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ENHANCING NATIONAL ENVIRONMENTAL SAFETY BY REPLACING TRADITIONAL VEHICLES WITH ELECTRIC CARS

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Abstract

The present study examines the environmental safety and sustainability benefits that can be achieved through the nationwide replacement of internal combustion engine vehicles (ICEVs) with battery electric vehicles (BEVs). A comprehensive life-cycle assessment (LCA) of BEVs is provided, covering the stages of raw material extraction, manufacturing, use, and end-of-life management. Key advantages of electrically powered vehicles are considered in the context of climate change mitigation, as BEVs emit approximately 50 % fewer greenhouse gases (GHGs) compared to their ICEV counterparts, with further reductions expected as electricity grids undergo decarbonization. Human health benefits include significant improvements in urban air quality due to zero tailpipe emissions and a reduction in noise pollution at low-speed operating conditions. The paper also assesses ecosystem impacts, noting that the shift in pollutant emissions during the BEV use phase — from tailpipes to power plants — generally results in net environmental gains. However, coal-dependent electricity generation may increase environmental toxicity and freshwater eutrophication. Circular economy strategies — such as battery reuse, material recycling, and sustainability-oriented product design — have the potential to significantly mitigate BEVs' environmental footprint. Integrating renewable energy sources for charging infrastructure, in conjunction with circular approaches, maximizes the potential for enhancing environmental safety through BEV adoption. Consequently, replacing ICEVs with BEVs can substantially reduce national environmental risks associated with the transport sector, provided that supportive policy frameworks ensure access to clean electricity and robust recycling infrastructure.

Keywords: *electric vehicles, life-cycle assessment, decarbonization, batteries, greenhouse gases, environmental safety, circular economy.*

Introduction

Battery electric vehicles (BEVs) are widely recognized for their potential to reduce the transport sector's environmental footprint. The EU's 7th Environment Action Programme envisions a circular economy with "nothing wasted" and transport emitting far lower greenhouse gases (GHG) and pollutants [1]. Replacing internal combustion engine vehicles (ICEVs) with BEVs can greatly diminish air pollutant emissions and noise in cities, and significantly cut life-cycle GHG emissions, thus advancing environmental safety and sustainability [1-2].

This paper goal is to provide a comprehensive, data-driven account of how electrifying the vehicle fleet enhances environmental safety and supports sustainability objectives.

Life-Cycle Environmental Impacts

Raw Materials Extraction

The BEV supply chain begins with mining and processing raw materials. BEVs require substantially more of certain materials (e.g. copper, aluminum, rare-earth metals) than ICEVs [3-4]. For example, BEVs use roughly four times more copper on average than a comparable ICEV [1]. Production of battery-grade materials (lithium, cobalt, nickel, graphite, etc.) is energy-intensive and polluting. Large volumes of energy and water are consumed, and emissions of CO_2 and toxic pollutants are released during mining and refining [4]. Metallurgical processes emit air pollutants (SO_2, NO_x, particulates) and heavy metals; mining disturbs land and risks soil/water contamination [4, 5].

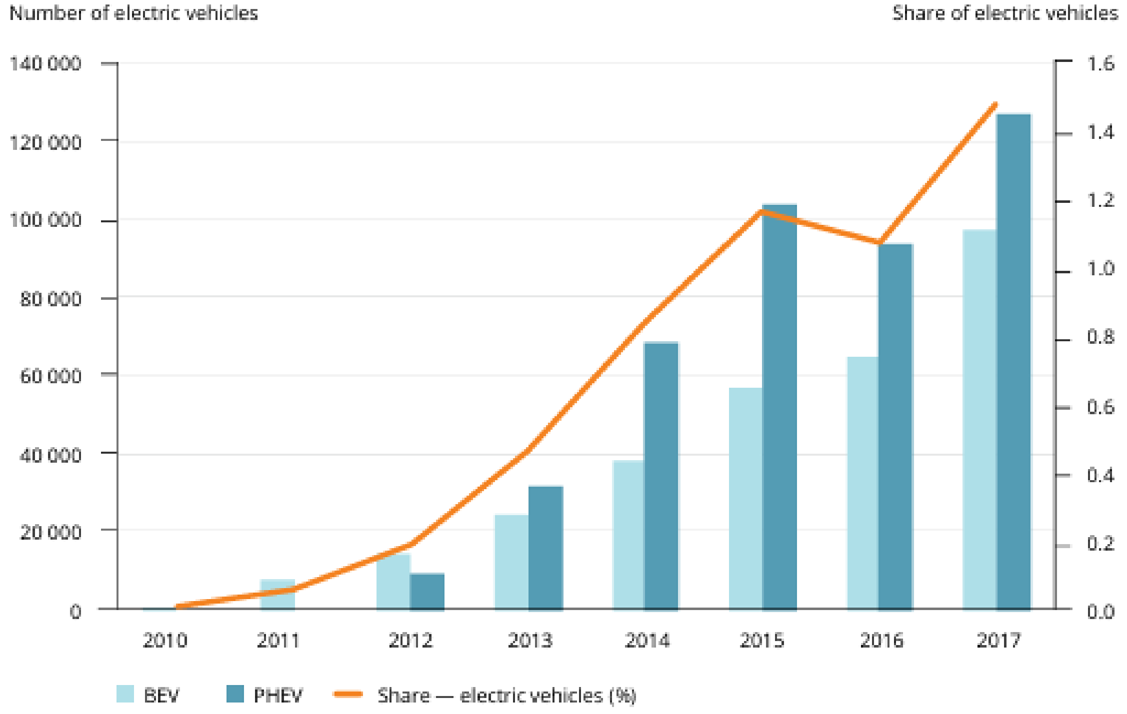

Figure 1. *Trends in the uptake of electric vehicles in the EU-28 over time [1]*

The depletion of scarce critical raw materials (CRMs) and rare earth elements (REEs) exacerbates these impacts by focusing extraction in regions with weaker environmental safeguards [6]. Consequently, BEVs' raw-material stage can have relatively higher GHG and toxicity impacts per vehicle than ICEVs [2, 7]. However, these up-front burdens are more than offset during the use phase by the absence of tailpipe emissions [2].

In summary, raw material extraction for BEVs carries substantial energy use, GHG emissions and ecological disturbance. Although raw-material impacts are important, they must be balanced against BEVs' downstream benefits. Mitigating these impacts calls for circular strategies (reuse, recycling, substitution) to reduce dependence on virgin materials [8].

Production (Manufacturing) Phase

BEV production emits more GHG and pollutants per vehicle than ICEV production, largely because of battery manufacture [9-11]. BEV manufacturing is electricity-intensive: most GHG emissions in the production phase come from powering factories and processing materials [11]. In particular, the battery pack dominates: studies find that Li-ion battery production often accounts for 30-50 % (or more) of a BEV's total production emissions [9, 10]. Depending on battery type and supply chain, *all* stages of battery production (from raw material processing to cell assembly) can contribute a large fraction of BEV manufacturing impacts [11].

Despite the higher initial impacts, these investment costs pay off over the vehicle's lifetime. For example, a medium-size BEV produced using the 2015 EU electricity mix emitted 60-76 gCO_2e per km driven, compared to ~143 gCO_2e/km for a similar ICEV in 2015, achieving ~50 % lower lifetime GHG use-phase emissions. Thus, even though BEV assembly has a higher carbon footprint, the life-cycle (production + use) typically favors BEVs under current and projected electricity mixes [2, 9]. Moreover, design choices (lighter materials, higher efficiency electronics) can reduce production impacts (using aluminum, carbon composites) [10].

Use-Phase Impacts

Climate Change Mitigation

The core climate benefit of BEVs is that they emit no CO_2 or other GHGs at the tailpipe. Emissions occur only upstream in electricity generation. When charged from a typical EU grid (2015 mix), a mid-sized BEV's well-to-wheel (WTW) CO_2 emissions were only 60-76 gCO_2e/km, versus 143 gCO_2e/km for the average ICE car at that time. This ~47-58 % reduction already means substantial climate mitigation [12].

Moreover, as the power sector decarbonizes, BEVs' advantage grows. The carbon intensity of the EU grid is projected to decrease from ~300 gCO_2e/kWh (2015) to ~80 gCO_2e/kWh by 2050 [13]. Accordingly, a typical BEV's emissions would drop from ~60 gCO_2e/km today to ~16 gCO_2e/km by 2050 (a 73 % reduction) [14]. In contrast, ICEVs have an upper bound set by combustion chemistry (around 250-300 gCO_2e/km even with advanced engines). Scenario analysis indicates that using low-carbon electricity (e.g. wind, nuclear) could make BEV lifetime emissions up to ~90 % lower than ICEVs, whereas charging from coal-fired grids can even invert the benefit [2].

Local Air Quality and Human Health

Replacing ICEVs with BEVs yields clear local air quality benefits. ICE cars emit NO_x, SO_2, CO and particulate matter (PM) at the tailpipe, whereas BEVs have zero exhaust emissions. This eliminates urban hotspots of NO_2 and PM10/2.5 from vehicles.

BEVs do still produce some particulates from tire and brake wear (and road dust resuspension) [15]. However, studies find that eliminating tailpipe PM and NOx usually outweighs this, especially since nonexhaust emissions (from tires/brakes) are similar for all vehicles. An important factor is the location of emissions: electric power plants are often sited away from dense population centers, so any pollution from electricity generation (like a coal plant) occurs outside urban airsheds. This advantage will grow as the electricity mix cleans up: as coal and oil generation fall, the net air quality benefit of BEVs will only increase [16].

Overall, BEVs significantly reduce population exposure to NO_2, CO and primary PM. This yields human health improvements (fewer respiratory and cardiovascular problems) and less ecological damage from acidification and eutrophication. International studies concur that electrification yields large local air quality gains [15]. The net effect is improved environmental safety – cleaner cities and healthier people – as long as the power sector is managed to minimize harmful emissions.

Noise Pollution

Electric motors run much more quietly than internal combustion engines. At low speeds in urban traffic, BEVs generate substantially less noise. The literature finds that "difference in noise emissions between BEVs and ICEVs strongly depends on vehicle speed" [17]. In stop-and-go city traffic or pedestrian areas, EVs can reduce noise annoyance by ~2-3 dB, which is noticeable at street level [18]. A mixed fleet of BEVs results in lower overall urban noise exposure for residents [17]. However, at higher speeds (above 30-40 km/h), tire and aerodynamic noise dominate, so EV and ICE cars are similarly loud. Real-world studies show that BEVs on highways are only marginally quieter than modern diesel cars [19]. In summary, BEVs contribute to traffic noise reduction mainly in urban low-speed conditions, improving comfort and reducing stress. The overall effect supports public health (better sleep, less annoyance), although acoustic alert systems may be needed for pedestrian safety.

Ecosystem and Other Impacts

The life-cycle impacts on ecosystems depend on both vehicles' emissions to air, water and soil. BEV usage indirectly affects ecosystems via power generation, mining and material processing, whereas ICEVs affect them via tailpipe and fuel production emissions. Figure 4 compares the use-stage impacts on several ecosystem categories. Terrestrial acidification is about equal between BEVs and ICEVs, because BEVs eliminate NOx emissions but ICEVs eliminate SO_2 from power plants - the net acidifying output is similar [18]. Terrestrial ecotoxicity (soil impacts) is also comparable, since it is largely driven by tire and brake metal wear (zinc, copper, etc.) which occur with any car [20].

However, BEVs show higher freshwater eutrophication and freshwater ecotoxicity impacts than ICEVs [1]. This counterintuitive result arises because mining and burning coal (for electricity) releases nutrients and metals into water bodies. In other words, coal-powered charging shifts some pollution to rivers and lakes. Reducing the use of coal for electricity generation would significantly reduce these impacts of BEVs [1]. In a greener grid scenario, BEVs would likely outperform ICEVs in almost all ecosystem categories. Other ecosystem effects not fully covered by Figure 2 include land use (mining footprint) and water use (for cooling power plants). Reducing these impacts requires stronger regulations on mining and continued power sector transformation.

In summary, BEVs dramatically improve air quality and reduce noise (urban health benefits) and cut lifecycle GHG. They impose some additional burdens (mining impacts, water pollutant emissions from power plants, battery toxicity). Nevertheless, most models show BEVs reduce overall air pollution and climate forcing relative to ICEVs [1, 18].

End-of-Life (EOL) and Circular Economy

At end-of-life, EV components must be managed safely. The large Li-ion batteries in BEVs contain metals and electrolytes that require careful handling. Current vehicle recycling practices must adapt to electric drivetrain specifics (e.g. more aluminum, rare-earth magnets in motors) [21]. Reuse and recycling of EV batteries and materials is crucial [9, 22]. Figure 3 illustrates the various EOL options for batteries: direct reuse in vehicles, cascaded reuse in stationary storage, remanufacturing, and material recycling (pyrometallurgy or hydrometallurgy). Each approach preserves value and reduces virgin material demand.

Circular economy strategies can significantly mitigate EV environmental impacts. For example, reusing a second-life battery in renewable energy storage avoids manufacturing a new pack, saving raw materials and energy [23]. Studies show that cascading one BEV battery in stationary storage can offset the production of ~11 new batteries (18 kWh each) [1]. Recycling recovers key metals (cobalt, nickel, copper, lithium, rare earths) that would otherwise require new mining. Table 1 summarizes common recycling processes: pyrometallurgy (smelting) and hydrometallurgy (leaching) can recover most battery metals [24]. A number of works note that *by 2021 more than 1/3 of the EU's cobalt demand could come from battery recycling,* though much supply still needs primary mining [25].

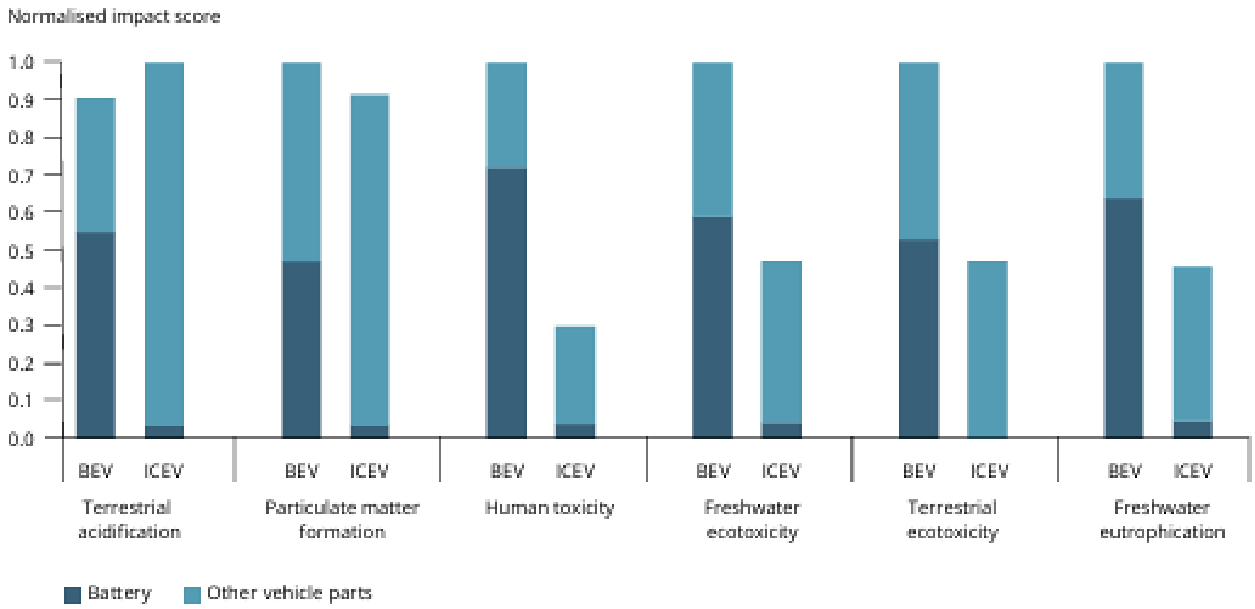

Figure 2. *Use-stage ecosystem impacts of BEVs* vs *ICEVs [1]*

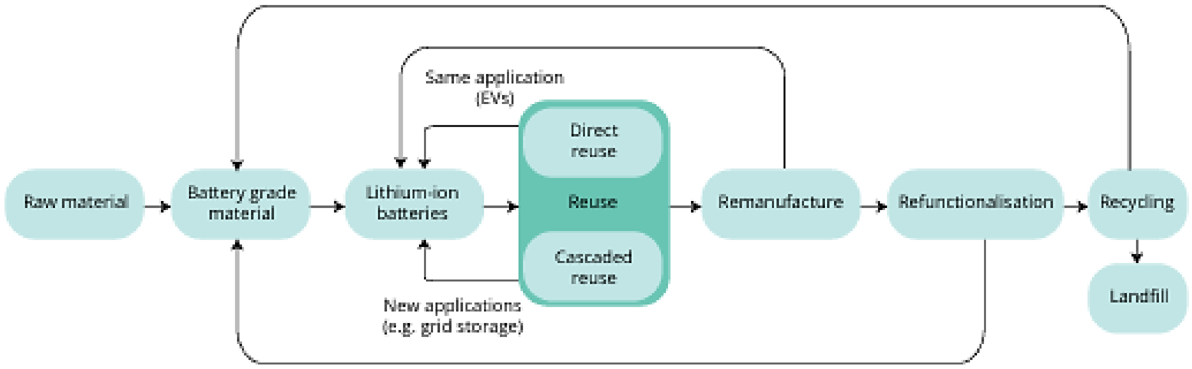

Figure 3. *Battery end-of-life pathways (adapted from Richa et al., 2017)*

Moreover, circular principles apply to vehicle design. For instance, using fewer rare-earth magnets in motors or replacing cobalt in cathodes with less-critical materials could preempt supply risks. Standardizing battery sizes and modules would facilitate remanufacturing and reuse. Overall, the combination of reuse, refurbishing, and recycling creates a closed loop: materials from end-of-life BEVs are fed back into new vehicles, dramatically reducing new extraction and energy use [21, 25].

In sum, the transition to BEVs brings inherently lower use-phase emissions, but also calls for circular economy solutions to address raw-material impacts. Employing these strategies will further enhance environmental safety: fewer toxic wastes, less mining footprint, and conservation of natural capital.

Table 1

Recycling process	Main processing steps	Recovered materials
Pyrometallurgy	Heating, smelting and refining	Cobalt, nickel, copper (oxidised), some iron
Pyrolysis	Shredding and smelting	Nickel, cobalt, copper
Hydrometallurgy	Hammer mill, leaching, purification and metal recovery	Copper, aluminium, cobalt, lithium carbonate

Conclusion

This in-depth review confirms that replacing ICE vehicles with BEVs significantly enhances national environmental safety. The life-cycle assessment shows that BEVs typically have higher upstream impacts (mining, production), but these are greatly outweighed by much lower use-phase emissions. With a modern European grid, BEVs emit roughly half the CO2 of ICE counterparts, and this gap will widen as power generation decarbonizes [12, 14]. Importantly, BEVs cut local air pollutants at the point of use, markedly improving urban air quality and reducing health risks [1]. Noise pollution is also reduced in city traffic. While BEVs do involve intensive mineral extraction, implementing circular economy measures (battery reuse, high recycling rates, design for low material use) can substantially mitigate these supply-chain impacts [24]. Our analysis highlights that realizing the full safety benefits requires clean electricity and strong recycling infrastructure. In sum, the shift to electric passenger cars is a crucial step toward a cleaner, safer environment, providing climate, health and ecosystem gains when combined with supportive policies on energy and materials management.

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ПІДВИЩЕННЯ НАЦІОНАЛЬНОЇ ЕКОЛОГІЧНОЇ БЕЗПЕКИ ШЛЯХОМ ЗАМІНИ ТРАДИЦІЙНИХ ТРАНСПОРТНИХ ЗАСОБІВ ЕЛЕКТРОМОБІЛЯМИ

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Анотація
У цьому дослідженні розглядаються переваги екологічної безпеки та сталого розвитку, які можуть бути досягнуті шляхом заміни транспортних засобів з двигунами внутрішнього згоряння (ДВЗ) на акумуляторні електромобілі (БЕМ) у національному масштабі. Надається комплексна оцінка життєвого циклу БЕМ, що охоплює етапи видобутку сировини, виробництва, використання та завершення терміну служби. Ключові переваги електромобілів з електричним живленням розглядаються з точки зору пом'якшення зміни клімату, оскільки БЕМ викидають приблизно вдвічі менше парникових газів, ніж аналогічні ДВЗ, з подальшим їх скороченням в разі декарбонізації мереж. Переваги для здоров'я людини включають значне покращення якості міського повітря завдяки нульовим викидам вихлопних газів та зменшенню шумового забруднення в умовах низьких швидкостей. У роботі також аналізується вплив на екосистеми: зазначається, що перенесення забруднюючих речовин на стадії використання БЕМ — від вихлопних газів до електростанцій — зазвичай призводить до чистих екологічних вигод, хоча електроенергія, що залежить від вугілля, може підвищити токсичні впливи на довкілля та рівень евтрофікації водойм. Стратегії циркулярної економіки — повторне використання акумуляторів, переробка матеріалів та проєктування з урахуванням сталого розвитку — можуть значно пом'якшити вплив електромобілів на навколишнє середовище. Комплексне використання відновлюваної енергії для заряджання разом з циркулярними підходами максимізує можливості зміцнення екологічної безпеки від впровадження електромобілів. Отже, заміна транспортних засобів з ДВЗ на БЕМ суттєво знижує національні екологічні ризики від транспорту, за умови, що підтримуюча політика забезпечує чисту електроенергію та надійну інфраструктуру переробки.

Ключові слова: електромобілі, життєвий цикл, декарбонізація, акумуляторні батареї, парникові гази, екологічна безпека, циркулярна економіка.