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Second Life Application Scenarios of a Lithium Iron Phosphate (LFP) Electric Vehicle Battery: A Life Cycle Assessment Approach

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Summary

This work employs a life cycle assessment approach to analyze alternative second life application scenarios of a lithium iron phosphate (LFP) electric vehicle (EV) battery that no longer meets the requirements of automotive purposes in less demanding applications, in particular as stationary energy storage system in a smart building. The results obtained from the Eco-indicator 99 method demonstrate the environmental benefit from reusing the existing EV battery in the secondary application instead of manufacturing a new battery to serve the same purpose, as well as exemplify the dependence of the results on the energy source in the smart building application.

Keywords: energy storage, EV (electric vehicle), LCA (Life Cycle Assessment), lithium battery, second-life battery

1 Introduction

Despite the fact that electric vehicles (EVs) produce no tailpipe emissions during their operation, their environmental impact can be traced not only to the energy operational processes for generating electricity to charge the EV battery, but also to the life cycle of the battery itself, among others [1]. Hence, the environmental footprint of EVs can be fully captured by employing a life cycle assessment (LCA) approach [2]. However, the reuse of EV batteries in less demanding applications can extend the use phase of their life cycle, thus it is of particular interest for both academia and industry [3].

Nowadays, the most common battery type in EVs is based on lithium-ion (Li-ion) due to its distinctive characteristics in terms of high energy density, high power density, long life and little maintenance requirements, when compared to other battery technologies [4,5]. Relevant LCA studies show that Li-ion battery technologies produce substantial environmental impacts during their life cycle, including the manufacture phase. Specifically, the work in Ref. [5] concludes that the main contributors to the environmental burden caused by a lithium manganese oxide (LMO) battery are the supply of copper and aluminum in the production of the anode and the cathode, along with the required cables or the battery management system. In the same direction, the study of the environmental impact from the production of a

Li-ion nickel-cobalt-manganese (NMC) traction battery for EVs in Ref. [6] reports that the manufacture of battery cells, positive electrode paste, and negative current collector are the most impact-intensive production chains. To this end, significant research efforts have focused over the years on the development of alternative Li-ion battery technologies and use of novel materials to increase the energy density, e.g. silicon nanowires as anode material [7], yet enhancing their environmental performance remains an open research challenge.

On the one hand, a careful review of the literature reveals that relevant studies assess not only the performance characteristics, but also the environmental impact during the whole life cycle of Li-ion batteries for EV applications. More specifically, a comprehensive LCA study applies the ReCiPe method on a potential next-generation Li-ion battery with molybdenum disulphide anode (MoS_2) and NMC oxide cathode, concluding that the environment impact of the NMC-MoS_2 battery is higher in most impact categories compared to a conventional NMC-Graphite battery [8]. Some critical issues regarding the LCA of Li-ion batteries for EVs are examined in Ref. [9], confirming that it is environmentally preferable to use water as a solvent instead of N-methyl-2-pyrrolidone (NMP) in the slurry for casting the cathode and anode of Li-ion batteries. Using LCA analysis, the comparison of the environmental impact of lead acid (LA), LMO and lithium iron phosphate (LFP) batteries in Ref. [10] shows that the LFP production has the lowest overall environmental impact. Furthermore, the LCA study on Li-ion and nickel metal hydride (NiMH) batteries for plug-in hybrid and battery EVs in Ref. [11] reports that the NiMH technology has the highest environmental impact. In this context, a common base for LCA of Li-ion batteries is proposed in Ref. [12] for evaluating the actual environmental performance of different battery chemistries.

On the other hand, a number of LCA studies consider the reuse of EV batteries that no longer meet the requirements of automotive purposes in less demanding applications, such as stationary energy storage systems, as a means of extending their useful life. In the light of these secondary applications, three alternative scenarios for an LFP battery (with a $Li_4Ti_5O_{12}$ anode and $LiFePO_4$ cathode) of an urban EV in Spain are examined in Ref. [13], including the reuse of the battery as an energy storage unit in a smart building with solar photovoltaic (PV) panels. Despite the additional environmental burden from manufacturing the PV panels, this work concludes that there is an environmental benefit from reusing the existing EV battery in the smart building application compared to manufacturing a new one for the same purpose. In the same direction, the second life application of a Li-ion battery with cell chemistry of $LiFePO_4$ cathode and graphite anode is analyzed in Ref. [14], assuming that the use, remanufacturing and reuse phases occur within the Province of Ontario, Canada. Moreover, the analysis of the environmental trade-offs of cascading reuse of EVs' Li-ion batteries in stationary energy storage at automotive end-of-life in Ref. [15] shows that the net cumulative energy demand and global warming potential can be reduced by 15% under conservative estimates and by as much as 70% in ideal refurbishment and reuse conditions.

Building upon the previous work in Ref. [13], the present paper analyzes the second life application scenarios of an LFP EV battery by combining the following cases for the second use phase: (i) either reuse of the EV battery or manufacturing of a new battery as an energy storage unit in a smart building, and (ii) either use of the Spanish electricity mix or energy supply by the PVs.

2 Materials and methods

2.1 LCA study characteristics

The goal of this LCA study is to examine the potential environmental benefits from the reuse of an LFP battery that no longer meets the requirements of automotive purposes, but still can be used as an energy storage unit in a building in Spain. The scope of the analysis considers the manufacturing phase, the use phases (primary and secondary applications) and the disposal phase of the EV battery, whereas other EV components are left out of the system boundaries. The data source for the life cycle inventory is the Ecoinvent database, which is incorporated in the LCA tool employed in this work, namely SimaPro. The impact categories included in the LCA study are: carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels.

2.2 LCA tool

SimaPro is one of the most widely used LCA software, chosen by industry, research institutes, and consultants in more than 80 countries. It is based on the ISO 14040 and 14044 standards, where the first considers the principles and framework for an LCA, while the latter specifies the requirements and guidelines for carrying out an LCA study. SimaPro incorporates the Ecoinvent database that covers more than 10000 processes, as a result of a joint effort by different Swiss institutions to update and integrate several life cycle inventory databases.

2.3 Materials

In general, a battery comprises an assembly of several parts, such as cells, battery management system (BMS) and cables. The manufacturing process of cells includes the production of cathode, anode, electrolyte and separator, as shown in Fig. 1. For the purposes of this work, the information for the materials and processes required for the manufacture of the LFP battery is based on the work in Ref. [11].

The main components for the production of the electrode paste include a binder substance (5-10% of the total paste), carbon black to improve conductivity (4-10% of the total paste), $LiFePO_4$ and an electrochemically active material. At this point, it is noted that an important modeling choice is the assumption of hydrothermal synthesis for $LiFePO_4$, among the many different synthesis paths available [11]. Moreover, polyvinylidene fluoride (PVDF) is selected for the binder material, while N-Methylpyrrolidinone (NMP) is the selected material for the solvent used to obtain the desired slurry texture, which is a substance that will be evaporated in the mixing process with the substrate.

The electrode substrate is a metal foil mainly composed of aluminum mixed with other metals. This metal foil is very thin (1520 µm) and is utilized as the current collector and gives physical support for being later coated with the electrode paste. Due to the lack of available data for the manufacture of this part of the cathode, it is assumed that the process is similar to the “sheet rolling” process in the Ecoinvent database.

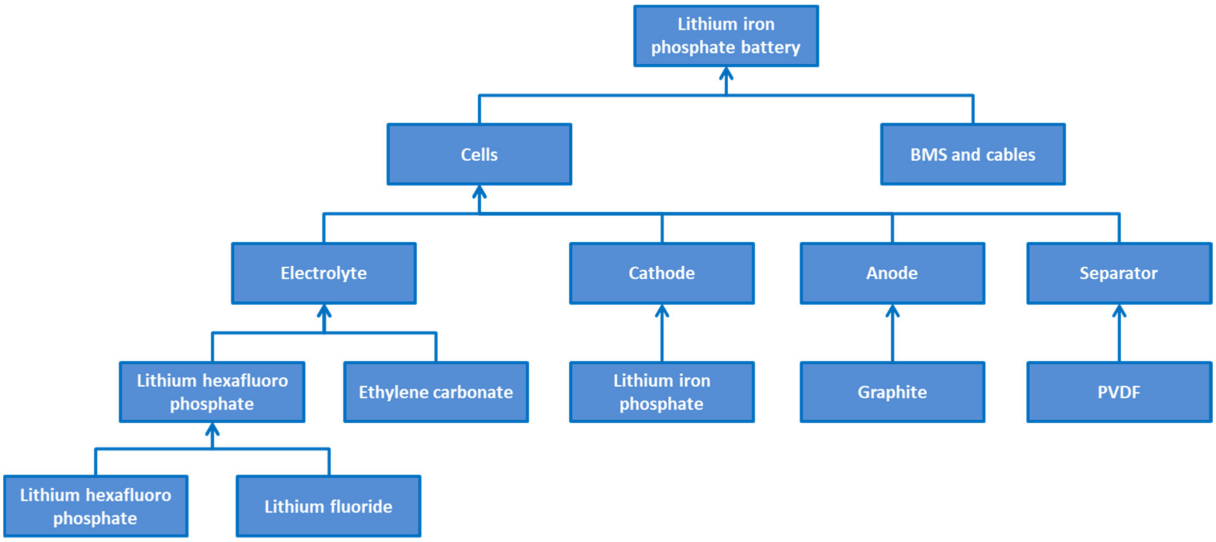

Figure1: Main components of LFP battery

As already pointed out, it is assumed that $LiFePO_4$ is produced by hydrothermal synthesis in the frame of this work. The production process of this compound involves the reaction of iron sulphate salt ($FeSO_4$ x $7H_2O$) with lithium hydroxide (LiOH) and phosphoric acid (H_3PO_4), as illustrated in Fig. 2. It takes place in a water medium inside a hermetic reactor at a temperature ranging between 150-250 °C, and it is maintained around 5 hours. After this process, $LiFePO_4$ precipitates and is picked up by a suction filter and later dried for 5 hours at a constant temperature of 60 °C.

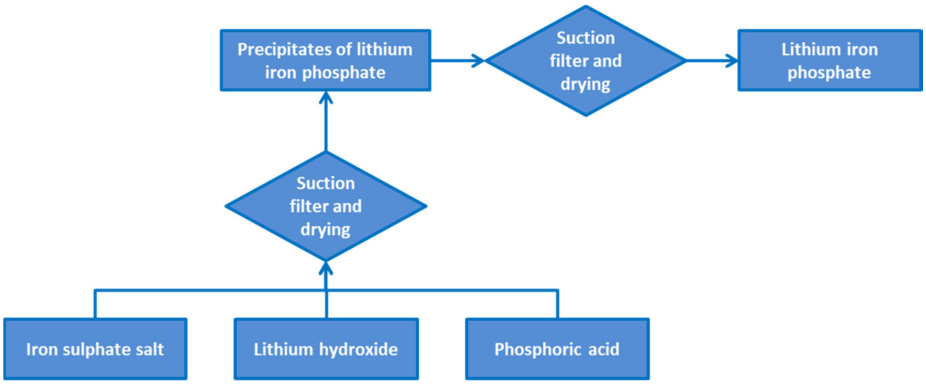

Figure2: Overview of $LiFePO_4$ production

2.4 Battery degradation and second life application

Relevant studies estimate that LFP batteries typically support 2000-2500 cycles for electric traction, until the effective capacity drops to 80% of nominal value, as a result of the gradual reduction of cell capacity due to the aging process. However, the battery can still be used in less demanding applications for additional 2000 cycles, until the residual capacity reduces to 60% of the initial capacity, up to the point that the voltage drop does not allow further use of the battery due to aging [16]. Secondary applications of EV batteries, after the end of their useful life in the automotive sector, include their use for energy storage in smartgrids or uninterruptible power supply. These applications are characterized by the lower stress of the battery cells, extending thus the lifespan of the battery pack.

In this context, the present work considers the primary use phase of a 24 kWh LFP battery with efficiency of 80% in an EV for 2500 days, and the secondary use phase of the same or new LFP battery in a smart building for 1500 days (or equivalently, four years) as an energy storage unit, taking into account the average household consumption in Spain in 2010. To this end, this work examines a total of 4 scenarios, assuming that, in the scenarios that refer to the use of the same battery in the primary and secondary application, the efficiency drops from 80% to 75% due to the aging of the battery.

2.5 Scenarios

Scenario 1 consists of 4 stages, i.e., the manufacturing process of the battery, the primary use phase of the battery in the EV for 2500 cycles, the secondary use phase as energy storage in a smart building using the Spanish electricity mix for 1500 cycles, and the disposal of the battery once it reaches its end of life. In contrast to scenario 1, scenario 2 is not based on the idea of reutilizing the LFP batteries once they have reached the end of life for electro-mobility purposes, but instead, a new battery with a smaller capacity of 12 kWh is manufactured and utilized for the smart building application, in replacement of the first battery with the degraded capacity. Scenarios 3 and 4, are similar to scenarios 1 and 2 respectively, but instead of evaluating the use of the battery in smart building applications by storing energy from the grid, the energy is supplied by PVs. Fig. 3 illustrates the stages included in each alternative scenario.

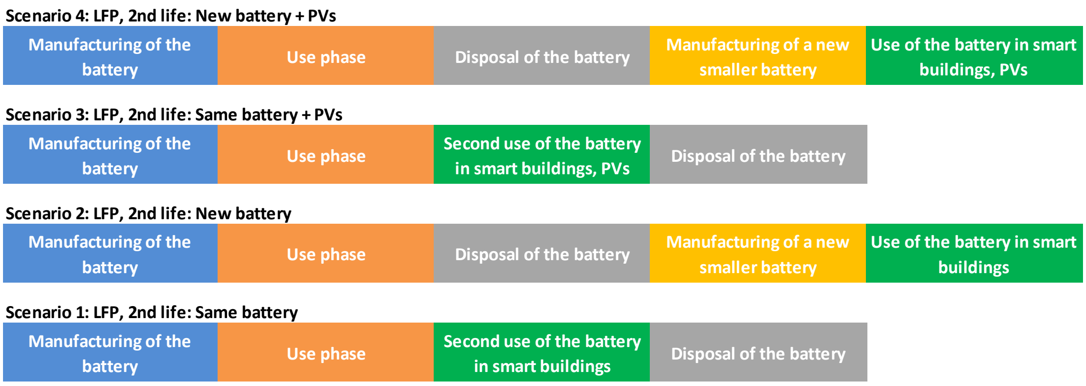

Figure3: Graphical representation of stages included in each alternative scenario of the LCA study

3 Results

3.1 Scenario 1

The single score of the LFP battery for scenario 1 with respect to the manufacturing process, use phase and second life application, obtained by using the Eco-indicator 99 method and disaggregated per impact category, is illustrated in Fig. 4. At this point, it is noted that the environmental impact of the disposal stage is left out of the scope of this comparative analysis, and thus not evaluated, given that it is common for all the alternative scenarios under study.

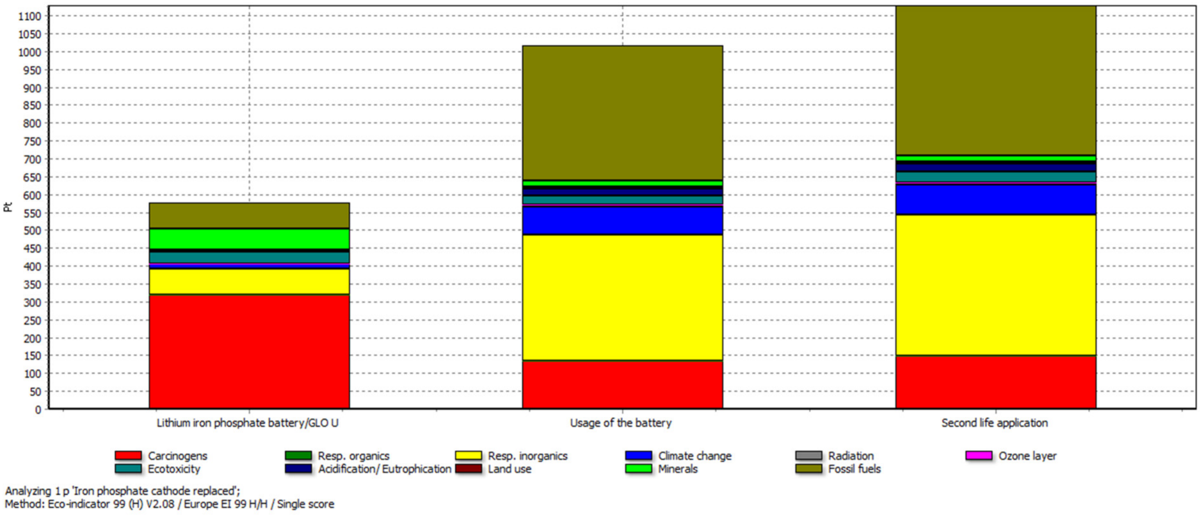

Figure4: Evaluation results of LFP battery manufacturing process, use phase and second life application in Scenario 1 using the Eco-indicator 99 method

The results of scenario 1 indicate that the lowest overall environmental impact is observed in the production of the battery, followed by its use in the EV, while the most environmentally harmful stage is the second use phase of the battery in the smart building for stationary energy storage, mainly caused by the large quantity of energy supplied to the battery by the grid, taking into account the Spanish electricity mix. It is important to note that the same source of electricity supply is assumed for both use phases (primary and secondary), thus the higher environmental impact in the second life application can be attributed, on the one hand, to the higher total energy demand in the building compared to that of the EV, and on the other hand, to the lower efficiency of the battery during the smart building application, leading to higher losses during the charging and discharging processes.

3.2 Scenario 2

Fig. 5 shows the single score of the two LFP batteries for scenario 2 with respect to their manufacturing process and corresponding use phases, obtained by using the Eco-indicator 99 method and disaggregated per impact category.

As expected, the results of this scenario show that the lowest overall environmental impact is observed in the production of the second (smaller) battery for the second life application, followed by the production of the first battery for the EV and the use phase of the first battery in the EV, while the most environmentally harmful stage is the use phase of the second battery mainly due to the large quantity of energy supplied to the battery using the Spanish electricity mix. Given that the same source of electricity supply is assumed for both use phases (primary and secondary), while both batteries have the same efficiency, the higher environmental impact caused by the second life application can be attributed to the higher total energy demand in the building compared to that of the EV.

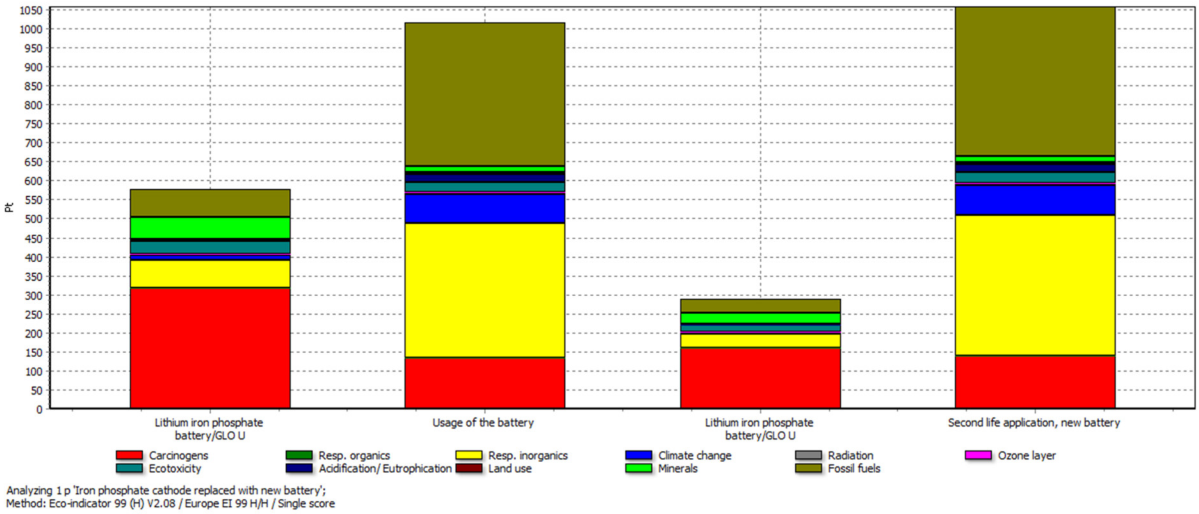

Figure5: Evaluation results of two LFP batteries manufacturing process and their use phase in Scenario 2 using the Eco-indicator 99 method

3.3 Scenario 3

Fig. 6 presents the single score of the LFP battery for scenario 3 with respect to the manufacturing process, use phase and second life application, obtained by using the Eco-indicator 99 method and disaggregated per impact category.

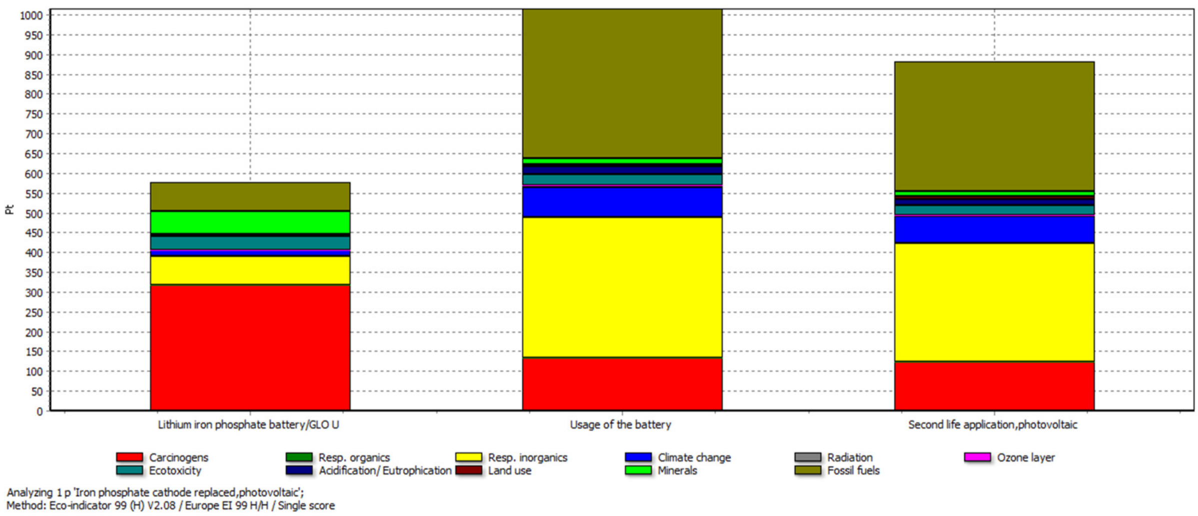

Figure6: Evaluation results of LFP battery manufacturing process, use phase and second life application in Scenario 3 using the Eco-indicator 99 method

As opposed to scenario 1, the results of scenario 3 reveal that the highest overall environmental impact is caused by the use of the battery in the EV, given that the PVs as the energy source in the smart building application significantly reduce the contribution of the second use phase of the battery (for stationary energy storage) by 21.7%. Importantly, it is emphasized that the environmental benefit from using PVs as the energy source in the secondary use phase, instead of the Spanish electricity mix as in the primary use phase, is observed despite the fact that the battery in the smart building application has a lower efficiency (due to the degradation), leading to higher losses during charging and discharging.

3.4 Scenario 4

The single score of the two LFP batteries for scenario 4 with respect to their manufacturing process and corresponding use phases, obtained by using the Eco-indicator 99 method and disaggregated per impact category, is depicted in Fig. 7.

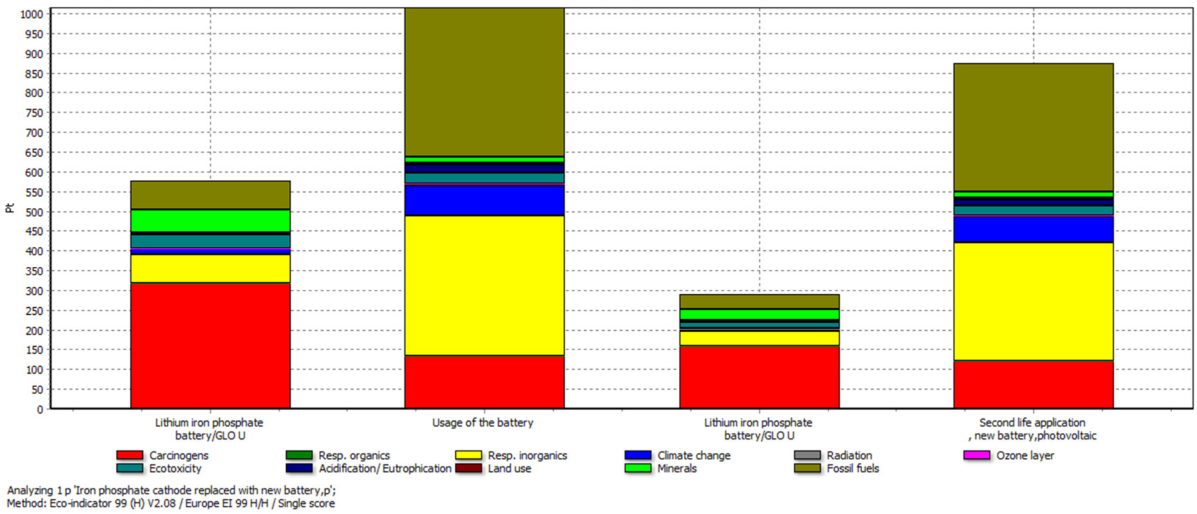

Figure7: Evaluation results of two LFP batteries manufacturing process and their use phase in Scenario 4 using the Eco-indicator 99 method

As opposed to scenario 2, the results of scenario 4 suggest that the use of the battery in the EV has the highest overall environmental impact, given that in this case, the energy supply by the PVs in the smart building application (instead of the Spanish electricity mix) significantly reduces the contribution of the second use phase of the battery by 17.4%. Moreover, it can be observed that the impact of the second life application in scenario 4 (that considers the use of a new battery) is slightly lower compared to that of scenario 3 (that considers the use of the existing battery). Nevertheless, the additional environmental burden from the production of the new battery in scenario 4 results in higher overall environmental impact compared to scenario 3, clearly indicating that it is environmentally beneficial to use the same battery in the smart building application, despite the fact that the reuse of the existing battery entails higher losses during charging and discharging due to the lower battery efficiency.

4 Conclusions

This LCA study examines the reuse of EV batteries of LFP technology for energy storage in smart buildings, as a typical example of second life applications that extends their use phase when they no longer meet the requirements for electro-mobility purposes. To this end, it analyzes the environmental impact of four alternative scenarios, where the second use phase considers either reusing an existing EV battery or manufacturing of a new battery, while electricity is supplied either by the Spanish grid or PVs. Using the Eco-indicator 99 method, the results obtained from the scenarios demonstrate that it is environmentally beneficial to reuse an existing EV battery for energy storage in the smart building, despite its degradation in terms of lower efficiency and higher losses as a result of the aging process, instead of manufacturing a new one for the same purpose and time frame. In addition, this work exemplifies the dependence of the overall environmental impact on the energy source of the smart building for the second life application, given that the energy supply from PVs has significantly lower contribution compared to the use of the Spanish electricity mix. Thus, the environmental benefit from the reuse of the EV battery can vary from country to country, depending on the country-specific electricity mix.

Last, it is noted that a limitation of this work is that the contribution of battery disposal was omitted from the overall environmental impact due to the lack of relevant data. Thus, directions of future work include the incorporation of battery recycling options in the LCA results to reflect the possible end-of-life treatment options for the EV batteries.

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