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Efficiency for Rightsizing:

Considerations on how to Tackle the Battery Capacity Competition of Electric Vehicles

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Electric vehicle (EV) battery size significantly impacts range, cost, and environmental footprint, prompting exploration of efficiency improvements to significantly reduce battery capacity (battery rightsizing) without compromising driving autonomy. This paper evaluates technologies and strategies to optimize energy consumption of EVs, thus enabling smaller battery capacities with autonomy penalties, based on real-world scenarios across different regions.

Despite advances in battery energy density and reduced costs, EVs typically offer shorter range and higher prices compared to internal combustion engine (ICE) vehicles, limiting widespread adoption. Psychological concerns about infrequent long-distance trips persist, even though typical daily driving needs are much lower. Boosting EV driving range by simply increasing battery size faces physical, cost, and efficiency challenges. Larger batteries add weight, which raises energy consumption per kilometer, and they represent a major fraction of the EV's total cost and CO_2 footprint. Furthermore, oversizing batteries leads to underutilized capacity in daily driving scenarios, making large batteries less sustainable and economically viable. With today's state-of-the-art EV powertrain technology and based on typical vehicle usage profiles, for most users, weekly charging with moderate-range batteries suffices. In parallel, advancements in fast charging infrastructure enable charging from 20% to 80% state of charge in under 30 minutes, with chargers offering 100–350+ kW power. Some manufacturers aim for ultra-fast charging (at up to 1 MW for 5-minute charges), but such infrastructure is limited and costly, especially in regions like Japan where charging power is capped at 50 kW with plans to reach 90 kW by 2030. High charging power increases infrastructure and thus user costs per kWh, potentially negating EV cost advantages over ICE.

The paper analyzes typical long-distance trips in Japan, Europe, and the USA, considering climate, trip distance, and average speeds, to assess the performance of reference and efficiency-improved EVs under realistic conditions. A state-of-the-art EV employing a 110-kWh battery pack is selected as reference for the analysis. An efficiency-improved variant of the vehicle is considered as well, retaining all core characteristics with a reduced (rightsized) battery capacity of 60 kWh. The resulting penalty in autonomy is compensated by the resulting weight reduction combined with targeting at least 10% energy consumption reduction, focusing on efficiency at highway speeds and improvements achieved by the introduction of next-generation, unconventional or even disruptive technologies, Figure 1. These include powertrain enhancements, improved thermal management with waste heat recovery, and unconventional methods like multi-speed gearboxes, system voltages above 1000V, radiation heating, solar roofs, active suspension energy recuperation, smart vehicle skins, and adaptive tire pressure systems.

The feasibility, financial attractiveness and efficiency effect of the considered single technologies strongly depend on the characteristics of the target vehicle, with the "right" efficiency improvement technology package being vehicle dependent. In real-world scenarios representative for the considered regions (Japan, Europe, and the USA), the efficiency-improved EVs with smaller batteries demonstrate comparable travel times to reference EVs and acceptable differences relative to ICE vehicles, validating the approach of battery rightsizing through efficiency without sacrificing usability on long trips.

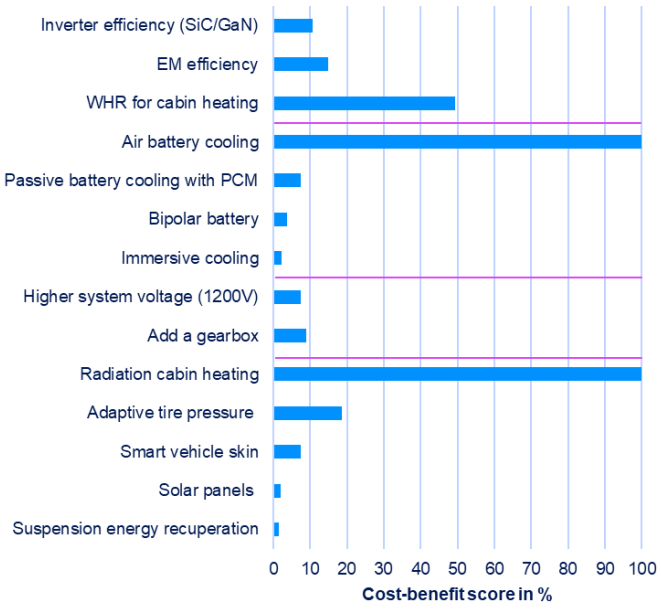

Fig.1 Cost benefit analysis of efficiency improvement technologies arranged in clusters (top to bottom): technology advancements, battery system, powertrain system and vehicle level