Sustainable Logistics: Are Electric Vehicles Really a Solution?

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Abstract: Green logistics is an approach aimed at reducing environmental impact, specifically ecological footprint, and contributing to the sustainability of transport, storage, and distribution practices. Strategies to achieve this goal include the use of low-emission vehicles, route optimization, the adoption of clean energy technologies for warehouse lighting, and efficient waste management. These solutions can contribute to achieving sustainable development goals of the European Green Deal. The main research question of this paper is whether an electric vehicle has a significantly lower environmental impact compared to a gasoline vehicle. To answer to this question, this study presents a life cycle assessment of an electric vehicle using lithium-ion battery technology (BEV) and compares it to an internal combustion engine vehicle (ICEV). Through a gate-to-grave approach, both vehicles' use and disposal phases were evaluated to identify the key issues of this part of their life cycle. The LCA methodology allows for an objective comparison of the environmental impacts of the two types of vehicles, and the results show that BEV emits 3000 times more CO2 eq than ICEV, as well as having higher acidification, ecotoxicity, and resource usage. Primary contributor to the vehicle's impact is the production of electric energy from fossil fuels. A second analysis was conducted, including the use of photovoltaic panels to generate the electric energy, significantly reducing the impact almost to zero, making the electric vehicle a valid solution for achieving green logistics objectives. However, the question of lithium batteries regarding the supply of raw materials and disposal remains open. The next phase of this research will explore the impacts of the two vehicles' production cycles.

Keywords: Green Logistic, LCA, Electric Vehicle, Greenhouse Emission, Photovoltaic.

I. INTRODUCTION

Climate change is already affecting the entire world, with extreme weather conditions such as drought, heat waves, heavy rain, floods and landslides becoming more frequent, including in Europe. Other consequences of the rapidly changing climate include rising sea levels, ocean acidification and loss of biodiversity [1].

In order to limit the increasing of global warming to 1.5°C (i.e., a threshold the Intergovernmental Panel for Climate Change (IPCC) suggests as safe), carbon neutrality by mid-21st century is essential. This target is also laid down in the Paris agreement [2] signed by 195 countries, including the EU. In December 2019, the European Commission presented the European Green Deal [3] , its flagship plan that aims to make Europe climate neutral by 2050.

In 2018, transport activities resulted in about 29 % of total EU CO2 emissions. Other study confirms that the transportation sector is one of the highest contributors to greenhouse gas emissions (Hofer et al., 2018; Keller et al., 2019; Du et al., 2019)

Logistics companies connect firms to markets by providing various services, including multimodal transportation, freight forwarding, warehousing, and inventory management. They are important for global manufacturing, which is complex and multilocational.

During the COVID-19 pandemic period, consumers increasingly opt for, or are forced to, use home delivery services. So, the use of road transportation for home delivery of products has increased, and it has been estimated that, as purchasing habits have changed, it will continue to increase in the coming years. [6] estimates that the number of light-duty vehicles in operation will rise to about 1.3 billion by 2030 and 2 billion by 2050.

The growing attention towards the environment and the continuous growth of goods movements have driven the logistics industry to rethink its impacts and emissions, leading to the emergence of green logistics.

Green logistics, also known as sustainable logistics or eco-logistics, refers to the practice of integrating environmentally friendly principles and practices into the planning, implementation, and management of logistics activities. It focuses on minimizing the environmental impact of logistics operations, such as transportation, warehousing, packaging, and reverse logistics, by reducing energy consumption, emissions, waste generation, and promoting the use of renewable resources and sustainable supply chain practices. The goal of green logistics is to achieve a more sustainable and efficient logistics system while mitigating the negative effects on the environment and promoting long-term environmental stewardship.

In this paper, the research questions that arise are:

RQ1: Is it possible to make freight transportation sustainable through electric machinery?

RQ2: Does an electric vehicle truly have a lower environmental impact compared to a gasoline vehicle?

RQ3: How much does the production of electric energy contribute to the impact of electric vehicles?

This study presents a life cycle assessment (LCA) of an electric vehicle using lithium-ion battery technology (BEV) in Italy and compares it to an internal combustion engine vehicle (ICEV). Through a gate-to-grave approach, both vehicles use and disposal phases were evaluated to identify the key issues of this part of their life cycle. Finally, the impacts of BEV will be evaluated and compared in the case of using energy from a photovoltaic system or mixed sources for recharging. The LCA, conducted using the SIMAPRO® software, allow to evaluate if electric vehicles are a valid alternative to traditional means of transportation in order to limit greenhouse gas emissions and atmospheric pollutants.

This paper is structured as follows: The first part will provide a brief review of the results from Life Cycle Assessment (LCA) analyses conducted on electric vehicles. The second part will present the methodology and the gate-to-grave LCA analyses conducted on the selected vehicles and will compare and discuss the obtained results. Finally, conclusions from results will be drawn, a summary of the key points will be presented, and future directions for further research in this field will be given.

II. CONTEXT/LITERATURE REVIEW

The transportation sector is a significant contributor to greenhouse gas emissions, air pollution, and resource depletion [7]. Traditional internal combustion engine vehicles powered by fossil fuels have long been recognized as major sources of these environmental impacts. The introduction of electric vehicles (EV) has raised hopes for reducing emissions and transitioning to more sustainable transportation options. However, it is crucial to conduct rigorous assessments to understand the full environmental implications of EVs. Several LCA studies [8]–[10] have been conducted to compare the environmental performance of EVs and non-electric vehicles. These studies consider the entire life cycle, including vehicle production, operation, and end-of-life stages. By examining multiple impact categories, such as greenhouse gas emissions, air pollutants, and resource depletion, these studies provide valuable insights into the environmental advantages and trade-offs associated with different vehicle technologies.

[11] presents the life cycle assessment of a BEV for Europe and compares it to an ICEV. The results of the hot spot analysis showed that the BEV manufacturing phase determined the highest environmental burdens mainly in the toxicity categories as a result of the use of metals in the battery pack. However, the greenhouse gas emissions associated with the BEV use phase were shown to be half than those recorded for the ICEV use phase. [12] compare the performances of an EV and an ICEV paying particular attention to the production of electricity that will charge the EV. The study demonstrates that the EV proves to be able to reduce air acidification, photochemical oxidant formation, and greenhouse gases. EV car and battery manufacturing have higher impacts for all categories than ICEV car manufacturing. [13] investigated the energy use and greenhouse gas emissions for different types of advanced vehicles (hybrid electric vehicle, a plug-in hybrid electric vehicle, a BEV, and a Fuel Cell Vehicle) and compared them to a conventional vehicle. The results indicate that all these fuel-efficient technologies improve the energy use and emissions throughout the lifetimes of the vehicles. An automotive Life Cycle Assessment (LCA) is being performed for conventional and alternative vehicles in Belgium by [14], the results show that the BEV has the best environmental score for all the considered impact

categories, ICEV have the worst impact on the greenhouse effect.

The reviewed LCA studies demonstrate the importance of adopting a comprehensive life cycle perspective when assessing the environmental impact of transportation. While EVs show promise in reducing greenhouse gas emissions, a holistic evaluation considering various impact categories is necessary to fully understand their environmental advantages and limitations.

III. CASE STUDY: BEV VS ICEV

The BEV vehicle chosen for conducting the LCA analysis is a two-seater electric light quadricycle in the "cargo" configuration, where the passenger seat has been removed to expand the cargo space. Due to its size, it is hypothesized that it can be used for the so-called "last mile" delivery, which involves small-scale distribution of goods within urban centers. The technical specifications are listed in the following table.

TABLE 1: TECHNICAL SPECIFICATIONS OF BEV AND ICEV

	BEV	ICEV
Power	6 kW	3 kW
Torque	625 Nm	4,5 Nm @ 5.000 rpm
Cubic Capacity	NA	50 cc
Battery Capacity	5.5 kWh	NA
Charging Time	3h	NA
Range	75 km (After 3h of charging)	75 km (With 1l of fuel)
Maximum speed	45 km/h	45 km/h
Total Weight	478 kg	87 kg
Storage volume	260l	

The minicar is powered by a 6 kW electric motor, supported by a 5.5 kWh lithium-ion battery. The car is classified as a light quadricycle in the L6e category and provides a range of approximately 75 kilometers, as declared by the automaker, with a maximum speed of 45 km/h. The speed is therefore quite low but suitable for urban speed limits. The car can be charged at a 220V electrical outlet, and a full recharge is achieved in 3 hours. The selected ICEV (Internal Combustion Engine Vehicle) for comparison is a 50cc moped, Euro 2, from 2005. The technical specifications are listed in table 1.

A. Methodology: LCA

Life Cycle Assessment (LCA) is a systematic approach used to evaluate the environmental impact of a product, process, or service throughout its entire life cycle. It assesses the environmental burdens associated with various stages, including raw material extraction, manufacturing, distribution, use, and disposal. LCA serves as a valuable tool for businesses and organizations as it provides a comprehensive understanding of the environmental impacts associated with their products or services. By conducting an LCA, companies can identify hotspots of environmental impact and make informed decisions to minimize negative effects. Additionally, LCA findings can be used for eco-labeling, eco-marketing, and sustainability reporting, allowing companies to demonstrate their commitment to environmental stewardship to stakeholders and consumers. Overall, LCA plays a crucial role in promoting sustainable practices within businesses by driving environmental consciousness, enabling informed decision-making, and fostering the development of more environmentally friendly products and processes. LCA procedure, as a global environmental management tool [15], is standardized in the ISO 1404x series, as reported in the following table 2.

TABLE 2: LCA ISO STANDARD REFERENCE

ISO n.	Title of International Standard/Guideline/Technical Report
ISO 14040: 2006	Environmental management – Life cycle assessment – Principles and framework
ISO 14044: 2006	Environmental management – Life cycle assessment – Requirements and guidelines
ISO/DTR 14047: 2003	Environmental management – Life cycle assessment – Examples of application of ISO 14042
ISO/TS 14048: 2002	Environmental management – Life cycle assessment – Data documentation format
ISO/TR 14049: 2000	Environmental management – Life cycle assessment – Examples of application of ISO 14041 to goal and scope definition and inventory analysis
ISO 14050 2nd Ed.: 2002	Environmental management – Life cycle assessment – Vocabulary

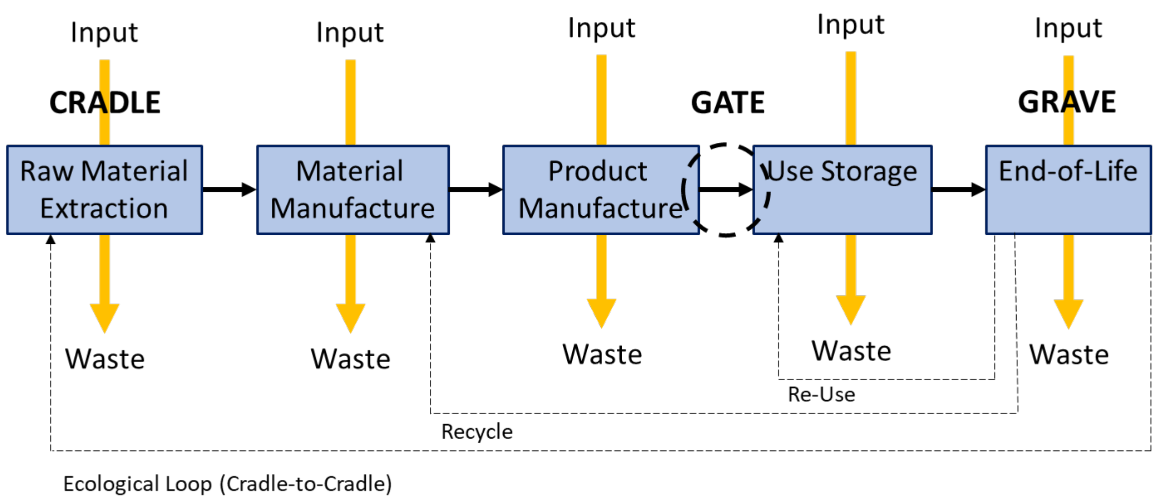

Figure 1: LCA burden according to ISO14040: 2006

This standard specifies the framework, principles, and requirements to carry out the evaluation studies of a life cycle and to disseminate them by reports. The LCA process entails:

- Compiling a comprehensive inventory of significant inputs and outputs within a system.
- Assessing the potential environmental impacts associated with these inputs and outputs.
- Interpreting the results obtained during the inventory analysis phase and estimating their impact in relation to the study's objectives.

The main categories of environmental impacts to be considered regarding the use of resources, human health, and ecological consequences.

LCA analyses can be categorized based on the established boundaries of analysis, as shown in the figure 1. In the case examined in this study, the gate-to-grave approach has been chosen, which encompasses the vehicle's operational lifespan and its disposal phase.

B. Inventory data

The subsequent figures 2, 3, Table 3 and 4 depict the data entered the software and the sequential steps taken to generate the analysis. It was considered a lifetime of 10 years and 11.200 km/year for both vehicles.

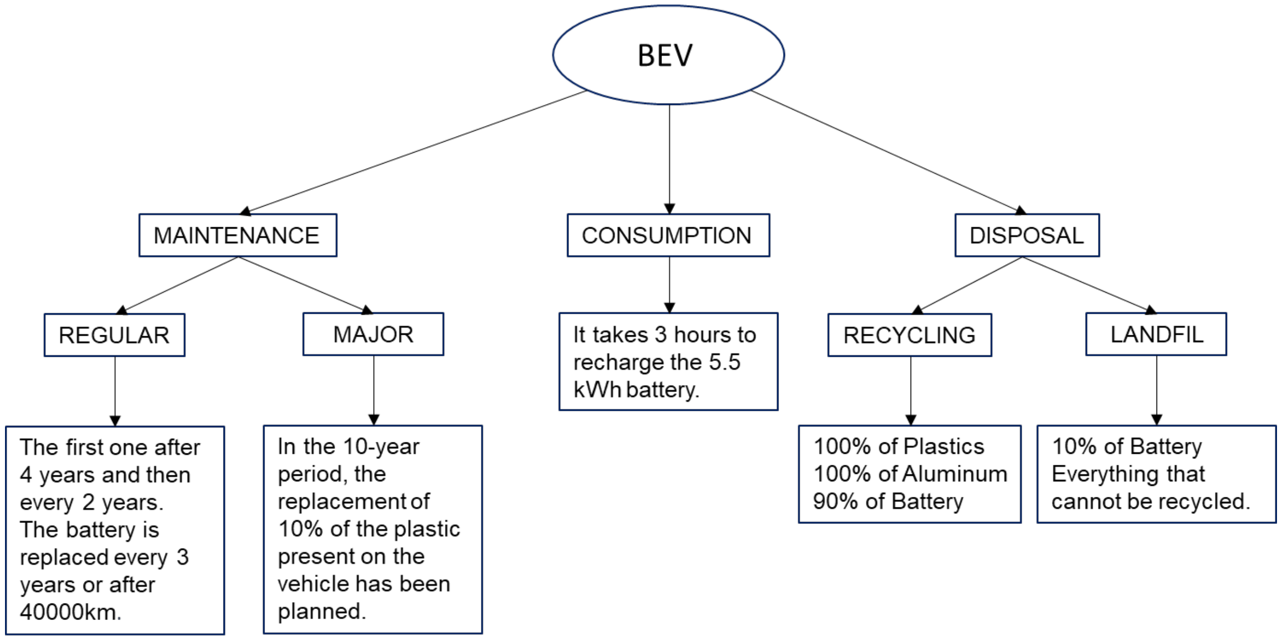

Figure 2: BEV data

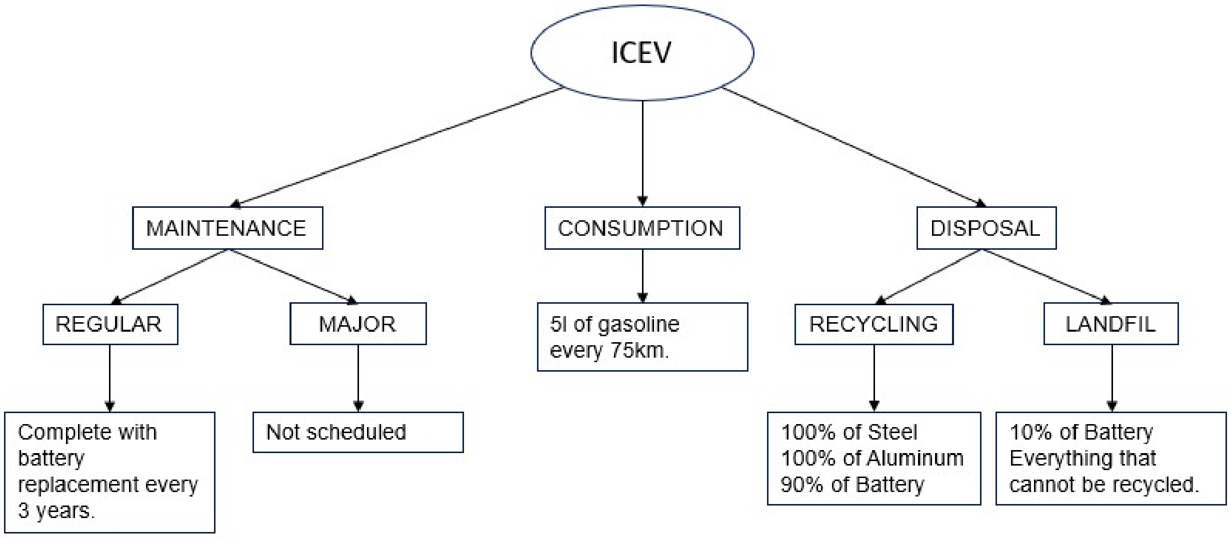

Figure 3: ICEV data

TABLE 3: INPUT DATA FOR LCA ANALYSIS

	BEV	ICEV
Repair times	4	3
Number of batteries replaced	3	3
Consumption	8240000 kWh	1490 l of gasoline
Plastic replaced	34.9 kg	NA

TABLE 4: INPUT DATA FOR LCA ANALYSIS REGARDING END OF LIFE

	BEV	ICEV
Plastic recycled	87.3 kg	
Batteries recycled	436 kg	7.56 kg
Aluminium recycled	175 kg	30.2 kg
Steel recycled	NA	31.9 kg
Total	701 kg	69.7 kg
Batteries disposed in landfill	48.8 kg	0.84kg
Other materials in landfill	140 kg	19.07 kg

C. Analysis and results

Below are the tree diagrams generated by SIMAPRO® software for the two vehicles. The thickness of the lines connecting the blocks is proportional to the environmental impact of the respective block. It is immediately apparent that for the BEV, the most impactful block is related to electric energy, specifically its production.

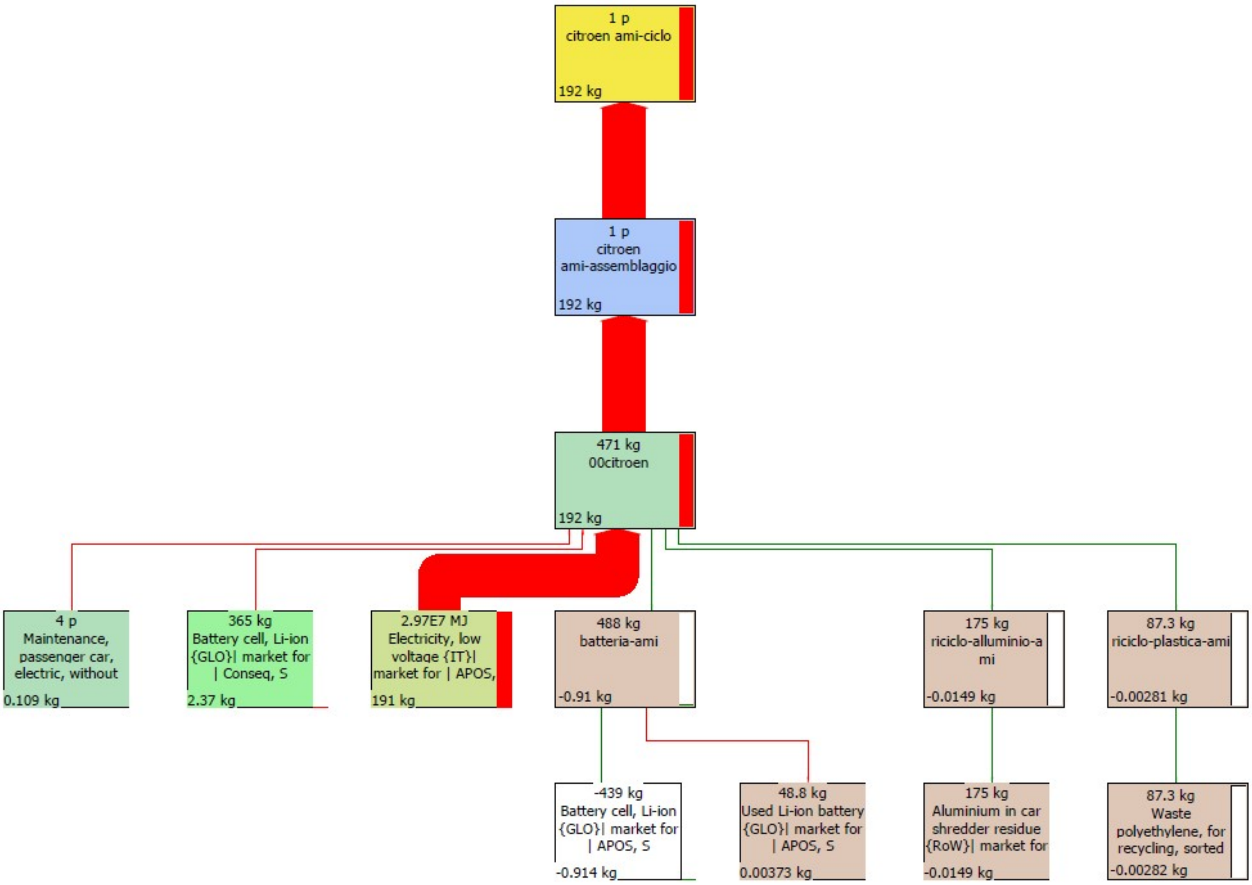

Figure 4: BEV tree diagram

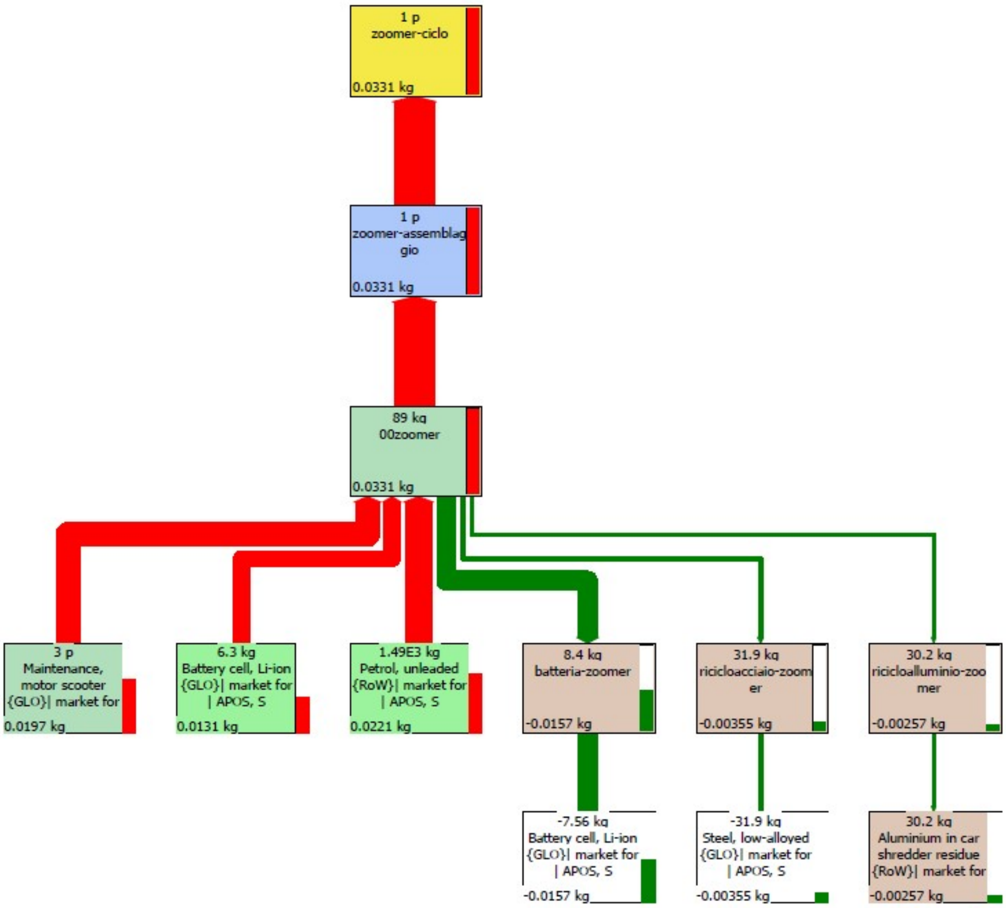

Figure 5: ICEV tree diagram

As for the ICEV, it is the fuel block. Therefore, a new analysis was conducted, if all the electric energy would come from a dedicated photovoltaic system.

TABLE 5: RESULTS

Impact Category	ICEV	BEV	BEV + PS
Kg CO2eq	1.48 x 10^3	3.67 x 10^6	0

As evident from the comparison of the calculated results presented in the table, considering the kg of CO2eq emitted by the two vehicles, the BEV emits significantly more CO2eq during its lifespan compared to the ICEV. This difference is due to the methods of energy procurement, as already demonstrated by [8], [16]. However, this CO2eq emissions number drops to zero when considering the presence of the photovoltaic system.

IV. RESULTS AND DISCUSSION

From the study conducted using SIMAPRO® software, two results emerged:

I. Despite the common assumption that an electric vehicle has a lower environmental impact compared to a gasoline vehicle, a different scenario appeared from the comparison. When considering the same annual distance traveled and the required refueling (fuel for ICEV and energy for BEV) over the study's timeframe of 10 years, BEV emitted a significantly higher amount of CO2eq (3,670,000 kg CO2eq) compared to ICEV (1,480 kg CO2eq). The comparison reveals that every Impact Category analyzed by SIMAPRO® is quantitatively higher for BEV.

II. As shown in table 5, the installation of photovoltaic systems at BEV's charging stations, which can be used by any other electric vehicle as well, would lead to approximately 100% savings in resources and daily emissions.

In the case of BEV, the predominant environmental impact is associated with the disposal of the lithium battery, which is the heart of the car. While, on one hand, the issue of emissions from exhaust gases in transportation has been addressed by opting for electric versions, and the energy consumed during charging has been addressed by choosing renewable energy sources, such as wind and solar, on the other hand, there is still a need to find a solution that primarily addresses the end-of-life stage of the vehicle and the battery.

V. CONCLUSION

The transformation of the logistics sector into green logistics is crucial for fighting the issue of the global warming, as required by the European Green Deal [3].

To examine whether electric vehicles are a viable solution for reducing transport emissions, a gate-to-grave life cycle assessment (LCA) was conducted comparing an electric minicar to a 50cc motorcycle. The analysis revealed that electric vehicle using lithium-ion battery technology are not emission-free and, in fact, emit more greenhouse gases than internal combustion engine vehicle. Through a careful examination of the different life cycle stages of electric vehicles, it was found that the most significant environmental impact was associated with the production of electrical energy. The SIMAPRO® software used for the analysis considered energy produced from a mix of sources, including fossil fuels. To further investigate this aspect, a second analysis was conducted assuming that all the electricity needed for the electric vehicle would be generated from a photovoltaic system. In this scenario, it can be concluded that the electric vehicle indeed has zero emissions.

By conducting these analyses, we can provide initial answers to the research questions we started with: Is it possible to make freight transportation sustainable through electric machinery? Does an electric vehicle truly have a lower environmental impact compared to a gasoline vehicle? How much does the production of electric energy contribute to the impact of electric vehicles? The logistics industry can contribute to achieving the goals of the European Green Deal by adopting electric minicars for urban distribution, but only if the vehicles are charged using 100% renewable energy sources such as solar or wind power [17]. Future developments of this research will involve conducting a cradle-to-grave LCA of the two vehicles, with particular attention to the production and disposal of lithium batteries.

In conclusion, the findings underscore the importance of considering the entire life cycle of vehicles and the significance of using renewable energy sources in achieving sustainable transportation. It is imperative for the logistics sector to embrace green practices and work towards minimizing its environmental footprint in alignment with the European Green Deal objectives.

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