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Article

Critical Materials for EV Batteries: Challenges, Opportunities, and Policymakers

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Abstract: Electric vehicles (EVs) are essential to the global energy transition, but their growing adoption increases demand for critical battery materials such as lithium, cobalt, nickel, and graphite. This article examines the composition and chemistry of EV batteries, highlighting advancements in energy density and material efficiency through solid-state, LFP, and sodium-ion batteries. While battery manufacturing capacity is set to triple by 2030, challenges such as geopolitical dependencies, environmental concerns, and supply chain vulnerabilities persist. Opportunities for sustainable material sourcing include responsible mining, recycling initiatives, and diversification of supply chains. Policymakers play a vital role in ensuring a stable and ethical EV battery supply, with recommendations focusing on accelerating R&D, enhancing circular economy efforts, and improving regulatory frameworks. A holistic approach integrating technological innovation, policy intervention, and industry collaboration is crucial to securing a sustainable and resilient EV battery ecosystem for the future.

Keywords: Electric Vehicle (EV) Batteries, Critical Materials, Battery Chemistry and Energy Efficiency, Policy and Technological Innovation.

1. Introduction

The transition toward electrified transportation, driven by the global imperative to reduce greenhouse gas emissions and fossil fuel dependence, has intensified the demand for electric vehicles (EVs) and, consequently, the lithium-ion batteries (LIBs) that power them [1-3]. These batteries rely heavily on a set of critical raw materials, including lithium, cobalt, nickel, and manganese, which are essential for ensuring high energy density, thermal stability, and extended lifecycle performance. However, the rapid scale-up of EV production has brought to the forefront significant challenges related to the sustainable supply, geopolitical risk, and environmental impact associated with the extraction and processing of these materials [4-7].

Facilitating the global energy transition necessitates the widespread adoption of electric vehicles (EVs) as the predominant mode of passenger transportation by 2030. As of 2023, the global fleet of passenger EVs comprised approximately 44 million units. However, to align 1.5°C Scenario, this figure must undergo a substantial expansion, reaching an estimated 359 million by the end of the decade [8-10]. This imperative for electrification is not confined solely to passenger transport but extends across all road transport sectors, including those historically regarded as infeasible for electrification, such as long-haul freight transport.

Although the outlook for EV battery production capacity remains promising, ensuring a stable, sufficient, and cost-effective supply of critical raw materials is paramount. According to 1.5°C Scenario, the electrification of road transport necessitates a fivefold increase in the annual production of EV batteries between 2023 and 2030 [11-14]. While the projected battery production capacity for 2030—estimated at 7,300 gigawatt-hours (GWh) per year—surpasses the anticipated demand of 4,300 GWh per year, sustained and coordinated efforts remain imperative to secure the requisite raw materials essential for large-scale battery manufacturing [15-17]. A number of previous studies have examined the challenges and considerations surrounding critical materials for electric vehicle batteries, as summarized below.

According to Chen et al. [18], the rapid proliferation of lithium-ion batteries (LIBs) in electric vehicles is expected to result in a substantial volume of spent LIBs in the near future. To address this impending challenge, three principal end-of-life management strategies are identified: remanufacturing, repurposing, and recycling. While remanufacturing and repurposing aim to extend the functional lifespan of batteries through secondary applications, recycling plays a critical role in closing the material loop by recovering and reintegrating valuable materials into the production value chain. The primary recycling approaches for spent LIBs include pyrometallurgy, hydrometallurgy, and direct recycling, each with distinct mechanisms and implications for material recovery efficiency and environmental impact.

Ma et al. [19] emphasize the importance of optimizing end-of-life treatment pathways for retired electric vehicle (EV) batteries, considering both economic viability and environmental sustainability. Their proposed strategy is applied across various secondary-use scenarios, including energy storage systems, communication base stations, and low-speed electric vehicles, each with distinct capacity configurations. At the end-of-life stage, the study evaluates hydrometallurgical, pyrometallurgical, and direct recycling approaches, factoring in the residual value of the batteries. The findings reveal that for the optimized reuse-recycling pathway, lithium iron phosphate (LFP) batteries yield a 58% increase in profit and an 18% reduction in emissions compared to hydrometallurgical recycling without prior reuse. Similarly, lithium nickel manganese cobalt oxide (NMC) batteries demonstrate a 19% profit increase and an 18% reduction in emissions.

Jiang et al. [20], highlights that the impact of recycling and reusing EV batteries on reducing material demand and carbon emissions. Integrating a national-level vehicle stock turnover model with life-cycle carbon emission assessment, we found that replacing nickel-cobalt-manganese batteries with lithium iron phosphate batteries with battery recycling can reduce lithium, cobalt, and nickel demand between 2021 and 2060 by up to 7.8 million tons (Mt) (67%), 12.4 Mt (96%), and 37.2 Mt (93%), respectively, significantly decreasing reliance on import. Moreover, battery recycling coupled with reuse can reduce carbon emissions by up to 6,532-6,864 Mt (36.0-37.9%), depending on four recycling methods employed.

Xu et al. [21] emphasize that, under a lithium nickel cobalt manganese oxide (NCM)-dominated battery scenario, the global demand for critical materials is projected to rise dramatically between 2020 and 2050. Specifically, lithium demand is expected to increase by a factor of 18–20, cobalt by 17–19, nickel by 28–31, and most other associated materials by 15–20. This anticipated surge necessitates a substantial expansion of global supply chains for lithium, cobalt, and nickel, as well as the likely discovery of new resource deposits. However, the projections are subject to considerable uncertainty, primarily driven by the pace of electric vehicle (EV) adoption and the battery capacity requirements per vehicle. A large-scale shift to alternative chemistries—such as lithium iron phosphate (LFP), lithium–sulphur, or lithium–air batteries—could significantly reduce reliance on cobalt and nickel.

This article contributes to the ongoing discourse on sustainable energy transitions by providing a comprehensive analysis of the material composition and evolving chemistry of electric vehicle (EV) batteries, with a particular focus on emerging technologies such as solid-state, lithium iron phosphate (LFP), and sodium-ion batteries. It underscores the criticality of lithium, cobalt, nickel, and graphite in battery production and highlights the projected expansion of manufacturing capacity by 2030. By contextualizing the persistent challenges—geopolitical dependencies, environmental impacts, and supply chain fragility—the study advances a nuanced understanding of the systemic risks confronting large-scale EV deployment. Moreover, this work identifies actionable pathways for sustainable material sourcing, including responsible mining practices, battery recycling innovations, and supply chain diversification. It offers policy-driven recommendations aimed at accelerating research and development, strengthening circular economy initiatives, and enhancing regulatory mechanisms. The article's integrative framework—linking technological advancement, policy intervention, and industrial collaboration—serves as a strategic roadmap for fostering a robust, ethical, and resilient EV battery ecosystem. As such, the study provides valuable insights for stakeholders across academia, industry, and government working to align energy innovation with sustainability imperatives.

2. Methodology

This study employs a comprehensive, multi-disciplinary approach to examine the challenges, opportunities, and policymaker interventions in securing critical materials for electric vehicle (EV) batteries. The methodology integrates qualitative and quantitative analysis, drawing on academic literature, industry reports, policy documents, and market data to provide an in-depth understanding of key factors influencing EV battery supply chains.

3. The Role of EVs in the Energy Transition

The global energy transition necessitates fundamental transformations in national energy systems, with electrification emerging as a pivotal strategy across end-use sectors, including buildings, transport, and industry [22-26]. Currently, electricity accounts for approximately 20% of total final global energy consumption. However, in alignment with a 1.5°C decarbonization pathway, electricity is projected to become the dominant energy carrier, surpassing 50% of total final global energy consumption by 2050 [27-33].

This shift would result in a threefold increase in global electricity demand, predominantly supplied by renewable energy sources, which are expected to account for 91% of total electricity generation. Electric vehicles (EVs) will play a critical role in this transition, driving the electrification of the transport sector, reducing dependence on fossil fuels, and enabling greater grid integration through technologies such as vehicle-to-grid (V2G) systems [34-38]. As EV adoption accelerates, ensuring sustainable battery production, charging infrastructure expansion, and grid modernization will be essential to maximizing their contribution to a low-carbon, renewable-powered energy future. Figure 1 illustrates segmentation of the overall final energy use by energy carrier under the 1.5°C Scenario, 2020-2050.

Road transport is a key sector in the global effort to decarbonize the transport industry, as it contributes over 75% of all transport-related emissions and accounts for approximately 20% of total global energy-related emissions. Battery EVs have emerged as the primary technological solution for reducing these emissions, largely due to rapid advancements in battery technology, which have led to significant performance improvements and cost reductions [40-42]. These developments have broadened the feasibility of EVs beyond passenger vehicles, extending to previously challenging segments, such as long-haul freight transport.

The adoption of EVs is accelerating exponentially, with 14 million electric passenger cars sold in 2023, representing 18% of total global automobile sales and marking a 340% increase since 2020. To remain aligned with IRENA's 1.5°C Scenario, global EV sales must continue this trajectory, reaching approximately 60 million units per year by 2030 [39-45]. This rapid expansion in EV adoption will drive a sharp increase in the demand for EV batteries, particularly for passenger cars and trucks, which require larger battery capacities compared to two-wheelers. While passenger cars will remain the dominant driver of unit sales, the rising electrification of commercial and heavy-duty transport will contribute significantly to overall battery demand.

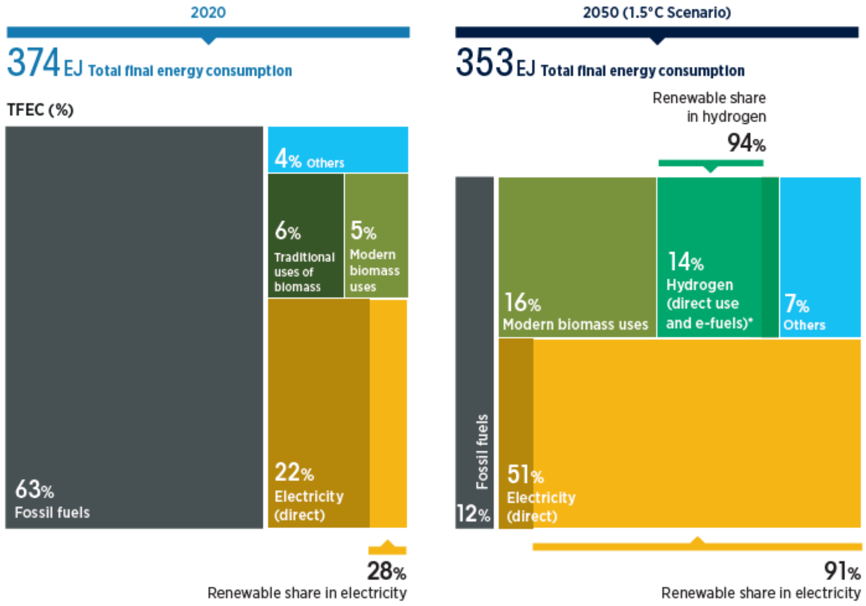

Figure 1. Segmentation of the overall final energy use by energy carrier under the 1.5°C Scenario, 2020-2050 [39].

4. EV Battery Composition and Chemistries

Electric vehicle (EV) batteries are composed of multiple battery cells systematically arranged within a battery pack, forming the core energy storage system of an EV. Each battery cell consists of three fundamental components [46-48]:

- Anode – The negative electrode, predominantly made of graphite, which serves as the host material for lithium ions during charging.
- Cathode – The positive electrode, typically composed of lithium metal oxides, such as lithium nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP), or lithium cobalt oxide (LCO), which dictates the battery's energy density, performance, and thermal stability.
- Electrolyte – A liquid or solid lithium salt solution, enabling the movement of lithium ions between the anode and cathode during charge and discharge cycles, thereby facilitating energy storage and release.

These components operate through a lithium-ion intercalation process, where lithium ions migrate between the anode and cathode to store or discharge energy. The choice of battery chemistry significantly influences energy density, lifespan, cost, and sustainability [49-51].

- Nickel-based chemistries (e.g., NMC, NCA) offer higher energy density, making them ideal for long-range EVs, but rely on scarce materials like nickel and cobalt.
- LFP batteries provide enhanced safety, longevity, and cost-effectiveness, making them well-suited for mass-market EVs and commercial applications, though they have lower energy density.
- Emerging alternatives, such as lithium manganese iron phosphate (LMFP) and sodium-ion batteries, are being developed to further reduce reliance on critical materials while maintaining performance efficiency.

These advancements in battery chemistry are critical for the sustainable scaling of EV adoption, balancing resource availability, environmental impact, and energy efficiency to support the global transition toward electrified transportation. Figure 2 illustrates the hierarchical structure of an EV battery system, starting from individual battery cells to battery modules, battery packs, and the complete battery system. This architecture plays a crucial role in determining the performance, efficiency, safety, and longevity of an electric vehicle (EV) battery.

Understanding the hierarchical structure of EV battery systems is crucial for optimizing energy storage, safety, and performance. Innovations in cell chemistry, thermal regulation, and system integration are shaping the next generation of EV batteries, making them more efficient, durable, and sustainable. The continued evolution of battery technology will be instrumental in accelerating the global transition to electrified transportation.

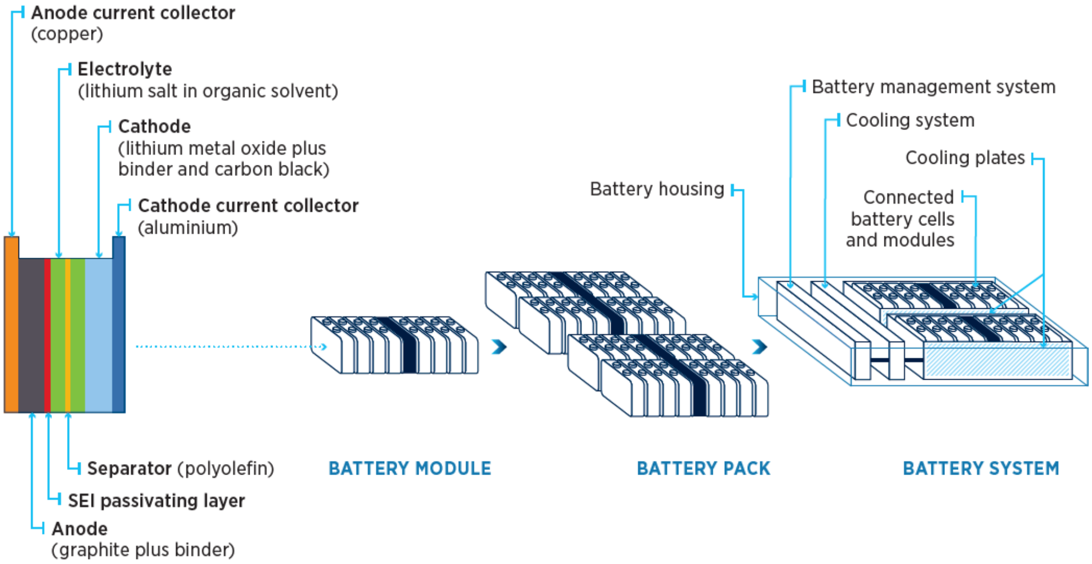

Figure 2. The internal components of a battery cell and the components of the battery system [39].

5. Technological Advancements in EV Battery Energy Density and Material Efficiency

The demand for critical materials in electric vehicles (EVs) is not exclusively driven by EV battery production; rather, a diverse range of industries and applications significantly influence the availability and pricing of these essential resources. It is imperative to recognize the broader industrial landscape in which these materials are utilized, as sectoral interdependencies play a crucial role in shaping global supply chains [49-51]. While EV batteries serve as a primary driver of lithium demand, their influence on the demand for other materials, such as cobalt, graphite, and nickel, is comparatively less pronounced. In contrast, certain key materials exhibit a more diversified demand profile.

For instance, copper—despite its integral role in EV manufacturing—is projected to have only a 4% demand share from EV batteries by 2030, with the majority of its demand stemming from the construction sector and power-related infrastructure, including electrical grids and renewable energy systems. Similarly, phosphorus and manganese are expected to account for only approximately 3% and 2% of their total demand, respectively, within the EV battery sector by 2030 [52-54].

The sustainable expansion of material supply chains, coupled with continuous advancements in battery chemistries, presents a viable pathway for nations to meet the escalating demand for EV battery materials. This remains achievable even under an accelerated transition to electric mobility, aligning with a 1.5°C decarbonization trajectory. A pivotal determinant in this process is the ability to scale up material supply in accordance with existing projections. Furthermore, the accelerated adoption of next-generation battery technologies with reduced dependence on critical materials—such as lithium iron phosphate (LFP), lithium manganese iron phosphate (LMFP), and sodium-ion batteries—has the potential to alleviate material shortages, even in scenarios where mining operations fail to expand at the anticipated rate [53-55].

The interplay between material supply capacity and technological innovation creates a broad spectrum of possible outcomes. For example, projections indicate that lithium markets could experience either surpluses or shortages by 2030, depending on the pace of supply expansion and battery technology adoption. Potential lithium surpluses are estimated at 0.60 million metric tons per year, constituting approximately 25% of the projected demand in 2030. Conversely, under more constrained supply conditions, shortages could reach as high as 1.3 million metric tons per year, accounting for nearly 40% of the estimated demand [54-56]. These uncertainties underscore the need for a multifaceted strategy that integrates supply chain resilience, resource efficiency, and rapid technological advancements to ensure a stable and sustainable material supply for EV batteries. Figure 3 presents key Critical Materials for EV Battery Production and Infrastructure.

Figure 3. A visual representation of key critical materials essential for the production of electric vehicle (EV) batteries and associated infrastructure [39].

These materials—lithium, cobalt, graphite, nickel, copper, phosphorus, and manganese—play pivotal roles in advancing battery technology, enhancing energy storage efficiency, and ensuring the scalability of electric mobility.

- Lithium: A fundamental component of lithium-ion batteries, lithium enables high energy density and long cycle life, making it indispensable for EV applications.
- Cobalt: Primarily used in cathodes of lithium-ion batteries, cobalt enhances thermal stability and battery longevity. However, efforts are underway to reduce its usage due to supply chain constraints and ethical concerns regarding mining.
- Graphite: Serving as the primary material for anodes in lithium-ion batteries, graphite facilitates efficient charge storage and conductivity, influencing battery performance.
- Nickel: A critical component in high-energy-density battery cathodes (such as NMC and NCA chemistries), nickel contributes to enhanced energy storage capacity and extended driving ranges for EVs.
- Copper: Essential for electrical conductivity, copper is widely used in battery connections, power electronics, and EV charging infrastructure, supporting efficient energy transmission.
- Phosphorus: Utilized in lithium iron phosphate (LFP) batteries, phosphorus offers improved safety and cycle life, making it a key component in emerging battery technologies.
- Manganese: Found in various cathode chemistries, manganese contributes to the structural stability of batteries while offering cost-effective alternatives to more scarce materials.

The increasing global demand for EVs is expected to exert significant pressure on the supply chains of these materials, necessitating sustainable extraction methods, recycling innovations, and advancements in alternative battery chemistries. As the industry evolves, a balanced approach combining material efficiency, circular economy practices, and strategic sourcing will be critical in ensuring the long-term viability of EV battery production. Technological innovation has already played a crucial role in reducing the demand for critical materials in electric vehicle (EV) batteries, significantly altering market dynamics.

Recent advancements in electric vehicle (EV) battery technology have significantly enhanced gravimetric energy density, yielding a 30% increase in battery cells and a 60% improvement in battery packs over the past decade. These improvements not only enhance energy efficiency and reduce costs but also play a pivotal role in mitigating material demand by enabling batteries to store more energy with fewer raw materials. As research and development continue, further breakthroughs are anticipated, reinforcing the sustainability and scalability of battery technology. One such advancement is the development of sodium-ion batteries by Contemporary Amperex Technology Co., Limited (CATL) and Northvolt, which currently achieve an energy density of 160 watt-hours per kilogram (Wh/kg), with next-generation models expected to surpass 200 Wh/kg [56-58].

6. Battery Manufacturing Capacity

The outlook for lithium-ion battery production remains highly positive, with global manufacturing capacity expected to expand more than threefold, increasing from 2,000 GWh/year in 2023 to 7,300 GWh/year by 2030. This projected growth trajectory aligns with the estimated 4,300 GWh/year demand from EV batteries under 1.5°C Scenario, ensuring that planned capacity will be sufficient to support the electrification of transport [59,61]. In 2030, global commitments to lithium-ion battery manufacturing have already reached a cumulative 10,000 GWh/year, highlighting long-term industry confidence in battery-driven applications. Additionally, lithium-ion battery production serves not only EV applications but also the growing demand for stationary energy storage systems and portable electronics, further influencing supply dynamics. Figure 4 presents the regions lithium-ion battery manufacturing capacity in 2023 and projected capacity for 2030.

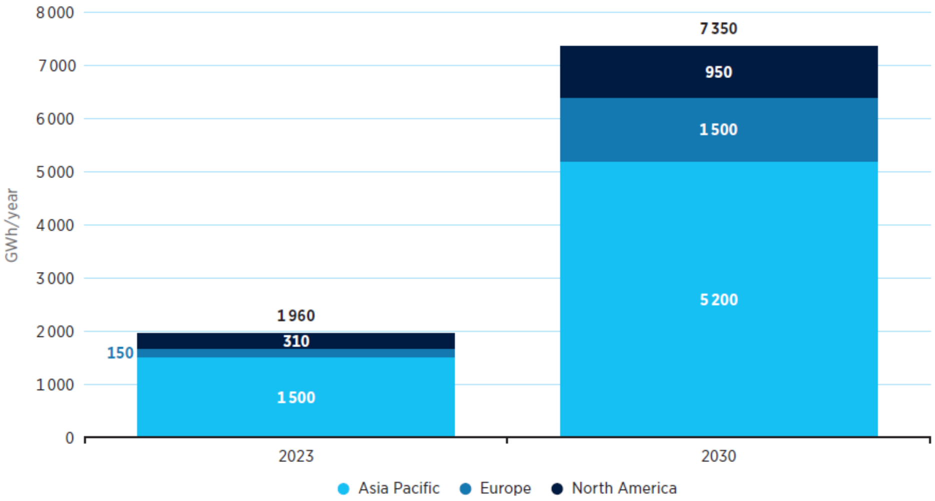

Figure 4. The regions lithium-ion battery manufacturing capacity in 2023 and projected capacity for 2030 [39].

From a regional perspective, the Asia-Pacific region currently dominates global lithium-ion battery production, accounting for approximately 75% of total capacity in 2023 (Ratel Consulting, 2023). However, this share is expected to decline to around 70% by 2030, as battery manufacturing capacity expands in other regions. Europe is poised for the most rapid growth, with a tenfold increase in battery production capacity between 2023 and 2030, outpacing the 250% growth in the Asia-Pacific region and the 200% increase in North America over the same period []. These shifts reflect the global effort to diversify supply chains, reduce geopolitical dependencies, and establish a resilient and sustainable battery manufacturing ecosystem to support the accelerating transition toward electrified mobility and renewable energy integration.

7. Challenges and Opportunities

The transition to electric vehicles (EVs) is a cornerstone of global efforts to reduce carbon emissions and achieve a sustainable transportation system. However, the rapid expansion of EV adoption is driving an unprecedented demand for critical materials, including lithium, cobalt, nickel, graphite, and rare earth elements, which are essential for battery production. Ensuring a sustainable and ethical supply chain for these materials presents both challenges and opportunities for governments, industries, and investors. This article explores the key obstacles to sustainable sourcing and the potential solutions that can help create a resilient and responsible supply chain for EV batteries.

A. Challenges in Sustainable Sourcing of Critical EV Battery Materials

- Geopolitical Risks and Supply Chain Vulnerability

The global supply of critical materials is highly concentrated in a few countries, increasing risks related to trade restrictions, political instability, and resource nationalism. For example:

- Lithium production is dominated by Australia, Chile, and China, with China also controlling a significant portion of lithium processing.
- Cobalt is largely sourced from the Democratic Republic of the Congo (DRC), where concerns over child labor and unethical mining practices pose serious challenges.
- Nickel reserves are primarily found in Indonesia, Russia, and the Philippines, raising concerns over geopolitical dependencies.

These dependencies create vulnerabilities that can lead to price volatility, material shortages, and supply chain disruptions, ultimately affecting the scalability and affordability of EV production.

- Environmental Impact of Mining and Processing

The extraction and processing of critical battery materials have significant environmental consequences, including:

- Water-intensive lithium extraction, which depletes freshwater resources in arid regions such as South America’s Lithium Triangle (Argentina, Bolivia, and Chile).
- Cobalt and nickel mining, which leads to deforestation, soil contamination, and biodiversity loss in countries like the DRC and Indonesia.
- High energy consumption and carbon emissions from refining processes, particularly in China, which dominates graphite, lithium, and rare earth element refining.

Sustainable sourcing requires minimizing ecological damage while ensuring that mining operations adhere to responsible environmental, social, and governance (ESG) standards.

- Ethical and Social Concerns
- Human rights violations in artisanal mining, particularly in cobalt extraction in the DRC, raise concerns over child labor, poor working conditions, and lack of fair wages.
- Indigenous land rights conflicts occur in Australia, Canada, and Latin America, where mining operations encroach upon ancestral territories.
- Local community displacement and lack of equitable benefits from mining projects exacerbate tensions between mining companies and affected populations.

Addressing these social challenges requires stronger regulations, corporate accountability, and fair-trade practices in the sourcing of battery materials.

- Limited Recycling Infrastructure and Circular Economy Gaps

While recycling can reduce dependency on newly mined materials, current battery recycling rates remain low due to:

- Lack of standardized recycling processes, making it difficult to recover materials efficiently.
- High costs of battery disassembly and material extraction, reducing economic incentives for large-scale recycling.
- Insufficient government policies to promote circular economy initiatives, limiting investment in urban mining and second-life battery applications.

  - Expanding battery recycling and reuse systems is critical to reducing the need for virgin raw materials.

B. Opportunities for Sustainable Sourcing

- Development of Sustainable Mining Technologies

Innovations in environmentally friendly mining can help mitigate the adverse impacts of extraction, including:

  - Direct Lithium Extraction (DLE) – A low-water, low-impact method that improves lithium recovery rates while reducing environmental harm.
  - Bio-mining and green extraction processes that use bacteria and natural solvents to extract metals with minimal ecological disruption.
  - Enhanced tailings management to prevent water contamination and land degradation.
  - Investing in low-impact mining solutions can make battery material extraction more sustainable.

- Advancements in Battery Chemistry to Reduce Material Dependency

Researchers are developing alternative battery technologies that reduce reliance on scarce or environmentally harmful materials:

  - Lithium Iron Phosphate (LFP) Batteries – Cobalt- and nickel-free, offering better safety and longevity at lower costs.
  - Sodium-Ion Batteries – A promising alternative that eliminates the need for lithium, cobalt, and nickel, making it a more sustainable option.
  - Solid-State Batteries – Offer higher energy density and safety while potentially reducing reliance on critical raw materials.
  - Accelerating the commercialization of next-generation batteries can alleviate material supply constraints.

- Strengthening Battery Recycling and Circular Economy Initiatives

Scaling up battery recycling is crucial for reducing demand for virgin materials. Opportunities include:

  - Establishing closed-loop recycling systems where used EV batteries are repurposed for new battery production.
  - Developing advanced material recovery technologies, such as hydrometallurgical and direct recycling methods, to efficiently extract valuable metals from spent batteries.
  - Implementing government incentives and regulations to promote battery take-back programs and second-life applications (e.g., using retired EV batteries for energy storage).

A well-developed circular economy can significantly reduce mining pressure and enhance material sustainability.

- Strengthening ESG Standards and International Cooperation

Governments and international organizations can:

  - Enforce stricter ESG regulations to ensure ethical labor practices, fair wages, and community engagement in mining operations.
  - Improve supply chain transparency by mandating traceability measures such as blockchain-based tracking of battery materials.
  - Foster global collaboration through initiatives like the Battery Passport Program, which ensures that EV battery materials meet environmental and social standards.
  - By integrating sustainability, traceability, and ethical sourcing frameworks, stakeholders can build a responsible and resilient battery supply chain.

The sustainable sourcing of critical materials for EV batteries is a complex yet essential challenge that requires a multi-pronged approach combining technological advancements, regulatory action, and industry collaboration. While challenges such as geopolitical dependencies, environmental degradation, and ethical concerns pose risks to supply chain stability, emerging opportunities in supply chain diversification, battery chemistry innovation, recycling, and responsible mining offer viable pathways to sustainability. By adopting forward-thinking policies and investing in sustainable resource management, governments and industries can ensure that the EV revolution remains environmentally responsible, socially equitable, and economically viable in the long term.

8. Policymakers to Ensure a Sustainable EV Battery Supply Chain

To secure a reliable, sustainable, and cost-effective supply of critical materials for EV batteries by 2030, policymakers must implement comprehensive strategies that address key challenges across the entire battery supply chain. These strategies should focus on technological innovation, supply chain resilience, regulatory efficiency, and international collaboration.

A. Accelerate Innovation in EV Battery Technology with Lower Material Requirements

Encouraging research and development (R&D) in alternative battery chemistries—such as lithium iron phosphate (LFP), lithium manganese iron phosphate (LMFP), and sodium-ion batteries—will help reduce reliance on scarce materials like cobalt and nickel. Supporting advancements in solid-state batteries and structural battery integration (e.g., cell-to-pack and cell-to-body technologies) will further enhance energy efficiency while minimizing material demand.

B. Monitor Markets Closely and Increase Industry Engagement

Policymakers should implement real-time market monitoring systems to track supply-demand trends, price fluctuations, and technological breakthroughs. Strengthening public-private partnerships with battery manufacturers, automakers, and material suppliers will ensure that regulatory frameworks remain adaptable and responsive to rapid industry advancements.

C. Accelerate the Deployment of EV Charging Infrastructure

Expanding EV charging networks will allow for the adoption of smaller battery-sized EVs, reducing material consumption per vehicle. This includes fast-charging stations, bidirectional vehicle-to-grid (V2G) systems, and smart-grid integration, which can optimize energy efficiency and charging accessibility, encouraging the mass adoption of compact EVs with lower raw material requirements.

D. Streamline Permitting Processes to Accelerate Mining Development

To meet surging material demand, governments must expedite permitting and approval processes for new mining and refining projects, ensuring that these developments adhere to high environmental, social, and governance (ESG) standards. Establishing clear, transparent, and predictable regulatory frameworks will attract investment and accelerate the scaling of responsible extraction.

E. Diversify Mining and Processing Locations for Supply Chain Resilience

Reducing overreliance on single-source supply regions—such as China for graphite refining or the Democratic Republic of Congo for cobalt mining—is critical for supply chain security. Policymakers should support industry stakeholders in developing geographically diverse mining and processing hubs across North America, Europe, Africa, and Asia.

A multi-faceted policy approach integrating technological innovation, industry collaboration, sustainable mining, and supply chain diversification is essential for securing a stable, ethical, and environmentally responsible supply of EV battery materials. By implementing these strategic policy measures, governments can accelerate the global transition to electric mobility while ensuring long-term sustainability, affordability, and resource security.

9. Conclusions

The transition to electric vehicles (EVs) is a critical component of the global energy transition, with EV adoption accelerating in response to climate change mitigation efforts and the shift toward renewable energy. This article explores the challenges, opportunities, and policy considerations surrounding critical materials for EV batteries, which play a pivotal role in ensuring the scalability and sustainability of the EV sector. The discussion begins by examining the role of EVs in the energy transition, emphasizing their contribution to decarbonizing the transportation sector and their increasing demand for battery technologies. The composition and chemistry of EV batteries are analyzed, highlighting key materials such as lithium, cobalt, nickel, graphite, and phosphorus, as well as emerging alternatives aimed at reducing reliance on scarce resources.

Advancements in battery energy density and material efficiency are explored, demonstrating how technological innovations—including solid-state batteries, lithium iron phosphate (LFP), and sodium-ion chemistries—are reshaping battery performance, cost, and sustainability. The prospects for battery manufacturing capacity are assessed, with projections indicating a threefold increase in lithium-ion battery production by 2030. However, supply chain vulnerabilities, environmental impacts, and geopolitical dependencies pose challenges to the sustainable sourcing of raw materials. This article identifies both obstacles and opportunities in securing critical battery materials, with a focus on strategies such as responsible mining, material recycling, and supply chain diversification.

Policymakers play a crucial role in fostering a sustainable EV battery supply chain, and this study outlines key recommendations, including accelerating R&D in alternative battery chemistries, promoting circular economy initiatives, enhancing international cooperation, and streamlining regulatory frameworks to facilitate ethical and environmentally responsible sourcing. The article concludes by emphasizing the need for a holistic approach that integrates technological innovation, policy intervention, and industry collaboration to ensure the long-term sustainability and resilience of EV battery materials, supporting a cleaner and more sustainable transportation future.

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References

[1] P. Barman, L. Dutta, and B. Azzopardi, “Electric Vehicle Battery Supply Chain and Critical Materials: A Brief Survey of State of the Art,” *Energies*, vol. 16, no. 8, p. 3369, Apr. 2023, doi: https://doi.org/10.3390/en16083369.

[2] F. E. K. Sato and T. Nakata, “Recoverability Analysis of Critical Materials from Electric Vehicle Lithium-Ion Batteries through a Dynamic Fleet-Based Approach for Japan,” *Sustainability*, vol. 12, no. 1, p. 147, Dec. 2019, doi: https://doi.org/10.3390/su12010147.

[3] H. Lütkehaus, C. Pade, M. Oswald, U. Brand, T. Naegler, and T. Vogt, “Measuring raw-material criticality of product systems through an economic product importance indicator: a case study of battery-electric vehicles,” *The International Journal of Life Cycle Assessment*, vol. 27, no. 1, pp. 122–137, Dec. 2021, doi: https://doi.org/10.1007/s11367-021-02002-z.

[4] C. O. Iloeje *et al.*, “A systematic analysis of the costs and environmental impacts of critical materials recovery from hybrid electric vehicle batteries in the U.S.,” *iScience*, vol. 25, no. 9, p. 104830, Sep. 2022, doi: https://doi.org/10.1016/j.isci.2022.104830.

[5] H. Lehtimäki *et al.*, “Sustainability of the use of critical raw materials in electric vehicle batteries: A transdisciplinary review,” *Environmental challenges*, vol. 16, pp. 100966–100966, Jun. 2024, doi: https://doi.org/10.1016/j.envc.2024.100966.

[6] A. Alsharif, A. A. Ahmed, M. Khaleel, A. Salem, O. Jomah, and Ibrahim Imbayah, “Comprehensive State-of-the-Art of Vehicle-To-Grid Technology,” *2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, May 2023, doi: https://doi.org/10.1109/mi-sta57575.2023.10169116.

[7] J. Deng, C. Bae, A. Denlinger, and T. Miller, "Electric Vehicles Batteries: Requirements and Challenges," *Joule*, vol. 4, no. 3, pp. 511–515, Mar. 2020, doi: https://doi.org/10.1016/j.joule.2020.01.013.

[8] B. Ballinger *et al.*, "The Vulnerability of Electric Vehicle Deployment to Critical Mineral Supply," *Applied Energy*, vol. 255, no. 1, p. 113844, Dec. 2019, doi: https://doi.org/10.1016/j.apenergy.2019.113844.

[9] Abdullah Ghayth, Mehmet Şimşir, M. Khaleel, A. Ahmed, and A. Alsharif, "An Investigation of Inverse-Automatic Mechanical Transmission of EV Using Gear Downshift Approach," *Int. J. Electr. Eng. and Sustain.*, vol. 1, no. 3, pp. 1–9, Nov. 2023, Accessed: Mar. 22, 2025. [Online]. Available: https://ijees.org/index.php/ijees/article/view/36

[10] M. A. Rajaeifar, P. Ghadimi, M. Raugei, Y. Wu, and O. Heidrich, "Challenges and Recent Developments in Supply and Value Chains of Electric Vehicle batteries: a Sustainability Perspective," *Resources, Conservation and Recycling*, vol. 180, no. 106144, p. 106144, May 2022, doi: https://doi.org/10.1016/j.resconrec.2021.106144.

[11] A. Alsharif, A. A. Ahmed, M. M. Khaleel, Y. Nassar, M. A. Sharif, and Hala Jarallah El-Khozondar, "Whale Optimization Algorithm for Renewable Energy Sources Integration Considering Solar-to-Vehicle Technology," *2023 IEEE 9th International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE)*, Nov. 2023, doi: https://doi.org/10.1109/wiecon-ece60392.2023.10456379.

[12] B. A. Andersson and I. Råde, "Metal resource constraints for electric-vehicle batteries," *Transportation Research Part D: Transport and Environment*, vol. 6, no. 5, pp. 297–324, Sep. 2001, doi: https://doi.org/10.1016/s1361-9209(00)00030-4.

[13] Abdullah Abodwair, Muhammet Guneser, M. Khaleel, Y. Nassar, Hala El-Khozondar, and A. Elbaz, "Feasibility Assessment of Hybrid Renewable Energy Based EV Charging Station in Libya," *Solar Energy and Sustainable Development*, vol. 13, no. 2, pp. 311–349, Nov. 2024, doi: https://doi.org/10.51646/jsesd.v13i2.292.

[14] B. Jetin, "Electric batteries and critical materials dependency: a geopolitical analysis of the USA and the European Union," *International journal of automotive technology and management*, vol. 23, no. 4, pp. 383–407, Jan. 2023, doi: https://doi.org/10.1504/ijatm.2023.136568.

[15] D. H. S. Tan, P. Xu, and Z. Chen, "Enabling sustainable critical materials for battery storage through efficient recycling and improved design: A perspective," *MRS Energy & Sustainability*, vol. 7, 2020, doi: https://doi.org/10.1557/mre.2020.31.

[16] A. Alsharif, C. W. Tan, R. Ayop, A. Ali Ahmed, M. Khaleel, and A. K. Abobaker, "Power Management and Sizing Optimization for Hybrid Grid-Dependent System Considering Photovoltaic Wind Battery Electric Vehicle," *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, pp. 645–649, May 2022, doi: https://doi.org/10.1109/mi-sta54861.2022.9837749.

[17] F. Maisel, C. Neef, F. Marscheider-Weidemann, and N. F. Nissen, "A forecast on future raw material demand and recycling potential of lithium-ion batteries in electric vehicles," *Resources, Conservation and Recycling*, vol. 192, p. 106920, May 2023, doi: https://doi.org/10.1016/j.resconrec.2023.106920.

[18] G. Harper *et al.*, "Recycling lithium-ion Batteries from Electric Vehicles," *Nature*, vol. 575, no. 7781, pp. 75–86, Nov. 2019, doi: https://doi.org/10.1038/s41586-019-1682-5.

[19] R. Ma *et al.*, "Pathway decisions for reuse and recycling of retired lithium-ion batteries considering economic and environmental functions," *Nature Communications*, vol. 15, no. 1, Sep. 2024, doi: https://doi.org/10.1038/s41467-024-52030-0.

[20] R. Jiang *et al.*, "Impact of electric vehicle battery recycling on reducing raw material demand and battery life-cycle carbon emissions in China," *Scientific Reports*, vol. 15, no. 1, Jan. 2025, doi: https://doi.org/10.1038/s41598-025-86250-1.

[21] C. Xu, Q. Dai, L. Gaines, M. Hu, A. Tukker, and B. Steubing, "Future material demand for automotive lithium-based batteries," *Communications Materials*, vol. 1, no. 1, pp. 1–10, Dec. 2020,

doi: https://doi.org/10.1038/s43246-020-00095-x.

[22] M. Khaleel *et al.*, “Evolution of Emissions: The Role of Clean Energy in Sustainable Development,” *Challenges in Sustainability*, vol. 12, no. 2, pp. 122–135, Jul. 2024, doi: https://doi.org/10.56578/cis120203.

[23] M. Abuqila, Y. Nassar, and M. Nyasapoh, “Estimation of the Storage Capacity of Electric Vehicle Batteries under Real Weather and Drive-mode Conditions: A Case Study,” *Wadi Alshatti University Journal of Pure and Applied Sciences*, vol. 3, no. 1, pp. 58–71, 2025, doi: https://doi.org/10.63318/.

[24] M. Abuqila, Y. Nassar, and M. Nyasapoh, “Estimation of the Storage Capacity of Electric Vehicle Batteries under Real Weather and Drive-mode Conditions: A Case Study,” *Wadi Alshatti University Journal of Pure and Applied Sciences*, vol. 3, no. 1, pp. 58–71, 2025, doi: https://doi.org/10.63318/.

[25] Y. Zhao and G. Kaur, “The future of recycling for critical metals: Example of EV batteries,” *Geosystems and Geoenvironment*, p. 100376, Mar. 2025, doi: https://doi.org/10.1016/j.geogeo.2025.100376.

[26] M. Khaleel, Z. Yusupov, Bsher Alfalh, Muhammet Tahir Guneser, Y. Nassar, and Hala El-Khozondar, “Impact of Smart Grid Technologies on Sustainable Urban Development: DOI: 10.5281/zenodo.11577746,”*Int. J. Electr. Eng. and Sustain.*, pp. 62–82, Nov. 2023, doi: https://doi.org/10.5281/zenodo.11577746.

[27] M. Khaleel, Z. Yusupov, A. Ahmed, A. Alsharif, Y. Nassar, and Hala El-Khozondar, “Towards Sustainable Renewable Energy,” *Applied solar energy*, vol. 59, no. 4, pp. 557–567, Aug. 2023, doi: https://doi.org/10.3103/s0003701x23600704.

[28] M. Salado, E. Lizundia, I. Oyarzabal, and D. Salazar, “The Role of Critical Raw Materials for Novel Strategies in Sustainable Secondary Batteries,” *physica status solidi (a)*, vol. 219, no. 15, p. 2100710, Jan. 2022, doi: https://doi.org/10.1002/pssa.202100710.

[29] J. Huang, X. Dong, J. Chen, and A. Zeng, “The slow-release effect of recycling on rapid demand growth of critical metals from EV batteries up to 2050: Evidence from China,” *Resources Policy*, vol. 82, p. 103504, May 2023, doi: https://doi.org/10.1016/j.resourpol.2023.103504.

[30] M. Khaleel, Abdussalam Ali Ahmed, and A. Alsharif, “Technology Challenges and Trends of Electric Motor and Drive in Electric Vehicle,” *Int. J. Electr. Eng. and Sustain.*, vol. 1, no. 1, pp. 41–48, Nov. 2023, Accessed: Aug. 08, 2024. [Online]. Available: https://ijees.org/index.php/ijees/article/view/14

[31] J. Baars, T. Domenech, R. Bleischwitz, H. E. Melin, and O. Heidrich, “Circular economy strategies for electric vehicle batteries reduce reliance on raw materials,” *Nature Sustainability*, vol. 4, no. 1, Sep. 2020, doi: https://doi.org/10.1038/s41893-020-00607-0.

[32] A. Alsharif *et al.*, “Impact of Electric Vehicle on Residential Power Distribution Considering Energy Management Strategy and Stochastic Monte Carlo Algorithm,” vol. 16, no. 3, pp. 1358–1358, Jan. 2023, doi: https://doi.org/10.3390/en16031358.

[33] A. Alsharif, A. A. Ahmed, M. M. Khaleel, and Masoud Albasheer Altayib, “Ancillary Services and Energy Management for Electric Vehicle: Mini-Review,” *NAJSP*, vol. 1, no. 1, pp. 9–12, Feb. 2023, Accessed: Mar. 22, 2025. [Online]. Available: https://najsp.com/index.php/home-/article/view/8

[34] C. O. Iloeje *et al.*, “A systematic analysis of the costs and environmental impacts of critical materials recovery from hybrid electric vehicle batteries in the U.S.,” *iScience*, vol. 25, no. 9, p. 104830, Sep. 2022, doi: https://doi.org/10.1016/j.isci.2022.104830.

[35] J. Deng, C. Bae, A. Denlinger, and T. Miller, “Electric Vehicles Batteries: Requirements and Challenges,” *Joule*, vol. 4, no. 3, pp. 511–515, Mar. 2020, doi: https://doi.org/10.1016/j.joule.2020.01.013.

[36] H. Lehtimäki *et al.*, “Sustainability of the use of critical raw materials in electric vehicle batteries: A transdisciplinary review,” *Environmental challenges*, vol. 16, pp. 100966–100966, Jun. 2024, doi:

https://doi.org/10.1016/j.envc.2024.100966.

[37] G. Zhao, X. Wang, and M. Negnevitsky, "Connecting battery technologies for electric vehicles from battery materials to management," *iScience*, vol. 25, no. 2, p. 103744, Feb. 2022, doi: https://doi.org/10.1016/j.isci.2022.103744.

[38] M. Petranikova, Pol Llorach Naharro, N. Vieceli, G. Lombardo, and Burçak Ebin, "Recovery of critical metals from EV batteries via thermal treatment and leaching with sulphuric acid at ambient temperature," *Waste management*, vol. 140, pp. 164–172, Mar. 2022, doi: https://doi.org/10.1016/j.wasman.2021.11.030.

[39] Critical materials: Batteries for electric vehicles, *Irena.org*, Sep. 30, 2024. https://www.irena.org/Publications/2024/Sep/Critical-materials-Batteries-for-electric-vehicles (accessed Oct. 15, 2024).

[40] A. M. Abdalla *et al.*, "Innovative lithium-ion battery recycling: Sustainable process for recovery of critical materials from lithium-ion batteries," *Journal of Energy Storage*, vol. 67, p. 107551, Sep. 2023, doi: https://doi.org/10.1016/j.est.2023.107551.

[41] A. Leader, G. Gaustad, and C. Babbitt, "The effect of critical material prices on the competitiveness of clean energy technologies," *Materials for Renewable and Sustainable Energy*, vol. 8, no. 2, Jun. 2019, doi: https://doi.org/10.1007/s40243-019-0146-z.

[42] J. Dunn, M. Slattery, A. Kendall, H. Ambrose, and S. Shen, "Circularity of Lithium-Ion Battery Materials in Electric Vehicles," *Environmental Science & Technology*, vol. 55, no. 8, Mar. 2021, doi: https://doi.org/10.1021/acs.est.0c07030.

[43] Ario Fahimi, Hector Alejandro Solorio, Rasoul Khayyam Nekouei, and Ehsan Vahidi, "Analyzing the environmental impact of recovering critical materials from spent lithium-ion batteries through statistical optimization," *Journal of Power Sources*, vol. 580, pp. 233425–233425, Oct. 2023, doi: https://doi.org/10.1016/j.jpowsour.2023.233425.

[44] K. Habib, S. T. Hansdóttir, and H. Habib, "Critical metals for electromobility: Global demand scenarios for passenger vehicles, 2015–2050," *Resources, Conservation and Recycling*, vol. 154, p. 104603, Mar. 2020, doi: https://doi.org/10.1016/j.resconrec.2019.104603.

[45] D. Karabelli *et al.*, "Tackling xEV Battery Chemistry in View of Raw Material Supply Shortfalls," *Frontiers in Energy Research*, vol. 8, Nov. 2020, doi: https://doi.org/10.3389/fenrg.2020.594857.

[46] Natalia Soldan Cattani, E. Noronha, J. Schmied, Moritz Frieges, H. Heimes, and Achim Kampker, "Comparative Cost Modeling of Battery Cell Formats and Chemistries on a Large Production Scale," *Batteries*, vol. 10, no. 7, pp. 252–252, Jul. 2024, doi: https://doi.org/10.3390/batteries10070252.

[47] A. Promi, K. Meyer, R. Ghosh, and F. Lin, "Advancing electric mobility with lithium-ion batteries: A materials and sustainability perspective," *MRS Bulletin*, vol. 49, no. 7, pp. 697–707, Jul. 2024, doi: https://doi.org/10.1557/s43577-024-00749-y.

[48] H. Sahivirta, B. P. Wilson, M. Lundström, and R. Serna-Guerrero, "A study on recovery strategies of graphite from mixed lithium-ion battery chemistries using froth flotation," *Waste management*, vol. 180, pp. 96–105, May 2024, doi: https://doi.org/10.1016/j.wasman.2024.03.032.

[49] P. J. Bugryniec, E. G. Resendiz, S. M. Nwophoke, S. Khanna, C. James, and S. F. Brown, "Review of gas emissions from lithium-ion battery thermal runaway failure — Considering toxic and flammable compounds," *Journal of Energy Storage*, vol. 87, p. 111288, May 2024, doi: https://doi.org/10.1016/j.est.2024.111288.

[50] A. Nunes, C. Y. See, L. Woodley, S. Wang, and G. Liu, "Estimating the tipping point for lithium iron phosphate batteries," *Applied Energy*, vol. 377, p. 124734, Oct. 2024, doi: https://doi.org/10.1016/j.apenergy.2024.124734.

[51] T. Li, M. Lu, Y. Zhang, X. Xiang, S. Liu, and C. Chen, "Structural evolution and redox chemistry of robust ternary layered oxide cathode for sodium-ion batteries," *Journal of Alloys and Compounds*, vol. 978, p. 173459, Jan. 2024, doi: https://doi.org/10.1016/j.jallcom.2024.173459.

[52] J. M. van Gaalen and J. Chris Slootweg, "From Critical Raw Materials to Circular Raw Materials," *ChemSusChem*, Oct. 2024, doi: https://doi.org/10.1002/cssc.202401170.

[53] S. Jagani, E. Marsillac, and P. Hong, "The Electric Vehicle Supply Chain Ecosystem: Changing Roles of Automotive Suppliers," *Sustainability*, vol. 16, no. 4, p. 1570, Jan. 2024, doi: https://doi.org/10.3390/su16041570.

[54] H. Gong and A. D. Andersen, "The role of material resources for rapid technology diffusion in net-zero transitions: Insights from EV lithium-ion battery Technological Innovation System in China," *Technological Forecasting and Social Change*, vol. 200, p. 123141, Mar. 2024, doi: https://doi.org/10.1016/j.techfore.2023.123141.

[55] H. K. Amusa *et al.*, "Electric vehicle batteries waste management and recycling challenges: a comprehensive review of green technologies and future prospects," *Journal of material cycles and waste management*, May 2024, doi: https://doi.org/10.1007/s10163-024-01982-y.

[56] R. Martínez-Sánchez, A. Molina-García, and A. P. Ramallo-González, "Regeneration of Hybrid and Electric Vehicle Batteries: State-of-the-Art Review, Current Challenges, and Future Perspectives," *Batteries*, vol. 10, no. 3, p. 101, Mar. 2024, doi: https://doi.org/10.3390/batteries10030101.

[57] Triyono Widi Sasongko, Udisubakti Ciptomulyono, Budisantoso Wirjodirdjo, and Andhika Prastawa, "Identification of electric vehicle adoption and production factors based on an ecosystem perspective in Indonesia," *Cogent business & management*, vol. 11, no. 1, Apr. 2024, doi: https://doi.org/10.1080/23311975.2024.2332497.

[58] Hussein Togun *et al.*, "A review on recent advances on improving fuel economy and performance of a fuel cell hybrid electric vehicle," *International Journal of Hydrogen Energy*, vol. 89, pp. 22–47, Sep. 2024, doi: https://doi.org/10.1016/j.ijhydene.2024.09.298.

[59] Evangelos Kallitsis, J. J. Lindsay, Mudit Chordia, B. Wu, G. J. Offer, and J. S. Edge, "Think global act local: The dependency of global lithium-ion battery emissions on production location and material sources," *Journal of cleaner production*, pp. 141725–141725, Mar. 2024, doi: https://doi.org/10.1016/j.jclepro.2024.141725.

[60] Akbar Ghasemi Yeklangi, A. Ghafari, Faeze Asgari Sima, and S. Akbari, "Advancing lithium-ion battery manufacturing: novel technologies and emerging trends," *Journal of Applied Electrochemistry*, Jun. 2024, doi: https://doi.org/10.1007/s10800-024-02142-8.

[61] D. Zhang *et al.*, "A multi-step fast charging-based battery capacity estimation framework of real-world electric vehicles," *Energy*, vol. 294, p. 130773, May 2024, doi: https://doi.org/10.1016/j.energy.2024.130773.

[62] E. Parviziomran and V. Elliot, "Barriers to circular economy: Insights from a small electric vehicle battery manufacturer," *Journal of Purchasing and Supply Management*, pp. 100905–100905, Mar. 2024, doi: https://doi.org/10.1016/j.pursup.2024.100905.

[63] L. Li, L. Dai, S. Niu, W. Fu, and K. T. Chau, "Critical Review of Direct-Drive In-Wheel Motors in Electric Vehicles," *Energies*, vol. 18, no. 6, p. 1521, Mar. 2025, doi: https://doi.org/10.3390/en18061521.