Supercabatteries for a New Sustainable Mobility

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Abstract. The escalation in private vehicles because of urbanization poses one of the major challenges which have both economic and environmental implications. Facts show that about 25% of carbon dioxide emissions result from vehicles. While electric mobility is a potential solution to mitigate pollutants, it is heavily dependent on power generation methods. Furthermore, the limited lifespan of the battery hinders the full utilization of other vehicle components. Technical term abbreviations will be explained upon first use. The language will remain clear, objective, and formal with a precise choice of subject-specific vocabulary. Recently, hybrid supercapacitors, a new type of electrochemical energy storage, have gained attention in the industrial sector due to their potential to provide up to 20 times longer service life than conventional lithium-ion batteries. This conference paper aims to analyze how supercabatteries, a specific category of hybrid supercapacitors, can reduce the environmental impact of vehicles by extending their service life.

Keywords: Supercabatteries · micro-mobility · micro-vehicles · supercapacitor · hybridization · Li-ion

1 Introduction

According to recent studies, urbanization is rapidly increasing, earning the title "The Century of Cities." [1, 2]. United Nations (UN) reports from 2019 show an urbanization rate of 56%, projected to reach 68% by 2060 [1].

One of the most concerning outcomes is the inability of pre-existing urban road networks to accommodate a fast-growing number of vehicles, leading to unsustainability. Despite various interventions to limit traffic, such as Limited Traffic Zone (LTZ) or restrictions on older vehicles, this phenomenon has significant economic and environmental consequences. The so-called "congestion price" [3] is a crucial variable in the economic sphere due to increased costs resulting from delays and excessive fuel consumption. Moreover, it has a detrimental impact on the environment, leading to a rise in pollutant emissions. Indeed, CO2 emissions from the global transportation industry have increased in recent years, rising from 5.8 GT in 2000 to 8.2 GT in 2018. Road vehicles are responsible for approximately three-quarters of these emissions. [4] Transportation accounts for more than 25% of global carbon dioxide (CO2) emissions from fossil fuels in internal combustion engine vehicles. [5].

Battery Electric Vehicles (BEV) have been suggested as a potential solution, but their effectiveness is not guaranteed as their carbon footprint is heavily influenced by both

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the national energy mix and the time of charging, resulting in up to a 73% fluctuation in indirect GHG emissions [6].

Studies have shown varying results regarding the carbon footprint of electric vehicles when compared to internal combustion vehicles. Some articles [6] suggest that in countries where electricity generation is predominantly fueled by fossils, electric vehicles have a higher carbon footprint. However, other articles [6] report the opposite.

The disposal of electric vehicle batteries presents a second challenge. For vehicles like cars and buses with a lifespan of over 10 years, battery disposal contributes to 7% of the carbon footprint. Moreover, it is 35 times more expensive than disposing of internal combustion engine vehicles. On the other hand, micro-mobility vehicles have a much shorter life, making battery disposal a major concern for them. Based on reports, the first generation of electric scooters for sharing had an average useful lifespan of under 6 months [7]. This period was completely inadequate in offsetting the CO2eq emissions produced during the manufacturing and transportation of the vehicles. However, there have been improvements as VOI [8] indicates their electric scooters now have a useful lifespan of 60 months, resulting in a 20% reduction in GHG emissions per pkm [7]. However, the report indicates that the carbon footprint of various electric vehicles is still too high. This conference paper aims to analyze the use of hybrid supercapacitors, specifically *supercabatteries*, as an alternative to batteries. The study will assess their potential for reducing the environmental impact.

2 The *Supercabatteries*

Hybrid supercapacitors (HSC) are energy storage devices that offer the benefits of both supercapacitors and batteries. Supercapacitors provide high power capacity and long cycle life, but they have lower energy density. Conversely, batteries possess high energy density but lower power capacity. Hybrid supercapacitors aim to conquer these limitations by combining supercapacitive and battery-like materials [9].

Another aspect to consider in developing hybrid supercapacitors is distinguishing between pseudocapacitive and battery materials. Pseudocapacitive materials provide high capacitance and rate capability, making them attractive for energy storage applications. However, the use of nanomaterials in batteries has allowed battery materials to achieve fast redox kinetics like those of pseudocapacitive materials, confusing in defining these materials. To precisely differentiate between pseudocapacitive and battery materials, the proposal by Zhang and Liu [10] recommends combining electrochemical signatures with quantitative kinetics analysis.

Hybrid supercapacitors offer a fusion of the best features of batteries and supercapacitors, resulting in advanced power capability, extended cycle life, and enhanced energy density. The utilization of nanomaterials, like carbon nanotubes and titanium dioxide-boron nanowires, in electrode components augments the efficiency of hybrid supercapacitors. Nonetheless, it is imperative to distinguish accurately between pseudocapacitive and battery materials to evade misunderstandings during the design of these energy storage devices [9, 10].

Hybrid supercapacitors with a battery-like electrode, are also called supercabatteries, and their main advantage is to have a considerably high cycle life, compared to the battery from which is hybridized [11].

3 Devices Considered and Methodology

3.1 Supercabatteries Taken into Account

The hybrid supercapacitors being analyzed for various types of vehicles are produced by Gonghe Energy Ltd.

Two models have been selected: one with a cylindrical shape, a maximum voltage of 4.2V, and a capacitance of 4000F, which is suitable for micro-mobility vehicles due to its small size and sufficient discharge C-rate. The datasheet [12] indicates that the useful life of these supercapacitors is 20,000 charge and discharge cycles.

This data has already been analyzed and cited here [13].Supercapacitors with a maximum voltage of 4.2 V and a capacity of 21000 F are available in a pouch-type suitable for heavier mobility like electric scooters or private cars. They are capable of being charged and discharged up to 50000 times and provide a slightly higher C-rate than the preceding versions. For both types, the shelf life is above 20 years, 2 times higher than the common Li-ion cells.

Refer to Table 1 below for a summary of the costs associated with these two categories of supercapacitors.

Table 1. Other relevant data for HSC compared to NMC Li-ion.

HSC type	Specific energy [Wh/kg]	Cost per kWh [$/kWh]
4000 F	200	440
21000 F	240	486
Li-ion		
NMC Li-ion	265	<200

These prices are over twice as high as those of Lithium-ion batteries. Nevertheless, upcoming chapters will assess if the longer lifespan of these supercapacitors when compared to Lithium-ion batteries justifies the higher investment regarding the carbon footprint. Furthermore, the reduction in carbon footprint will be assessed.

3.2 Italian Electric Generation Scenario

As previously stated, the national energy mix has a profound impact on the carbon footprint. For this conference paper, we selected the Italy energy mix as a benchmark, utilizing data from 2019 [14].

Figure 1 reveals that over 50% of the electricity generated by thermoelectric plants is powered by natural gas.

For every kWh of electricity produced, according to [15, 16] estimates the release of 306.94 gCO2eq into the atmosphere. The data from [16] and Fig. 2 demonstrate that renewable sources have a negligible impact compared to thermoelectric plants. The obtained value is reasonable and shows a 25% decrease from the U.S. average. This outcome supports the viability of electric car usage in the Italian environment.

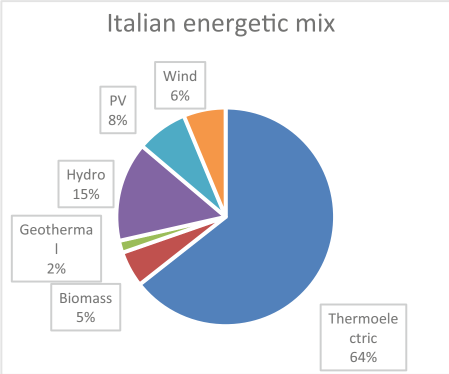

Fig. 1. Italian energetic mix power sources percentage

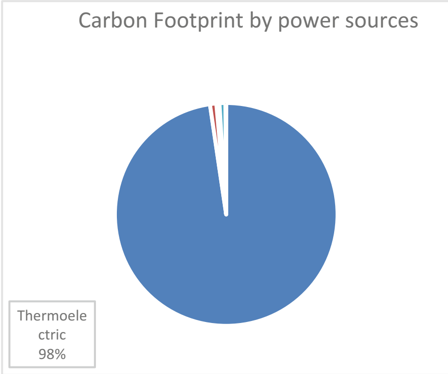

Fig. 2. Carbon footprint of the power sources for electric generation in Italy by percentage

4 Carbon Footprint

4.1 Carbon Footprint of Micro Vehicles

Micro-mobility vehicles frequently face criticism for their poor durability resulting from subpar battery management or low quality [7]. Early electric scooters, for instance, had an average lifespan of less than a year. Additionally, their manufacture primarily in China weighs heavily on the calculation of their carbon footprint. According to reports [7], electric scooters travel 2,000 kms per year, while electric bikes travel 2,400 kms per year. The average lifespan of electric scooters and electric bikes is limited by the technical obsolescence of the battery. The battery often fails before the motor, which has an average life between 10,000 and 25,000 km, and the control electronics. To compute carbon footprint calculations, we used data and formulas cited in the following articles.

Using supercabattery-based accumulators can maximize vehicle performance and prolong its lifespan. The use of supercabatteries has shown an extension of medium useful life for scooters up to 10,000 km and up to 20,000 km for electric bicycles. All calculations were objective and based on factual data [7]. Triple mileage scenario figures are calculated considering various interventions of maintenance.

According to Fig. 3, the use of HSC-based accumulators in electric scooters can decrease their carbon footprint by 32%, thereby significantly reducing both emissions and raw material usage CO2 cost. However, for longer distances, this reduction shrinks to 22%, as distance travelled has a much greater impact.

In the case of electric bicycles, Fig. 4, supercabatteries can reduce the carbon footprint by 28% and 22%, respectively. Their carbon footprint is lower than in the case of electric scooters because they are more robust vehicles and allow them to travel longer distances.

4.2 Carbon Footprint of Battery Electric Car (BEV)

As noted previously, the environmental sustainability of electric cars is in question since most nations generate electricity using thermal power plants.

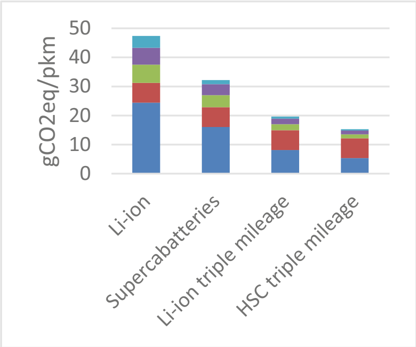

Fig. 3. Carbon footprint of electric kick scooter on various scenarios

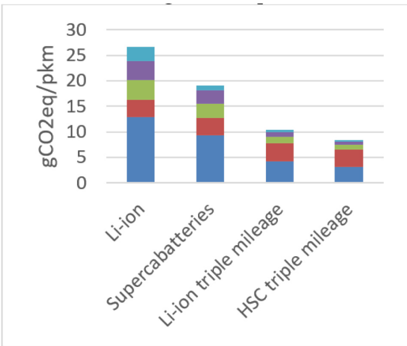

Fig. 4. Carbon footprint of electric bike in various scenarios

The graph presented below indicates that the term related to transportation is much less significant in comparison to micro-vehicles. Extending the useful life of electric cars can reduce carbon footprint by 27% and 21%, respectively. The extended lifespan's impact is minimized by the fact that maintenance expenses are considerably less burdensome on the budget (Fig. 5).

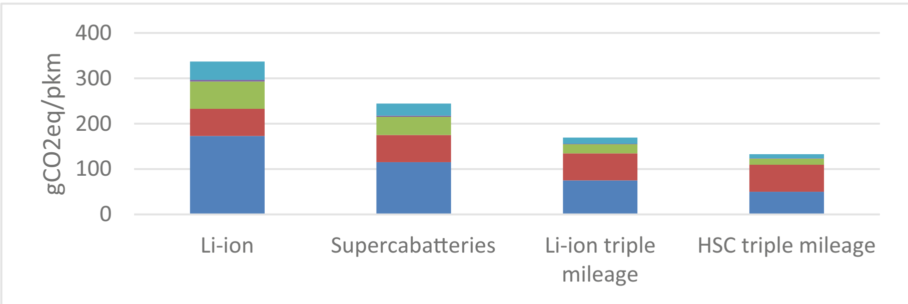

Fig. 5. Carbon footprint of BEV in various scenarios

5 Conclusions

Adopting HSC technology can reduce the carbon footprint of multiple vehicle types by over 20%. This reduction occurs even in scenarios with significant renewable electricity generation, thanks to the long lifespan of HSCs compared to the vehicles they power. Additionally, HSCs improve vehicle efficiency by enabling greater mileage coverage. It remains to be assessed from an economic standpoint whether it is sensible to invest in advanced power units and at what point this becomes financially feasible for those who drive their vehicles infrequently, as the additional expenses could render their adoption economically infeasible.

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