bodies and academia (often in collaboration) for strategic planning, product improvement and marketing.

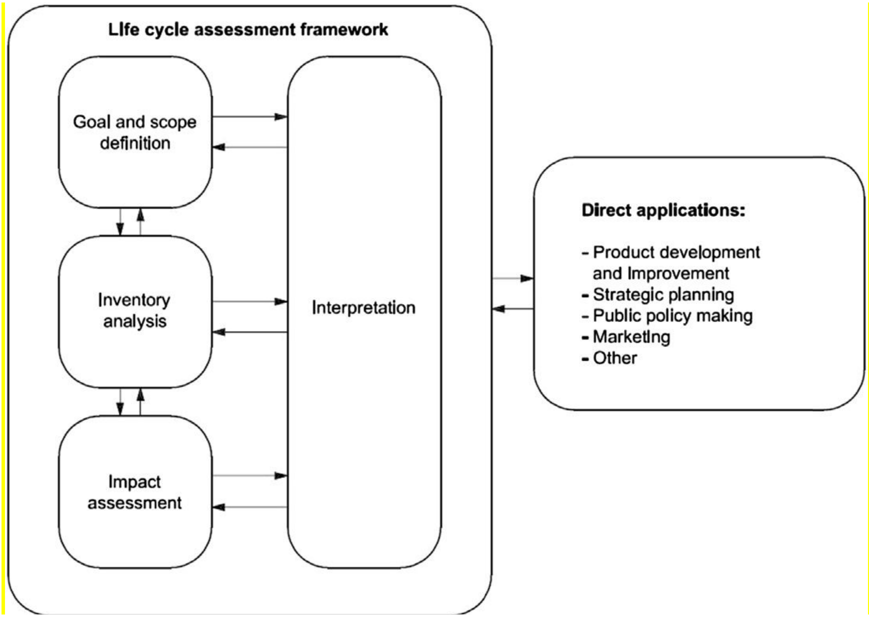

Figure-1. Phases in the life cycle assessment framework. Source: NEN-EN-ISO 14040:2006 (en) reproduced with permission from NEN, Delft, www.nen.nl.

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) throughout 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 [18].

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 policymakers, 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 [17].

The purpose of FU is to lay the groundwork for providing a reference unit to which the inventory data is standardized [19]. The choice of the functional unit can have a significant impact on the resulting impact assessment [20].

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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.

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 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. [21].

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 open LCA, 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.

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, concerning 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 [22].

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.

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 to propose 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 [22].

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

C. LCIA Software Tools

The modelling of the environmental impacts derived from the activity was carried out with the openLCA free software [23], and the Ecoinvent 3.3 database [24]. The modelling of the processes that give rise to each of the inventoried flows has been selected from among the processes available in Ecoinvent, making the appropriate adjustments to adapt them to the context of the Wiring harnesses.

The selection of the impact methods is made based on two criteria: (i) at least one impact method per focus group, to be sure that all different approaches are covered in the comparison, and (ii) widely documented methods and applied divers to case studies, to facilitate the comparison and understanding of different outcomes obtained.

Three different LCIA software tools were examined:

- CML 2 baseline 2000 V2.03/World, 1990
- Eco-indicator 99 (E) V2.03/Europe EI 99 E/E
- IMPACT2002þ V2.02/IMPACT2002þ

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 consider only one single, more general, impact category: “eco-toxicity”.

The CML method [25] developed by the Centrum for Milieukunde 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.

Within this research the Eco-indicator 99 is used a damage-oriented method. Of all the emissions, extractions and land use in all processes, the damage they cause to human health, ecosystem quality and resources are calculated. In the end, these three categories are combined into a single score [26]. One of the advantages of the single score output of the Ecoindicator 99 method is that it makes it relatively easy to compare different components.

The life cycle impact assessment (LCIA) was calculated at the mid-point and damage level using the IMPACT2002þ method [27], becauseIMPACT2002þ

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model is one of the most widely used models in LCA analysis, the fate exposure inconsistent way based on multimedia modelling.

4. RESULTS

A. Goal Definition and Scope

A significant number of studies have analyzed and compared the various impact methods available, to contribute with informed selection, and development of more comprehensive ways to assess resources in LCA, including ([6], [7], [5], [8], [9], [10]). Many of these studies state that there is no one single method that can be applicable to all case studies, but rather that there are advantages and disadvantages to all methods, and thus their selection must be done with care, understanding the approach, assumptions and limitations inherent to each method.

Some papers, such as [28], have looked at the evaluation of environmental impacts of the manufacturing industry of IP wiring cable restraints in Morocco, to compare the associated impacts with sub-processes and to distinguish the most polluting category, using one method impact CML. This paper aims at covering the gap identified in the previous studies, by performing a comprehensive life-cycle assessment for the same wiring harness by selecting 3 different methods. This paper includes a methodological analysis on life cycle impact methods, to clarify how selecting among the different methods can influence the results to total depletion impact. 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.

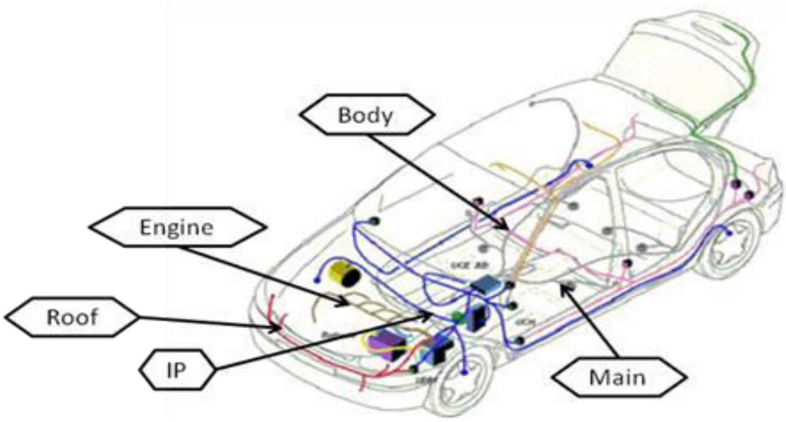

Figure-2. Wiring Harnesses of a vehicle.

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 the waste state or the disposal of final residues.

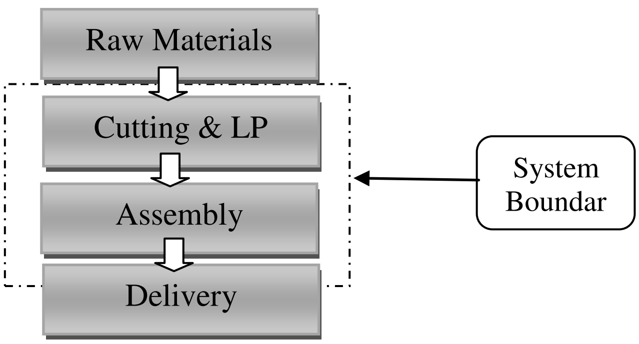

Figure-3. Production diagram of a cable.

The manufacturing process was divided into 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 were applied to workpieces 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.

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- 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.

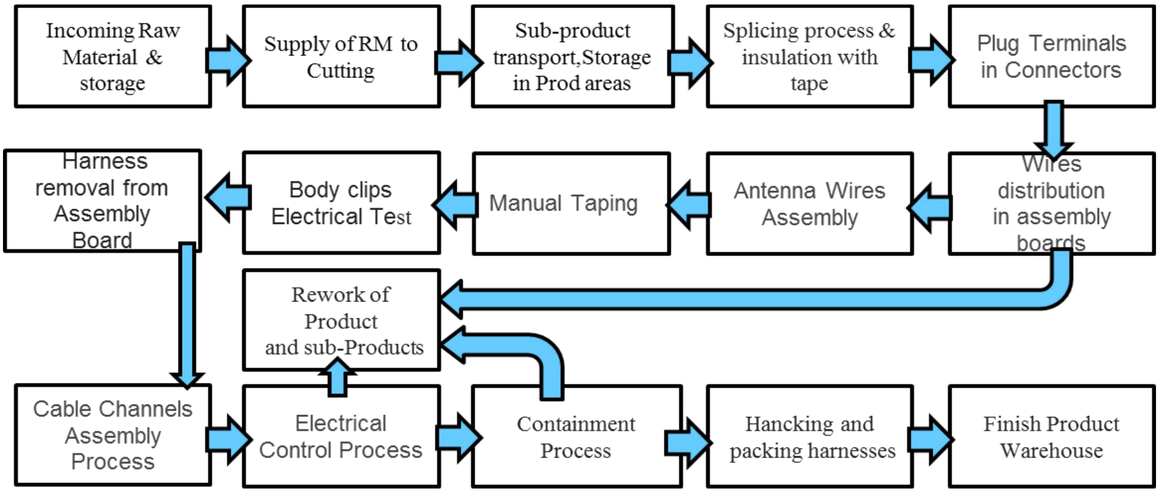

Figure-4. Process flow diagram PFD of instrument panel (IP) cable.

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 products 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.

Table-1. Composition of instrument panel (IP) cable.

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

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

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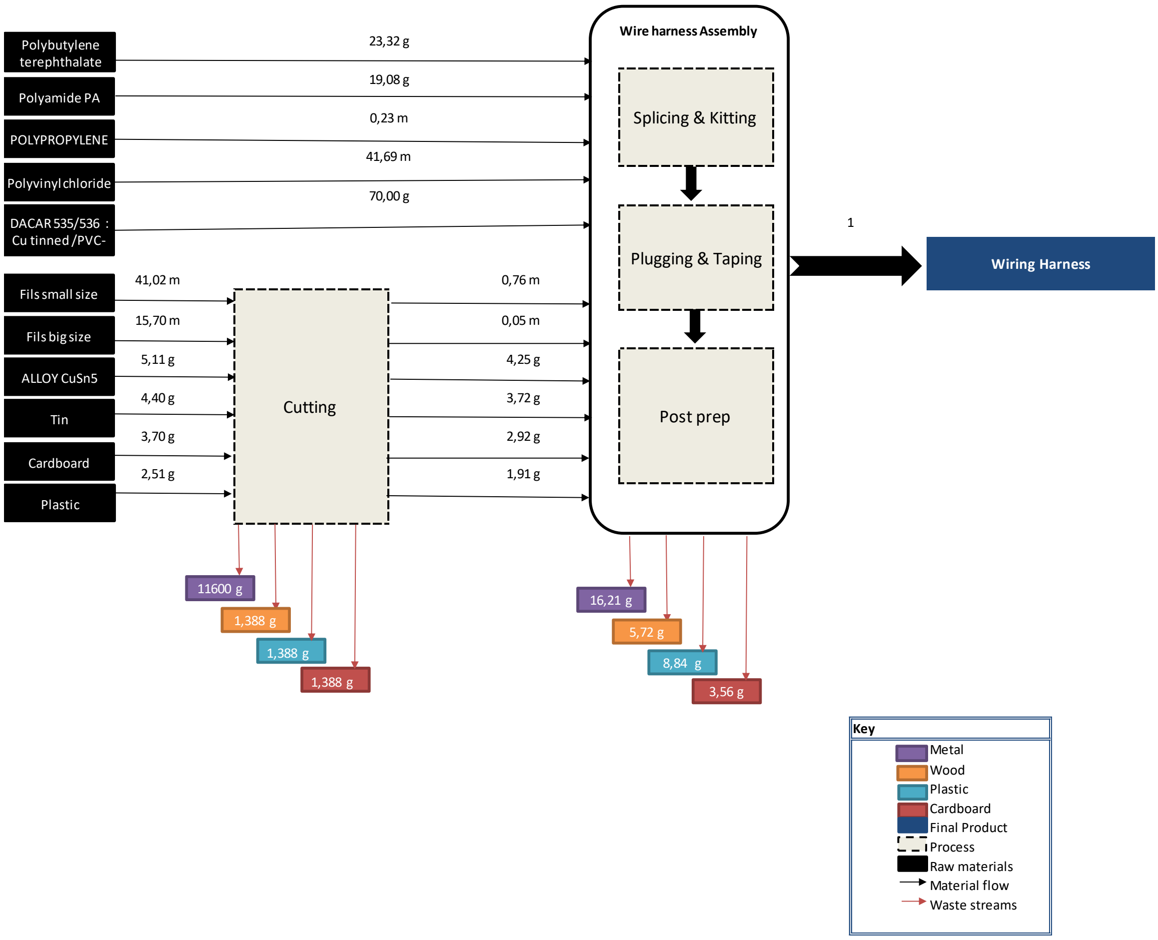

Figure-5. Life cycle flow chart and inventory data of instrument panel (IP) cable, expressed per FU.

According to ISO guidelines (ISO, 2006b), the 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". For this study, three methods have been selected to represent the different approaches to wiring harness resources. These methods include Eco-indicator99, Recipe2008, and Impact2002.

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, analysing and weighting were done with OPEN LCA software.

In our framework, the list of the selected impacts in the study is the following: Ecosystem Quality change, human toxicity, depletion resources. The results of the simulation shown in Figure-6 and Figure-7 respectively.

Figure-6 shows the environmental impacts of each LCA software tool.

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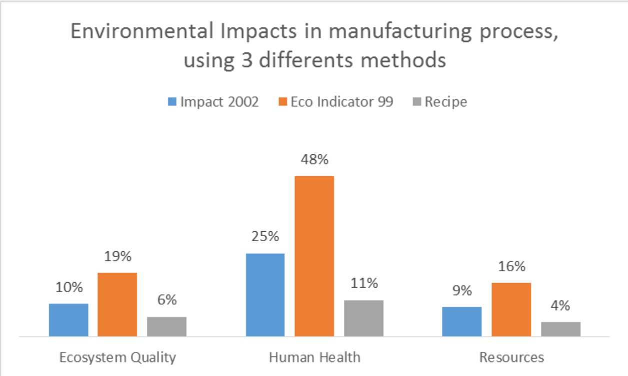

Figure-6. The environmental impacts in the manufacturing process of a wiring harness.

Figure-7 shows the Normalized characterization factors for selected impact methods and critical metals in the manufacturing of the IP wiring harness.

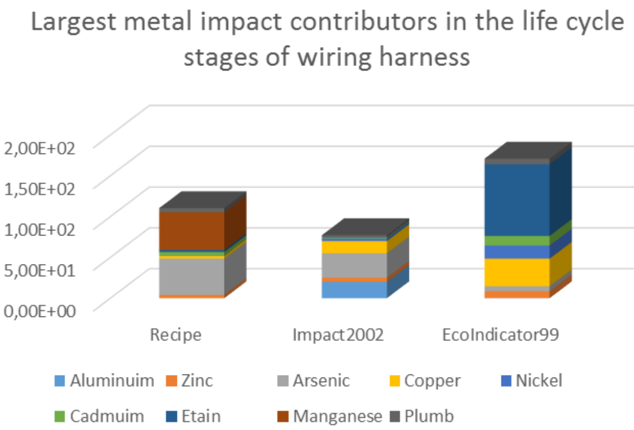

Figure-7. The largest metal impact contributors in the LCA of a wiring harness.

5. INTERPRETATION AND DISCUSSIONS

As presented in Figure-6, the most significant categories of impacts are Human Health Toxicity in the different tools, followed by Quality Ecotoxicity. The depletion of the resource was almost negligible in all impact methods. The results on the Environmental impacts made by the wiring harness' manufacturing are so coherent, even if they don't provide the same values.

Figure-7 shows in detail the top metals responsible for the overall impact on life cycle of the wiring harness. The largest contributors, metals are identified as Arsenic in Recipe and Impacts 2002 methods, followed by Manganese and Copper.

Precious metals appear among the largest contributors of environmental impacts, namely Arsenic and Manganese, except for the Eco-indicator99method which lacks CFs for these metals. The Eco-indicator99 presented significant metals as Etain, Copper and Cadmium. This method has a higher variability comparing to the other methods due to the absence of CFs for a considerable number of metals.

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.

The selection of impact method for the evaluation of wiring harness should consider the goal of the assessment, the approach proposed by the method, and the identified gaps of CFs in some of the methods used. The results obtained should also be communicated in terms of the approach applied, together with its assumptions and limitations.

6. CONCLUSIONS

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 instelpanel harness. A fixed composition for right-hand harness was chosen. The results obtained from the impact assessment phase clearly show the impacts categories such as climate change, resource depletion, ecotoxicity and human health. The objective was achieved by analyzing three LCA software tools: Eco Indicator 99, Recipe and Impact 2002, which are the most used tools for LCA modeling.

This paper aimed to present how different LCA results can be achieved due to using different LCA software tools for the same product system and considering the same goal and scope definitions. The analysis of the current software tools points out some shortcomings, namely:

- The most significant categories of impacts are Human Health Toxicity, the effective impacts of the assembly stage are mostly due to the metals use; Arsenic and Manganese with Recipe and Impact 2002, and Etain and Copper with Eco Indicator 99,
- There are different numbers of CFs and sub compartments in each software tool for each impact category, and this can generate different LCA results.

Further research could focus on providing cause-effect analysis of the problem to understand the root causes and to propose ways of dealing with them. Future research needs also to carry out to find optimal recycled materials which will not only help to reduce the negative environmental impact which causes during the wiring harness production phase but will also help to reduce waste materials. The snapshots and scenarios of today will need to be revised and extended to suit future contexts and a wider geographical scope.

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