International Journal on Robotics, Automation and Sciences

Environmental and Social Burdens of Electric Vehicle Battery Lifecycles

B. Abdul Hakkim, M. Mubeen Tajudeen*, Grienggrai Rajchakit

Abstract **– Electric vehicles (EVs) are widely promoted as a sustainable alternative due to their ability to reduce greenhouse gas emissions. However, the environmental and social impacts of EV battery production are often overlooked. This paper examines the hidden environmental costs of EV batteries using a lifecycle assessment approach, covering raw material extraction, manufacturing, transportation, usage, recycling, and disposal. Special emphasis is placed on lithium and cobalt mining, including the issue of child labor. Environmental justice concerns, health risks, and policy challenges are also discussed, along with mitigation strategies and future technological alternatives for sustainable electric mobility.**

Keywords—Electric Vehicles, EV Batteries, Lithium Mining, Child Labor, Environmental Impact, Sustainability.

I. Introduction

The global transition toward electric vehicles (EVs) has emerged as a key strategy for reducing greenhouse gas emissions and dependence on fossil fuels. Governments worldwide support EV adoption through subsidies, regulations, and investments in charging infrastructure. Powered primarily by lithium-ion batteries, EVs produce zero tailpipe emissions and are widely viewed as a cleaner alternative to internal combustion engine vehicles.

However, the rapid shift to electrification has obscured significant environmental and social challenges associated with EV battery production. Lithium-ion batteries require large quantities of critical raw materials such as lithium, cobalt, and nickel, whose extraction and processing impose serious ecological impacts [1]-[4]. These impacts include water scarcity caused by lithium brine extraction [5], land degradation from open-pit mining, and the generation of toxic waste [6]. In addition to environmental damage, human rights concerns persist within battery supply chains, particularly child labor and unsafe working conditions in artisanal mining regions [7]. To fully evaluate the sustainability of electric mobility, it is essential to consider the entire lifecycle of EV batteries [8]. This article examines the hidden environmental costs associated with battery production, use, and disposal by reviewing scientific studies, lifecycle assessments, and real-world case studies [9]. The objective is to provide a balanced understanding of the environmental burden of EV batteries and to highlight pathways for reducing these impacts through sustainable technologies, recycling strategies, and policy interventions [10].

*Corresponding Author email: mubeentajudeen@tdtu.edu.vn, ORCID: 0000-0002-2882-1340
B. Abdul Hakkim is with Department of Electronics & Communication Engineering, Dhanalakshmi Srinivasan University, Perambalur, Tamil Nadu, India. (e-mail: abdulhakkima827@gmail.com)
M. Mubeen Tajudeen is with Faculty of Mathematics and Statistics, Ton Duc Thang University, Ho Chi Minh City, Vietnam. (e-mail: mubeentajudeen@tdtu.edu.vn)
Grienggrai Rajchakit is with Department of Mathematics, Faculty of Science, Maejo University, Sansai 50290, Ching Mai, Thailand. (e-mail: kreangkri@mju.ac.th)

International Journal on Robotics, Automation and Sciences (2026) 8, 2:80-86
https://doi.org/10.33093/ijoras.2026.8.2.10
Manuscript received: 08 Feb 2026 | Revised: 24 Apr 2026 | Accepted: 11 May 2026 | Published: : 31 Jul 2026

Published by MMU PRESS. URL: http://journals.mmupress.com/ijoras

This study presents a holistic Life Cycle Assessment (LCA) perspective on electric vehicle batteries and their role in green transportation. While EVs are widely promoted for their zero tailpipe emissions, a complete sustainability assessment must also consider the upstream and downstream impacts associated with battery production and disposal. In particular, the extraction of critical raw materials such as lithium and cobalt, the energy-intensive manufacturing process, and the challenges of end-of-life management contribute significant environmental and social burdens. By examining these stages together, this paper provides a more balanced view of the true cost of electric mobility and highlights the need for cleaner production, responsible sourcing, and effective recycling strategies.

II. Background and Literature Review

A. EV Battery Technologies

Electric vehicles predominantly use lithium-ion battery technology due to its high energy density, recyclability, and declining cost. Common chemistries include lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), and lithium nickel cobalt aluminum oxide (NCA). Each chemistry presents trade-offs in terms of energy density, safety, cost, and material requirements.

B. Lifecycle Assessment (LCA) Framework

Lifecycle assessment (LCA) is a method for analyzing the environmental impacts associated with all stages of a product's life — from raw material extraction through manufacturing, use, and disposal or recycling. LCA is critical for understanding the often hidden environmental "costs" of EV batteries, as it goes beyond tailpipe emissions and considers upstream and downstream effects.

C. Key Issues in Current Research

Previous work has highlighted several issues:

• High energy use and carbon emissions during battery manufacturing.

• Significant water consumption and land degradation from raw material extraction.

• Toxic chemical pollution and waste from processing minerals.

• Challenges in recycling and safe disposal of spent batteries.

The case studies and reports included in this review were selected based on three main criteria: relevance to electric vehicle battery lifecycle impacts, availability of reliable and recent data, and direct discussion of environmental or social burdens associated with raw material extraction, manufacturing, use, recycling, or disposal. Priority was given to peer-reviewed journal articles, authoritative reports, and studies published between 2021 and 2025 that provided clear and comparable findings on lithium, cobalt, battery manufacturing emissions, recycling challenges, and related sustainability issues. Studies that lacked sufficient methodological detail, focused only on general EV adoption without battery lifecycle analysis, or did not provide useful evidence for the present discussion were excluded.

III. Raw Material Extraction: Ecological and Social Costs

A. Lithium Mining and Water Scarcity

Lithium — the key element in most EV batteries — is primarily extracted in salt flats (salars) in Chile, Argentina, and Bolivia through brine evaporation techniques. This process requires vast amounts of water to pump underground brine to the surface. Research shows that lithium extraction significantly reduces available freshwater in regions already challenged by arid climates, harming local agriculture and ecosystems.

The environmental burdens of EV battery raw material extraction vary significantly by region and mining method. In the Lithium Triangle of South America, lithium is often extracted from brine operations in arid areas, where water consumption can intensify local water stress and affect surrounding ecosystems and communities. In contrast, hard-rock lithium mining in regions such as Australia typically involves more land disturbance, energy use, and processing-related emissions. These regional differences show that the environmental and social impacts of battery supply chains are not uniform, and they reinforce the importance of environmental justice, since the burdens are often concentrated in specific communities while the benefits of EV adoption are distributed elsewhere.

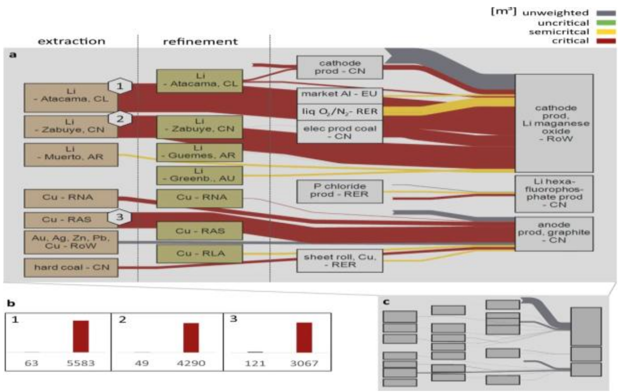

FIGURE 1. Distribution of process water uses along the supply chain.

For example, in the Atacama Desert of northern Chile, lithium operations have drained water from local aquifers, contributing to soil salinization and the loss of wetlands critical for biodiversity. Local communities have protested due to water shortages that affect livestock, farming, and human consumption.

B. *Cobalt Mining and Child Labor*

Cobalt, used in many high-energy lithium ion batteries, is largely mined in the Democratic Republic of the Congo (DRC), where artisanal and small-scale mining (ASM) accounts for a significant proportion of global supply. These artisanal mines are often informal, unregulated, and hazardous:

• Children as young as eight have been documented working long hours in cobalt mines without protective equipment.

• Workers face life-threatening risks such as tunnel collapses, exposure to toxic dust, and chemical hazards.

Human rights organizations have repeatedly reported child labor, exploitation, and unsafe conditions in these mines, raising ethical and environmental justice concerns about the EV supply chain.

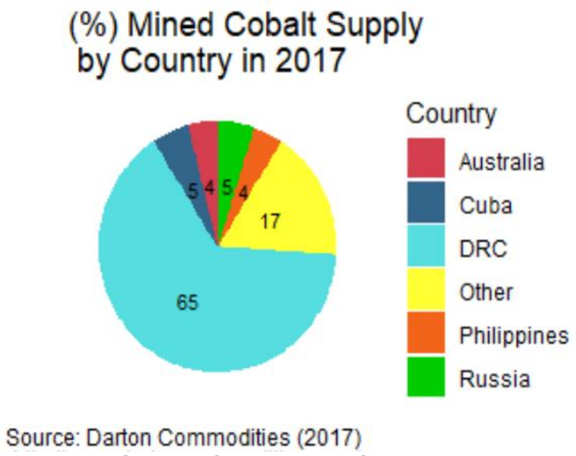

FIGURE 2. Cobalt Mining Countries.

C. *Nickel and Other Critical Materials*

Nickel, manganese, and graphite are also crucial to battery performance but come with their own ecological footprints. Nickel mining often involves open-pit techniques that strip vegetation and topsoil, disturb habitats, and create large amounts of waste rock. Processing operations can release sulfur dioxide and other pollutants into the air and water, threatening human health and ecosystems.

D. *Habitat Destruction and Biodiversity Loss*

All forms of raw material extraction disturb landscapes and ecosystems. Mining operations require substantial land areas for open pits, tailings storage, and infrastructure. This disrupts wildlife habitats, fractures ecosystems, and can lead to biodiversity loss.

IV. MANUFACTURING EMISSIONS &ENERGY USE

A. *High Energy Intensity*

Producing lithium-ion batteries is energy intensive. The electricity used in production often comes from fossil fuels, especially in countries where manufacturing is concentrated — such as China. As a result, emissions from battery manufacturing can be significant, sometimes offsetting a large portion of the emissions savings achieved during the vehicle's use phase. Studies estimate that battery production can contribute hundreds of kilograms of CO_2 per kilowatt-hour of battery capacity.

B. *Regional Differences*

The environmental impact of battery manufacturing varies by region depending on energy sources:

• In regions with coal-dependent grids, manufacturing emissions are higher.

• Regions using renewable energy sources (like hydroelectric or solar) produce cleaner batteries.

Reducing manufacturing emissions will require transitioning factories to renewable energy and improving production efficiency.

TABLE 1. Environmental Impacts Across EV Battery Lifecycle.

Lifecycle Stage	***Environmental Impact***	***Social Impact***
Mining	Water depletion, land degradation	Child labor, health risks
Manufacturing	High CO_2 emissions	Worker exposure
Usage	Indirect emissions	Minimal
End-of-Life	Toxic waste	Recycling labor risks

V. END-OF-LIFE CHALLENGES: RECYCLING AND WASTE

A. *Composition and Hazardous Nature of Spent Batteries*

Electric vehicle batteries contain hazardous materials such as lithium compounds, cobalt, nickel, manganese, and electrolytes that pose serious environmental and health risks if not managed properly. When spent batteries are disposed of in landfills or damaged during handling, these substances can leak into soil and groundwater, leading to long-term contamination and ecosystem damage.

B. *Battery Disposal Risks*

Spent EV batteries contain toxic materials like heavy metals that pose environmental and health risks if disposed of in landfills. Leaching of these substances into soil and groundwater threatens ecosystems and community health.

C. *Recycling Complexity*

Recycling lithium-ion batteries is technically challenging and currently economically unattractive without strong policy incentives. Only a small percentage of EV batteries are recycled globally. The process must recover valuable materials like lithium, cobalt, and nickel efficiently. Current recycling technologies vary in effectiveness and often focus on recovering cobalt and nickel while lithium recovery remains lower.

D. Economic Barriers and Low Recycling Rates

The high cost of collection, transportation, and processing often outweighs the economic value of recovered materials, especially for lithium. As a result, global recycling rates for EV batteries remain low. Developing cost-effective recycling technologies and establishing regulatory incentives are essential to improve recycling rates and conserve critical resources.

E. Potential for Resource Optimization

Improved recycling could:

• Reduce the need for virgin raw material extraction.

• Lower the environmental footprint of battery production.

• Provide economic incentives for domestic supply chains.

However, scaling these technologies will require investment, innovation, and supportive regulation.

VI. Pollution, Health Risks & Environmental Justice

A. Air and Water Pollution

Mining and processing release particulate matter and toxic chemicals into air and water systems. In mining regions, communities often suffer from respiratory issues, contaminated drinking water, and impaired agricultural lands due to pollution.

B. Human Health Impacts

Exposure to heavy metals such as cobalt, nickel, and lithium compounds can cause neurological, respiratory, and skin problems. Workers without protective gear face elevated risks of long-term health conditions.

C. Environmental Justice Concerns

The environmental burdens of mining operations are disproportionately borne by vulnerable, low-income communities. Residents near mining sites — often in developing countries — face degraded environments with limited access to healthcare or clean water, while consumers in affluent nations benefit from cleaner driving experiences.

This study extends beyond conventional engineering assessments by highlighting the social dimensions of EV battery lifecycles, including child labour, unsafe mining conditions, and environmental justice concerns. These issues are central to ethical technology development because the benefits of electric mobility should not come at the expense of vulnerable communities involved in raw material extraction and processing. A truly sustainable transition to electric vehicles must therefore address not only carbon reduction and battery performance, but also the fairness, safety, and transparency of global supply chains. By incorporating these social burdens into the lifecycle discussion, the present work provides a more balanced and responsible perspective on green transportation.

This inequity raises questions of environmental justice: who bears the cost of “green” technologies, and who receives the benefits?

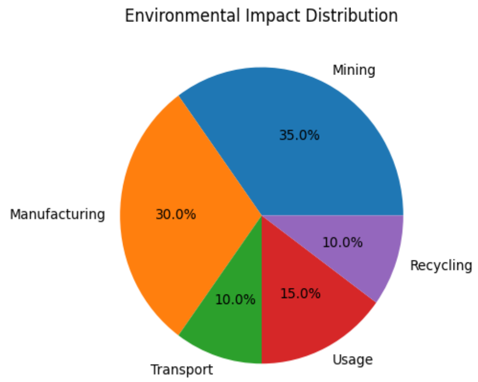

FIGURE 3. Environmental Impact Distribution.

VII. Case Studies and Data Analysis

A. Chile’s Atacama and Water Stress

The Atacama Desert, one of the driest places on Earth, has become a focal point of lithium extraction. The water intensity of brine pumping exacerbates an already fragile water balance, threatening local indigenous communities and ecosystems that depend on scarce freshwater resources.

B. Cobalt Mining in the DRC

The Democratic Republic of the Congo supplies over 60% of the world’s cobalt. Artisanal miners — including children — extract cobalt by hand, often without safety gear or labor protections. Numerous reports have documented children descending into mine shafts to search for ore, risking collapses and exposure to toxic dust.

C. Lifecycle Emissions Comparison

A typical EV with a 60-kWh battery may incur around 4–6 tons of CO_2 emissions from battery production alone, depending on the energy mix used during manufacturing. This “upfront” carbon debt must be offset by lower emissions during the vehicle’s use phase — which occurs faster in countries with cleaner electricity grids.

VIII. Transportation and Supply Chain Impacts

A. Global Distribution of Raw Materials

Electric vehicle batteries depend on raw materials that are geographically dispersed across the world. Lithium is mainly extracted in South America and Australia, cobalt in the Democratic Republic of the Congo, nickel in Southeast Asia, and graphite largely in China. These materials are rarely processed or used in the same region where they are mined, resulting in long-distance transportation across continents.

B. Emissions from Transportation

The movement of raw materials and battery components involves multiple transportation modes, including maritime shipping, road freight, and rail transport. Maritime shipping, which often uses heavy fuel oil, emits significant amounts of carbon dioxide, sulfur oxides, and particulate matter. Road transportation using heavy-duty trucks further increases greenhouse gas emissions and contributes to air pollution.

C. Multi-Stage Supply Chain Complexity

The EV battery supply chain involves several stages, including mining, refining, cell manufacturing, battery pack assembly, and vehicle integration. Each stage requires additional transportation, increasing cumulative energy consumption and emissions. This fragmented supply chain significantly adds to the overall environmental footprint of EV batteries.

D. Environmental and Social Implications

Beyond emissions, supply chain transportation leads to land-use changes, habitat disruption, and increased risk of marine pollution. The complexity of global supply chains also makes it difficult to monitor environmental regulations and labor practices, indirectly contributing to ethical issues such as unsafe working conditions.

Key Details: Raw materials and battery components are often transported across continents, increasing emissions. The globalized supply chain adds to the overall environmental footprint of EV batteries.

IX. Mitigation Strategies and Solutions

A. Sustainable Mining Practices

Improving mining regulation and technology can reduce water use, pollution, and habitat destruction. Solutions include:

- More efficient water management techniques.
- Reclamation and restoration of mining sites.
- Transparency and certification programs for ethical sourcing.

B. Improving Battery Chemistry

Research into alternative chemistries (such as LFP batteries which do not require cobalt) can reduce reliance on conflict minerals and improve safety. Solid-state batteries and sodium-ion batteries are emerging candidates with potentially lower environmental footprints.

C. Renewable Energy in Manufacturing

Shifting battery production facilities to renewable energy reduces carbon emissions from manufacturing. Solar, wind, and hydroelectric power can help decarbonize supply chains.

D. Recycling and Circular Economy

Investing in recycling infrastructure and technologies that efficiently recover lithium, cobalt, and nickel will reduce the need for virgin material extraction. Incentivizing battery reuse (e.g., repurposing EV batteries for stationary storage) extends lifetime value.

E. Policy and Regulation

Governments can implement policies such as:

- Extended Producer Responsibility (EPR)
- Mandatory recycling targets
- Ethical sourcing requirements
- Transparency standards for supply chains

Such measures can align industry incentives with environmental and social goals.

Automation can play an important role in reducing the social and environmental burdens associated with EV battery lifecycles. In mining, automated drilling, hauling, sorting, and monitoring systems can reduce human exposure to hazardous conditions, improve operational safety, and enhance efficiency in water and energy use. In battery recycling, robotic disassembly and automated material recovery can minimize worker contact with toxic substances, improve recovery rates for valuable metals, and support safer and more consistent recycling operations. These technologies can therefore help reduce labor-related risks, lower environmental impacts, and make battery supply chains more sustainable. From the perspective of green transportation, such automation-based solutions strengthen the case for cleaner and more responsible electric mobility.

X. Future Technologies

A. Solid-State Batteries

Solid-state batteries are considered a promising next-generation energy storage technology for electric vehicles. Unlike conventional lithium-ion batteries that use liquid electrolytes, solid-state batteries employ solid electrolytes, which improve safety by reducing the risk of leakage and fire. These batteries offer higher energy density, longer lifespan, and faster charging capabilities. Importantly, solid-state technology can reduce the amount of critical materials such as cobalt and nickel, thereby lowering the environmental and social impacts associated with mining activities.

B. Sodium-Ion Batteries

Sodium-ion batteries are emerging as an alternative to lithium-based systems due to the abundance and low cost of sodium. Sodium is widely available and does not require environmentally intensive mining processes like lithium or cobalt.

To better contextualize future battery options, a comparative summary of current Li-ion batteries and emerging alternatives such as sodium-ion and solid-state batteries can be included. Recent life cycle studies show that the environmental advantage of alternative chemistries depends not only on material composition, but also on manufacturing design, recycling pathway, and battery lifetime.

E-ISSN: 2682-860X

TABLE 2. Comparative environmental footprint of current and emerging battery chemistries.

Battery type	***Key environmental points from recent literature***	***Notes***
Li-ion batteries	Current benchmark technology; production is material- and energy-intensive, with reported cradle-to-gate impacts around 58–92 kg CO_2-eq per kWhcell in one 2024 study chemistryforsustainability.	Strong established supply chain, but relies on lithium, cobalt, nickel, and intensive recycling.
Sodium-ion batteries	Often presented as a lower-mineral alternative because sodium is abundant, but reported production impacts can still be similar to or slightly higher than some Li-ion designs, around 75–87 kg CO_2-eq per kWhcell in the same 2024 study chemistryforsustainability.	Benefits depend on design, lifetime, and manufacturing route.
Solid-state batteries	Considered promising for safety and energy density, but a 2026 study found recycling-stage burdens can be higher than Li-ion, and life-cycle benefit depends heavily on lifespan pubs.rsc.	Potentially sustainable, but not automatically lower-impact across all stages.

Although sodium-ion batteries currently have lower energy density compared to lithium-ion batteries, ongoing research is improving their performance. Their reduced reliance on scarce minerals makes them a more environmentally sustainable option, particularly for large-scale and low-cost applications.

C. Environmental Benefits and Sustainability Potential

Both solid-state and sodium-ion batteries have the potential to significantly reduce the environmental footprint of electric vehicles. By minimizing the use of critical and conflict minerals, these technologies can decrease mining-related pollution, resource depletion, and ethical concerns such as child labor. Continued investment in research and development, along with supportive policies, will be essential to accelerate the adoption of these sustainable battery technologies.

TABLE 3. Mitigation Strategies for Sustainable EV Battery Lifecycles.

Category	***Mitigation strategy***	***Example***
Technical	Improve battery chemistry to reduce cobalt use	Solid-state batteries, sodium-ion batteries
Policy-based	Regulate ethical sourcing	Supply chain transparency, mining standards
Corporate/Ethical	Invest in cleaner manufacturing	Renewable energy use in factories

XI. Policy and Regulation

A. Ethical Sourcing and Supply Chain Transparency

Governments play a crucial role in enforcing ethical sourcing of raw materials used in electric vehicle batteries. Regulations that require supply chain transparency help ensure that materials such as lithium and cobalt are extracted without human rights violations, including child labor and unsafe working conditions. Certification schemes and mandatory reporting can improve accountability across global supply chains.

B. Environmental Standards for Mining and Manufacturing

Strict environmental regulations are essential to reduce pollution and ecosystem damage caused by mining and battery manufacturing activities. Governments can enforce limits on water usage, emissions, and waste disposal while mandating environmental impact assessments before approving mining and production projects. Such standards help minimize long-term environmental degradation.

C. Extended Producer Responsibility (EPR)

Extended Producer Responsibility policies require battery manufacturers and vehicle producers to take responsibility for batteries throughout their entire lifecycle, including collection, recycling, and disposal. EPR frameworks encourage the development of recycling infrastructure and promote eco-design practices that make batteries easier to recycle.

D. International Cooperation and Policy Alignment

Since EV battery supply chains are global, international cooperation is necessary to harmonize regulations and standards. Collaborative policies can prevent environmental damage from shifting to regions with weaker regulations and ensure a fair and sustainable transition to electric mobility. Key Details: Governments must enforce ethical sourcing, environmental standards, and extended producer responsibility to reduce the hidden costs of EV batteries.

XII. Conclusion

Electric vehicles present a promising route toward reducing tailpipe emissions and mitigating climate change. However, the transition to electrified transport is not without hidden environmental and social costs — especially within the battery lifecycle. From water stress and ecosystem degradation due to lithium extraction to human rights abuses like child labor in cobalt mining, the production and disposal phases of EV batteries carry significant burdens. These impacts are often externalized, borne by vulnerable communities in resource-rich regions while benefits accrue to wealthier consumer markets.

A truly sustainable mobility future requires comprehensive strategies that address these hidden costs: improved mining practices, ethical sourcing, cleaner manufacturing, robust recycling infrastructure, and thoughtful policy frameworks.

Only by acknowledging and tackling the full spectrum of environmental and social impacts can EVs fulfill their promise as a genuinely green transportation solution.

Solid-state & sodium ion batteries are offer improved safety and higher energy density for electric vehicles while reducing reliance on critical materials such as cobalt and nickel, thereby supporting more sustainable electric mobility.

A truly sustainable EV lifecycle depends on several critical success factors. First, raw material sourcing must be ethical, transparent, and free from human rights abuses such as child labour and unsafe mining conditions. Second, battery manufacturing should rely on cleaner energy sources and efficient production processes to reduce carbon emissions and resource use. Third, robust recycling and circular economy systems are essential to recover valuable materials, reduce dependence on virgin mining, and minimize end-of-life waste. Together, these factors define the pathway toward sustainable and responsible electric mobility.

Acknowledgment

The authors would like to express sincere appreciation to peer reviewers for their careful consideration and review of this work.

Funding Statement

There is no funding agencies supporting the research work.

Author Contributions

B. Abdul Hakkim: Investigation, Data collection, Implementation, Writing – original draft preparation.

M. Mubeen Tajudeen: Conceptualization, Methodology, Supervision, Formal analysis, Writing – review and editing, Corresponding author.

Grienggrai Rajchnkit: Validation, Resources, Project administration, Writing – review and editing.

Ethics Statements

This project does not require ethical approval as there is not involved human participants, animals, or sensitive data.

Declaration of AI-assisted Technologies in the Writing Process

No artificial intelligence tools were used in the research or writing of this article.

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