Materials Today Communications 13 (2017) 192–209

Contents lists available at ScienceDirect

Materials Today Communications

journal homepage: www.elsevier.com/locate/mtcomm

Innovative composites and hybrid materials for electric vehicles lightweight design in a sustainability perspective

M. Delogu, L. Zanchi, C.A. Dattilo*, M. Pierini

Department of Industrial Engineering, University of Florence, via Santa Marta 3, 50139, Florence, Italy

ARTICLE INFO

Keywords:
Life cycle assessment
Composites
Hybrid material
Lightweight
Electric vehicles

ABSTRACT

Lightweight design and electrified powertrain have become important strategies in the automotive industry to reduce fuel demand and break down emissions respectively. Lightweighting of Electric Vehicles (EVs) is considered a step forward because advantages of both EVs and lightweight design could be combined to reduce environmental impacts even further. This paper would contribute to the advancement of knowledge in this field and it deals with the environmental analysis, by means of Life Cycle Assessment (LCA), of composite-based and hybrid material lightweight solutions for EVs modules in comparison with the corresponding reference ones, by assuming no changes in the powertrain system (e.g. battery resizing). Particular attention is given to primary data collection to build the environmental eco-profiles of four innovative composites. Then, a four-level approach to interpret LCA outcomes in a clear and comprehensive way is proposed in this paper. Despite the relevant mass reduction, environmental benefits are not registered for all the analysed solutions, and the main reason is the large impact from the production stage of the new materials, raw materials particularly. Outcomes from this paper showed that Abiotic Depletion Potential ($ADP_{el.}$) generally had a different trend if compared to Global Warming Potential (GWP) and Primary Energy Demand (PED) so their evaluation in parallel is recommended. Overall, the innovative materials that have a high impact in the production stage could not be suitable in the case of EVs where the emission rate in the use stage is lower than the one of traditional vehicle, so a different application should be also evaluated.

1. Introduction

Transport sector represents almost a quarter of Europe's greenhouse gas (GHG) emissions and is the main cause of air pollution in cities. In particular, road transport is by far the biggest emitter accounting for more than 70% of all GHG emissions from transport in 2014 [1]; moreover vehicles are responsible for a huge depletion of natural resources for materials and fuels production. In the recent years, the car manufacturers have been implementing several technical solutions to meet EU legislation requirements (2009/443/EC, 2000/53/EC, 2014/95/EU) and satisfy consumer expectations. One of the key challenge is the road transport decarbonisation [2]; at this regard, the main strategies to face this problem include alternative propulsion systems, mass reduction, aerodynamics and engine efficiency improvements [3].

Lightweight design has become an important lever in the automotive industry since it is proved to produce effective fuel demand reduction and emissions abatement. Lightweighting relies on mass vehicle reduction by means of material substitution, coupled with vehicle component redesign, while maintaining vehicle size and so satisfying consumer demand. The reduction of impacts from Internal Combustion Engine Vehicles (ICEV) by means of lightweight materials has been extensively examined in the recent years. In this context, Life Cycle Assessment (LCA) is the methodology mostly used to evaluate environmental impacts and compare alternative design solutions. Several studies have applied LCA to explore benefits stemmed from lightweight materials if compared to traditional ones in the ICEV design [4–9]. Many LCA studies examined the substitution of metals (generally steel) with fibre-reinforced plastics [9–13], while only a small number of works compared alternative composites solutions (i.e. bio-polymers and bio-composites) [14–16] and new metals alloys [17,18]. Steel is generally proved to provide a large potential for mass reduction and its replacement with high strength steel, advanced high strength steel or cast aluminium enables GHG emissions reduction since from the production stage. On the other hand, wrought aluminium, carbon-fibre reinforced plastic (CFRP) and magnesium yield relevant mass reduction but at the cost of GHG emissions increase during material processing. In other cases, LCA is used to evaluate environmental impacts of EVs over the traditional ones [19–21].

---

* Corresponding author.
E-mail address: caterinaantonia.dattilo@unifi.it (C.A. Dattilo).

http://dx.doi.org/10.1016/j.mtcomm.2017.09.012
Received 12 September 2017; Accepted 27 September 2017

Lightweighting of EVs could represent a step forward because advantages of both EVs and lightweight design could be combined to reduce environmental impacts even further [22]; in addition, the application of lightweight materials in the EVs is expected to be particularly profitable since mass reduction could improve performances in terms of drive distances and battery size containment [23]. Overall, still few works exist about this topic [24,25] and there is a great deal of room for improvements in this field. Indeed, present EVs are mainly based on ICEV architecture, expect for specific EV components and body reinforcements, thus resulting into a total high vehicle mass; exceptions are perhaps the Tesla Roadster and the BMWi models. In particular, the intrinsic qualities of composite materials and their integration in multi-material assemblies have not yet been explored. Unlike the advanced lightweight alloys, which offer moderate weight savings, novel CFRP solutions could bring stronger weight savings that making them particularly profitable for the EVs.

Developments on specific design methodologies and innovative production technologies are also supporting the multi-material design as a way to achieve further mass reduction [26]; however, the environmental consequences of hybrid design in comparison with monomaterial one is still unexplored, to the best knowledge of authors [27]. Consequently, the development and application of novel lightweight measures have become more important over the past years and advancements in materials research, and related manufacturing technologies, play an important role.

Due to the wide variety of materials and the different functional specifications of several vehicle modules, the material selection process needs to balance many aspects (technical performances and feasibility, materials recyclability, environmental impact of material production); this leads to face controversial issues and trade-off necessarily [18,25,27–29]. For instance, from an environmental point of view, the use of lightweight materials is often responsible for increase in the production stage impact, particularly materials processing, thus counterbalancing the expected benefit during use stage [25,27]. GHG emissions and life-cycle energy demand are generally the most investigated impact categories when lightweighting is addressed [25,27,30]; however, to investigate the sensitive trade-off between production and use stages, the selection of proper environmental impact categories, beyond these indicators, appears fundamental [16,24]. Defining a set of environmental indicators targeted to the given sector is generally debated as an opportunity to strength the LCA methodology and its role as a supporting tool in the early design phase of automotive products [19,29,31,32].

This paper deals with the environmental assessment, by means of LCA, of lightweight solutions specifically developed for EV components based on innovative materials belonging to four classes: thermoplastic matrix composites, fibre reinforced thermoset matrix composites, advanced hybrid materials and bio-composites made from renewables. Lightweight materials and their application were developed within the EU-project ENLIGHT according to a module-specific lightweight approach. The project aim was to advance highly innovative lightweight material technologies for application in structural vehicle parts of future EVs along four axes: performance, manufacturability, cost effectiveness and lifecycle footprint [23]. Therefore, this study provides real examples of composite-based and hybrid material design solutions for EV lightweight purpose. Besides their technical feasibility, their environmental performances are analysed by means of LCA in comparison with the corresponding reference solutions, by assuming no changes in the powertrain system (e.g. motor adaptation, battery resize). To comply with the requirements of data accuracy for an LCA, a particular attention is dedicated to primary data collection to build the environmental eco-profiles of the innovative lightweight materials and technologies, currently not covered by the commercial database.

Efforts are also dedicated to discuss and enlarge the environmental assessment to a diverse set of impact categories, in addition to the CO_2 emissions, according to the current research directions. A clear and complete visualization of results is considered fundamental for a comprehensive interpretation and to guide decision toward the best choice [24]. To enhance a structured and exhaustive interpretation of results, in this paper, a four-level approach is proposed. Global Warming Potential (GWP), Abiotic Potential Depletion elements ($ADP_{el.}$) and Primary Energy Demand (PED) will be looked into especially.

This paper is structured as follows: definition of the method and levels of LCA results interpretation (chapter 2); description of the lightweight solutions for the analysed EV components with particular regards to the innovative materials and technologies (chapter 3); goal and scope definition and inventory data (chapter 4); LCA results and discussion (chapter 5); conclusions (chapter 6).

2. Method

The method adopted in this paper mainly relies on a typical LCA structure (according to ISO 14040:2006 and ISO 14044:2006). Overall, the LCA was carried out within each module design workflow as well as materials development and technologies phases, representing powerful instruments to compare different design/materials/technologies alternatives and to orient towards sustainable solutions. In this paper only results concerning the finalized design solutions, and related materials, are reported. Therefore, first materials and manufacturing technologies are described in a way that allows identifying reasons behind their selection and reconstruct the processes involved in the materials processing and manufacturing to build their eco-profiles (paragraph 3.1). All the studied components are described (paragraph 3.2), then a description of all the relevant data and key parameters defined for the LCA elaboration are provided (paragraphs 4.1 and 4.2). The LCA was developed by taking into account directions from the International reference Life Cycle Data system (ILCD) handbook [33] and eLCAr project [31] providing guidelines for the LCA of EVs. Moreover, due to the presence of multi-material design solutions, a *breakdown approach,* consisting on the analysis of each mono-material part of the modules, is applied in order to guarantee data accuracy and enhance comparison between reference and lightweight solutions. As a consequence, LCA outcomes for each module are obtained as the sum of LCA of several mono-material parts. To comply with the requirements of an accurate and complete LCA results examination, a four-level flow chart guiding the results interpretation is applied (Fig. 1).

The first three levels – Life Cycle stages, Production stage and Break-even point – are generally present in the studies from literature, however they are often partially developed or not clearly structured, thus hindering a comprehensive results interpretation and comparison between works [24]. The fourth level, on the contrary, concerns new indicators to investigate the relationship between impacts and some design elements.

The first level (Level 1) concerns the analysis of the contribution of each Life Cycle (LC) stage – *Production,* including materials and

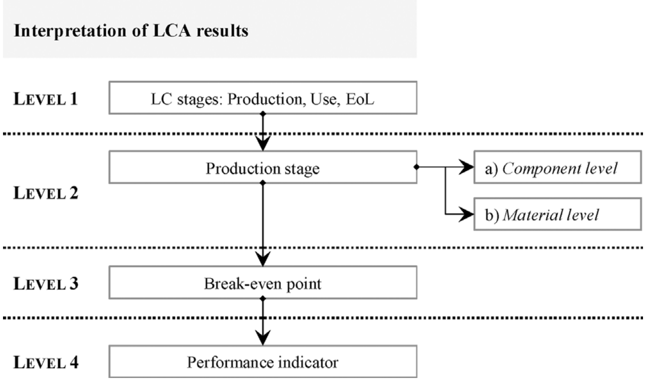

Fig. 1. Flow chart describing different levels of LCA results interpretation.