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Primary and secondary use of electric mobility batteries from a life cycle perspective

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HIGHLIGHTS

- A life-cycle assessment of primary and secondary use of EV batteries is performed.
- Three scenarios of battery use in an EV are assessed, characterized by C-rate.
- Two residential energy storage strategies are analyzed: peak shaving and load shifting.
- Cycling the battery at 0.4C in the EV results in 42–50% less impacts per km than at 0.8C.
- Benefits of extending the life of the battery strongly depend on the electricity mix.

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ABSTRACT

With age and cycling, batteries used in Electric Vehicles (EVs) will reach a point in which they will no longer be suitable for electric mobility; however, they still can be used in stationary energy storage. This article aims at assessing the Life-Cycle (LC) environmental impacts associated with the use of a battery in an EV and secondly, at assessing the LC environmental impacts/benefits of using a battery, no longer suitable for electric mobility, for energy storage in a household. Three electricity mixes with different shares of renewable, nuclear and fossil energy sources are considered. For the primary battery use, three in-vehicle use scenarios are assessed, addressing three different driving profiles. For the secondary use, two scenarios of energy storage strategies are analyzed: peak shaving and load shifting. Results show that a light use of the battery in the EV has 42–50% less impacts per km than an intensive use. After its use in the vehicle, the battery life can be extended by 1.8–3.3 years; however, this is not always beneficial from an environmental point of view, since the impacts are strongly dependent on the electricity generation mix and on the additional efficiency losses in the battery.

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1. Introduction

Improvements in battery technology are likely to make possible the widespread use of Electric Vehicles (EVs) for personal mobility, since they are seen as one of the solutions to reduce global Greenhouse Gas (GHG) emissions, improve air quality, reduce crude oil dependence and increase energy security. The penetration rate of EVs is increasing and is expected that in the future a large share of vehicles will be battery powered [1–4]. Nowadays, both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs) use lithium ion batteries with a significant size/weight and capacity (from 10 kWh up to 85 kWh). These are responsible for a significant contribution to the overall emissions and energy consumption associated with the manufacturing and disposal phase of the vehicle [5,6].

Despite the fact that battery packs used in EVs are managed by a Battery Management System (BMS), to ensure that they operate within safe parameters and to maximize their life [7], these packs will reach a point when they will no longer be suitable to be used in an EV. When the capacity loss is so high, that the normal use of the vehicle is affected in terms of distance traveled per charge, the battery pack should be replaced.

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Giving a second life to a battery pack, no longer suitable for electric mobility, may bring environmental and economic benefits by extending the service life of the pack, since there is some capacity still available [8,9]. The use of a battery for energy storage in buildings tens to contribute to a more constant load diagram and may mitigate the environmental impacts associated with energy consumption, by storing energy from generation periods with lower impacts and using it in periods where energy production would have higher impacts (for instance, charging the battery at night, when the contribution from Renewable Energy Sources (RESs) is usually higher and supplying it during the day, when the contribution from fossil powered power plants is higher).

The objective of this article is two-fold: firstly, it aims at assessing the LC environmental impacts of a lithium-ion battery used in an EV (primary use); secondly, it aims at assessing the LC environmental impacts, or benefits, of using a lithium-ion battery, no longer suitable for electric mobility, for energy storage in buildings (secondary use). For the primary use, three in-vehicle use scenarios are assessed, which address three different driving profiles in terms of the stress imposed to the battery. For the secondary use, two scenarios of energy storage strategies are assessed: peak shaving and load shifting. Moreover, since environmental impacts in both primary and secondary use are influenced by electricity generation, several mixes within the European Union, with different shares of renewable, nuclear, and fossil energy sources, are considered. By assessing different electricity mixes and energy storage strategies, it is possible to identify the scenarios that are potentially more beneficial in terms of environmental impacts. The reminder of the paper is structured as follows: on Section 2 the life-cycle model for both primary and secondary use of the battery is presented, as well as the battery use scenarios for each application; on Section 3 the life cycle environmental impacts associated with both use phases are assessed; and on Section 4 conclusions are drawn.

2. System models and usage scenarios

The assessment of the environmental impacts of both primary and secondary use of the EV lithium-ion battery is performed by applying the Life-Cycle Assessment (LCA) methodology [10,11]. LCA is widely used to assess the environmental performance of products or systems, including batteries and electric vehicles [5,6,12–14]. It covers all the stages of a product life cycle, from raw material extraction to final disposal, including production of the product, distribution and use, and usually assesses several environmental indicators. In this article, the environmental impacts are assessed for the following impact categories from CML 2001 baseline [15]: Abiotic Depletion; Acidification; Eutrophication; and Global Warming.

Table 1
Efficiency along the electricity path, using a standard 240 VAC charger (L2), with lithium-ion batteries as energy storage. It should be noted that, for the overall system efficiency, the battery efficiency was accounted twice due to the charge and discharge cycles.

	Efficiency (%)
Transmission	98
Distribution	92
L2 Charger	96
Battery (L2 Charge/discharge)	90/95
Inverter	95

2.1. Life-cycle model of battery primary use - electric mobility

The system boundary of the battery LC model for the assessment of the environmental impacts from its primary use (in an EV) is presented in Fig. 1. The model includes the production of all battery components and the battery end-of-life, as well as electricity generation for vehicle operation. The functional unit is 200000 km, which is the predicted service life of the vehicle [16]. The number of batteries required to perform that function (i.e. the reference flow as described by the LCA methodology) depends on the conditions under which the battery is used. In order to capture different levels of stress imposed to the battery, three driving profiles are assessed, described in detail in Section 2.1.1.

The battery pack characteristics considered in the assessment, in terms of capacity and battery chemistry, are those from the Nissan Leaf battery. The battery pack uses Lithium Manganese Oxide (LMO) for the cathode material and graphite for the anode material. The main characteristics of the battery pack has a design capacity of 24 kWh with a cell specific energy of 114 Wh kg^{-1} and a total weight of 300 kg (more details in Table S-A.11 in the Supplementary data). A life-cycle inventory for the battery production is implemented, based on [17]. Recycling of the battery at the end-of-life (EoL) is assumed to be performed through a hydrometallurgical process [18], and data for the life-cycle inventory is based on [19]. The energy required for the battery dismantling is also taken into account, according to [20]. The production of the vehicle is not considered, since environmental impacts are the same for all scenarios addressed.

Impacts of the use phase (vehicle operation) are calculated taking into account the electricity mix impacts for the period of the day during which the battery is being charged. Two scenarios are considered for EV charging: at night (00:00–07:00) and during the

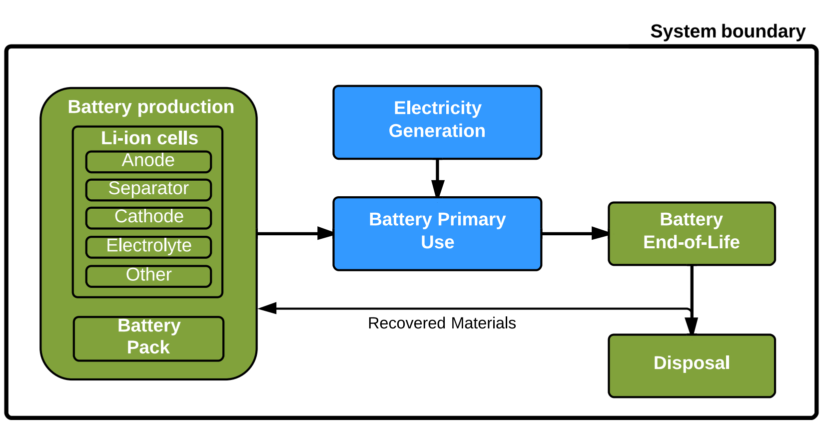

Fig. 1. System boundary of the battery life-cycle model for primary use (electric mobility).

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