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Environmental performance of advanced hybrid energy storage systems for electric vehicle applications

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HIGHLIGHTS

- The environmental impact of advanced energy storage systems is assessed.
- The methodology used is Life Cycle Assessment following the ISO 14040 and 14044.
- Twelve impact categories are assessed to avoid burden shifting.
- Increasing the efficiency and extending the lifetime benefits the environmental performance.
- The results show that there are hot spots where to act and reduce the overall impact.

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ABSTRACT

In this paper the environmental performance of an advanced hybrid energy storage system, comprising high power and high energy lithium iron phosphate cells, is compared with a stand alone battery concept composed of lithium manganese oxide cells. The methodology used to analyse the environmental impacts is Life Cycle Assessment (LCA). The manufacturing, use phase and end-of-life of the battery packs are assessed for twelve impact categories. The functional unit is 1 km driven under European average conditions. The present study assesses the environmental performance of the two battery packs for two scenarios: scenario 1 with a vehicle total drive range of 150,000 km and scenario 2 with total driving range of the car of 300,000 km. The results of scenario 1 show that the increased efficiency of the hybrid system reduces, in general, the environmental impact during the use stage, although the manufacturing stage has higher impact than the benchmark. Scenario 2 shows how the extended lifetime of the hybrid system benefits the emissions per km driven.

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1. Introduction

Electric vehicles (EVs) are an emerging technology with the capability to increase vehicle performance and to reduce environmental impact of personal transportation [1]. Also, they have a more efficient drive train than conventional cars and may emit less CO_2 per kilometre driven, depending on the generation mix of electricity and the efficiency of the EV drive train [2]. The batteries needed for those cars must fulfil specific power and energy requirements: they are relatively small (15–20 kW h) with respect to their energy content, but they must provide significant peak power (up to 150 kW) required for acceleration, recuperation and sustain fast charging. Many researchers [3–7] (among others) have analysed different topologies of Energy Storage Systems (ESSs) on their applicability regarding electric mobility in terms of driving range, charging time and lifetime (which are the three major concerns within this topic). The mentioned studies are focused on models that optimise the energy management of the ESSs; their findings agree that the hybrid energy/power systems is crucial for saving energy, reaching high overall efficiency and enhancing system dynamics. Therefore, advanced energy storage systems are needed to provide both high power and reasonable energy density. Li-ion batteries have been perceived as one of the most promising options among the different battery chemistries because of its significant advantage in energy density [6], but they are required to be controlled during their charging/discharging operations to avoid harmful operative conditions, such as overcharge/discharge and cell voltage unbalancing [8]. A dual-cell battery comprising high power and high energy cells seems to be a promising option to fulfil the requirements of EVs; the concept includes an enhanced electronic architecture for an efficient energy and current

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distribution managed by a smart control strategy, to optimise use while reducing system degradation [9].

To perform the technology development of such storage systems it has to be considered not only technical aspects and cost but also the environmental impact of the final product [10]. In this study, the environmental performance of a hybrid energy storage system (HESS) is assessed; the methodology used to analyse the environmental impacts is Life Cycle Assessment (LCA). LCA is a tool which assists in identifying opportunities to improve the environmental performance of products at various points in their life cycle, and informing decision-makers in industry, government or non-government organizations on this matter [11,12].

The aim of the paper is to document the LCA of the developing novel battery topology compared with a stand-alone system including all the life cycle stages. Many authors [13–17] have assessed the environmental impact of different battery chemistries for EVs, those studies are always based on the comparison of different battery chemistries: lead-acid, nickel cadmium, lithium-ion, nickel-metal hydride, etc. They reckon on the manufacturing stage of the batteries excluding the influence of the use and recycling, only Notter et al. [15] include a full life cycle approach, nevertheless their results are compared with other vehicle technologies and not among different battery chemistries. Thus none of them aim at assessing improvements in environmental impacts of advanced designs of the storage systems for EVs and the majority does not consider the entire life cycle of the batteries. In the present study the environmental performance of a novel dual-cell battery display is assessed and compared to the current stand-alone battery systems. The life cycle stages included in the study are: manufacturing, use and end-of-life. The results show how the improvements made in the HESS help to decrease the environmental footprint during the life cycle of the battery packs for electric vehicle applications. The results also identify hotspots in the life cycle of batteries where further development should be carried out to improve the overall environmental performance of the product.

2. Goal and scope

The purpose of the present study is to assess the life cycle environmental impact of a HESS and to compare the results with a stand-alone energy storage system, for a comprehensive understanding of the environmental impacts of the assessed system. The main decision to be supported is whether the technology of the hybrid battery system contributes to a better environmental performance of battery packs for full electric vehicles. The defined functional unit is 1 km driven under European average conditions. The study is a process based LCA modelled with an attributional approach.

Two scenarios are assessed in this study. In scenario 1 the expected lifetime of the electric vehicle is 150,000 km, in this scenario it is assumed that at the EoL of the car both battery packs are considered as waste and therefore sent to the recycling plant. In scenario 2 the expected lifetime of the electric vehicle is 300,000 km; here it is assumed that once the stand-alone battery pack reaches the limit of cycles, the user replaces the battery pack by a new one of the same characteristics. Thus, when the defined driving range of the vehicle is reached, two battery packs of the stand-alone design are needed meanwhile the HESS will cover that range with one battery pack. Fig. 1 illustrates these two scenarios.

3. System details

In this section the description of the assessed products and life cycle stages analyzed in the study are documented.

3.1. Hybrid energy storage system

The hybrid system assessed in this LCA is focused on a smart control solution for traction batteries; the concept consists on: a dual-cell battery concept comprising high-power (HP) and high-energy (HE) cells; an enhanced electronic architecture for an

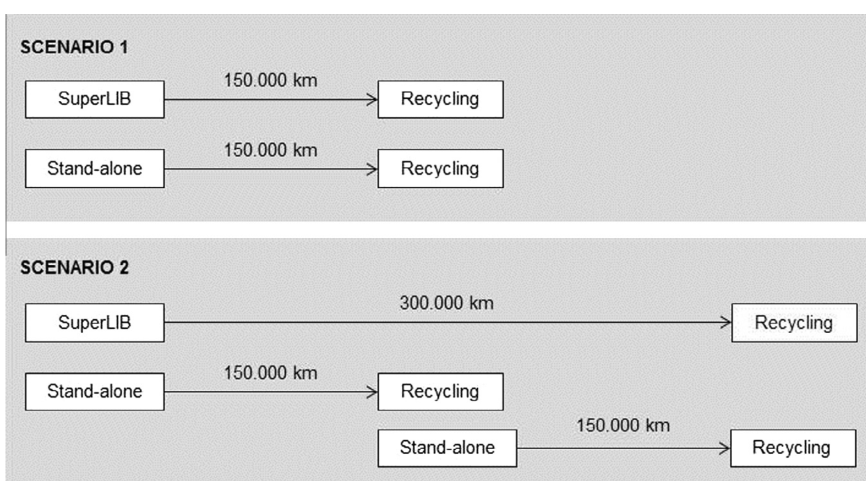

Fig. 1. Schemes of scenarios 1 and 2.

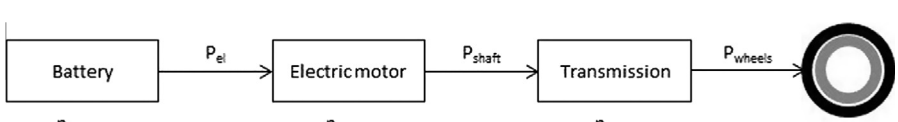

Fig. 2. Main elements and power flow inside an electric vehicle, where $\eta_{battery}$, η_{motor} and η_{trans} are the efficiency of the battery, the motor and the transmission respectively. P_{el}, P_{shat} and P_{wheels} are the power delivered from battery, motor and to the wheels.

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