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Literature review on the development and trends of battery technology in Indonesia (2020–2025)

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Abstract

The worldwide shift toward low-carbon energy systems has intensified demand for advanced battery technologies, particularly in the context of electric vehicle (EV) proliferation. Despite Indonesia's strategic position as the world's largest nickel producer holding approximately 21% of global nickel reserves comprehensive scholarly synthesis that integrates material innovation, industrial policy, regulatory frameworks, recycling systems, and consumer adoption within a unified analytical framework remains absent from the existing literature. This gap motivates the present study, which employs a Systematic Literature Review (SLR) methodology drawing upon 26 peer-reviewed articles and reports published between 2020 and 2025, sourced from IEEE Xplore, ScienceDirect, SpringerLink, Scopus, and Google Scholar. Thematic content analysis was applied to classify findings across nine interconnected dimensions: battery material evolution, manufacturing investment, charging infrastructure, regulatory challenges, recycling systems, consumer behavior, environmental impact, SWOT analysis, and emerging technologies. The principal contribution of this study lies in constructing an integrated ecosystem mapping of Indonesia's battery industry a synthesis not previously offered in the literature revealing that while NMC and LFP lithium-ion technologies have been rapidly adopted and manufacturing capacity is projected to reach 140 GWh by 2030, critical structural weaknesses persist in domestic research capacity, regulatory harmonization, and circular economy implementation. Solid-state and sodium-ion batteries are identified as strategically significant future directions. These findings offer actionable guidance for policymakers, researchers, and industry stakeholders seeking to strengthen Indonesia's long-term competitiveness in the global battery supply chain.

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Introduction

The global imperative to decarbonize energy systems has driven unprecedented growth in battery technology research and manufacturing, particularly to support the rapid expansion of electric vehicles (EVs) as a cornerstone of sustainable transportation (Jenar, 2025). Indonesia occupies a uniquely advantageous position as the world's foremost nickel supplier, holding approximately 21% of global nickel reserves a critical material in lithium ion battery cathode production (Jenar et al., 2025). Recognizing this strategic opportunity, the Indonesian government enacted Presidential Regulation Number 55 of 2019, targeting 2.1 million electric vehicles by 2030 and mandating domestic battery innovation and manufacturing ecosystem development (Fahmi et al., 2022). Subsequent policies, including the 2020 ban on raw nickel ore exports, were designed to accelerate downstream industrialization and attract foreign direct investment (Pandyaswargo et al., 2021).

Despite this policy momentum, a critical scholarly gap remains. Existing studies have addressed isolated dimensions of Indonesia's battery landscape without systematically synthesizing the interrelationships between material innovation, industrial investment, regulatory frameworks, recycling infrastructure, and technology adoption within a single cohesive analytical framework (Ardodi & Pasaribu, 2024; Sugiyono et al., 2022). No prior review has comprehensively mapped Indonesia's battery technology trajectory across the 2020–2025 period a timeframe characterized by significant policy shifts, major industrial investments, and the emergence of next-generation technologies such as solid-state and sodium-ion batteries.

To address these limitations, this study employs a qualitative Systematic Literature Review (SLR) with thematic content analysis, drawing on 26 peer reviewed publications from 2020 to 2025. A qualitative SLR approach was selected because the heterogeneous nature of the reviewed literature spanning engineering, economics, law, and environmental science necessitates interpretive thematic synthesis to reveal structural relationships that numerical analysis alone cannot capture(Snyder, 2019). The novelty of this study lies in its integrated ecosystem mapping of Indonesia's battery industry across nine thematic dimensions, offering a multi dimensional analytical framework that prior single topic studies have not provided.

Scholarly inquiry into Indonesia's battery technology landscape has expanded considerably over the 2020–2025 period, encompassing five major thematic clusters: material innovation, industrial manufacturing and investment, infrastructure development, sustainability and recycling, and emerging technologies. This section synthesizes prior studies across these dimensions, highlighting both individual contributions and structural relationships among them.

Material innovation constitutes a critical determinant of industrial competitiveness(Latif et al., 2025) traced the evolution of lithium ion battery development in Indonesia, underscoring the strategic primacy of NMC and LFP chemistries given the country's abundant nickel, manganese, cobalt, and iron reserves. Beyond conventional chemistries, (Habibi, 2024) engineered a bio electrolyte from avocado seeds generating 3.4 V sustained for 156 hours, while (Karimzadeh et al., 2023) demonstrated that ALD coatings substantially enhance separator thermal stability and electrolyte wettability. (Hubble; et al., 2022) further showed that tailored electrolyte engineering mitigates capacity degradation in sub-zero environments.

Government policy has substantially shaped the translation of material advantages into industrial capacity. (Pandyaswargo et al., 2021) analyzed how the 2020 nickel ore export ban positioned downstream industrialization as a mechanism for strengthening domestic supply chains and attracting foreign investment. (Puspita, 2024) documented PT Hyundai LG Indonesia Green Power's manufacturing facilities targeting 30 GWh annual capacity, while (Astuti et al., 2024) examined Indonesia Battery Corporation's integration with Hyundai Motor and LG Energy Solution into a Global Value Chain spanning mining through EV assembly. These studies collectively reveal a policy to investment causal pathway, though (Adzhani et al., 2025) caution that without commensurate domestic R&D growth, Indonesia risks remaining a manufacturing platform rather than an independent innovator.

Dharmawan and Kumara (2021) documented rapid expansion of SPLU, SPKLU, and SPBKLU charging networks following Presidential Regulation No. 55 of 2019, while noting suboptimal utilization due to limited public awareness and low EV penetration. (Sutopo et al., 2022) confirmed that Battery Management Systems (BMS) are architecturally indispensable for operational safety and longevity across diverse charging contexts.

(Siombo & Adi, 2025) identified persistent inconsistencies in TKDN regulations, fiscal incentives, and battery waste management frameworks. (Rudijanto et al., 2025) assessed that current national safety standards fall substantially short of UNECE R100 and UL 2580 benchmarks, creating dual vulnerability by undermining consumer confidence and limiting export market access.

(Faizhata et al., 2025) found hydrometallurgical recycling achieves 90–95% recovery rates for lithium, nickel, cobalt, and manganese. (Mubarok et al., 2024) identified that critically low public awareness and underdeveloped reverse logistics infrastructure remain structural bottlenecks for circular economy implementation.

Adzhani et al. (2025) identified cost, charging infrastructure, and charging duration as the main barriers to EV adoption in Indonesia, while Habiburrahman et al. (2024) highlighted weak after-sales services and limited institutional support. Fathoni et al. (2025) emphasized that eco-innovation diffusion depends on regulatory consistency, industrial collaboration, technological capability, and financial incentives. Meanwhile, Widhiyanti et al. (2025) showed that EVs can reduce CO_2 emissions by 50–70% when integrated with renewable energy. Future studies by Ardodi and Pasaribu (2024), Fahmi et al. (2022), and Jenar et al. (2025) identified solid-state and sodium-ion batteries as promising technologies, while Adzhani et al. (2025) and Ngurah and Putra (2024) demonstrated that AI based BiLSTM models can improve battery lifespan prediction. Overall, Indonesia's battery ecosystem shows strong industrial potential but still faces regulatory, infrastructure, and innovation challenges.

Table 1. Comparison of Previous Research

Authors and Year	Aim	Methodology	Main Findings
Adzhani et al. (2025)	To investigate factors influencing EV adoption in Indonesia	Mixed method and stakeholder analysis	Government incentives and environmental awareness positively influence EV adoption
Alfaruqi (2023)	To explore opportunities for post lithium battery development in Indonesia	Literature review	Sodium ion and alternative batteries have strong future potential in Indonesia
Amelia et al. (2023)	To develop nickel rich cathode materials using coal fly ash	Experimental laboratory research	Coal fly ash can improve cathode performance and support sustainable battery material development
Apribowo et al. (2024)	To optimize BESS integration into renewable energy systems	Optimization modeling	BESS significantly improves renewable energy penetration and grid flexibility
Ardodi and Pasaribu (2024)	To identify industrial competencies required in the EV sector	Qualitative analysis	Multidisciplinary competencies are essential for future EV industry development
Astuti et al. (2024)	To examine the collaboration between IBC and Hyundai in EV battery development	Qualitative descriptive analysis	International collaboration accelerates battery investment and technology transfer in Indonesia
Dharmawan et al. (2021)	To examine EV charging systems in Indonesia	Technical analysis	Charging infrastructure distribution and efficiency remain limited
Fahmi et al. (2022)	To evaluate the environmental impact of EV batteries	Life Cycle Assessment (LCA)	Battery production contributes significantly to environmental impacts across the lifecycle
Habibi et al. (2024)	To develop environmentally friendly battery electrolytes	Experimental research	Natural materials can function as eco friendly electrolyte alternatives

Hubble et al. (2022)	To analyze lithium ion battery performance under temperature variations	Review study	Thermal stability is a critical factor affecting battery degradation and safety
Jenar et al. (2025)	To review EV thermal management systems in tropical climates	Literature review	Tropical temperatures accelerate battery degradation and require adaptive cooling systems
Karimzadeh et al. (2023)	To review the application of Atomic Layer Deposition in lithium ion batteries	Systematic literature review	ALD technology improves electrode stability, battery lifespan, and electrochemical performance
Latif et al. (2025)	To examine sustainable lithium battery development in Indonesia	Literature review	Recycling and natural materials are essential for sustainable battery ecosystems
Marhatang et al. (2024)	To develop a battery based solar home system prototype	Prototype development	Battery storage enhances solar energy reliability and stability
Mubarok et al. (2024)	To evaluate battery workforce and research capacity development	Institutional analysis	Indonesia requires large scale battery talent development and research strengthening
Ngurah and Putra (2024)	To evaluate BiLSTM performance for SOH prediction	Deep learning experimental study	BiLSTM improves the accuracy of lithium ion battery degradation prediction
Pandyaswargo et al. (2021)	To analyze the development of Indonesia's EV and battery industry after the nickel export ban policy	SWOT analysis and policy review	Indonesia has strong potential to become a regional EV battery hub through nickel downstream industrialization
Pirmana et al. (2023)	To analyze the economic and environmental impacts of EV production	Economic environmental assessment	EV production supports economic growth but requires sustainable supply chain management
Puspita (2024)	To analyze legal frameworks for battery industry investment	Legal analysis	Investment regulation accelerates national battery industrialization
Rakhmawati and Oktaviani (2023)	To develop a neural network based SOC estimation model	Neural network simulation	ERNN improves SOC estimation accuracy under dynamic operating conditions
Rudijanto et al. (2025)	To analyze regulatory gaps related to EV battery fires	Regulatory analysis	Indonesia still lacks comprehensive battery safety regulations
Siombo and Adi (2025)	To evaluate the effectiveness of Indonesia's EV ecosystem development	Regulatory and policy analysis	Infrastructure readiness and policy consistency remain major challenges
(Fathoni et al., 2025)	To evaluate the contribution of battery electric vehicles to reducing national fuel consumption	Energy policy analysis	Battery electric vehicles can significantly reduce fossil fuel dependence and support energy transition
Sutopo et al. (2022)	To develop battery swapping standardization for electric motorcycles	Open innovation framework	Standardization is essential for EV interoperability and ecosystem integration
Widhiyanti et al. (2025)	To compare EV policies across Southeast and South Asia	Comparative policy analysis	Indonesia still faces implementation and policy consistency challenges
Wijaya et al. (2025)	To analyze the relationship between green development and resource nationalism in Indonesia's EV industry	Political economy approach	EV industrialization may increase environmental and social risks if sustainability governance remains weak

Methodology

This investigation adopted a Systematic Literature Review (SLR) framework to examine the trajectory and emerging patterns of battery technology advancement in Indonesia between 2020 and 2025. The SLR approach was selected to ensure methodological rigor, procedural transparency, and replicability in evidence synthesis qualities that are essential when integrating heterogeneous bodies of knowledge spanning engineering, industrial policy, environmental science, and consumer behavior (Snyder, 2019b). The review process was structured according to a four phase PRISMA informed protocol encompassing identification, screening, eligibility assessment, and final inclusion, as described below.

Identification

An initial database search was conducted across five internationally recognized academic repositories: IEEE Xplore, ScienceDirect, SpringerLink, Scopus, and Google Scholar. The search string combined domain specific keywords including battery technology Indonesia, lithium ion battery, nickel based battery, solid state battery, energy storage system, electric vehicle battery, and battery recycling. These terms were deliberately selected to provide comprehensive coverage across the thematic spectrum of material innovation, system engineering, industrial policy, and circular economy. The initial search yielded 147 candidate documents.

Screening

Retrieved documents were subjected to title and abstract screening to eliminate irrelevant, duplicate, or out of scope entries. Studies focused exclusively on regions outside Indonesia without comparative relevance to the Indonesian context were excluded at this stage, as were non peer reviewed sources such as newspaper articles, opinion pieces, and unpublished grey literature. Following screening, 89 documents were retained for further evaluation.

Eligibility Assessment and Quality Appraisal

Full text review was conducted on the 89 screened documents. Eligibility criteria required that each study: (1) was published in an indexed journal or peer reviewed conference proceedings; (2) presented a clearly articulated research methodology with traceable and measurable results; (3) was directly relevant to battery technology, electric vehicle ecosystems, or energy storage policy within Indonesia; and (4) fell within the 2020–2025 publication window. Quality appraisal was additionally guided by journal indexing status (Scopus, WoS, or SINTA indexed), clarity of methodological reporting, and the empirical or analytical rigor of the findings. Studies lacking methodological transparency, presenting unverifiable data, or offering only anecdotal observations were excluded at this stage.

Final Inclusion

Following eligibility assessment, 26 studies were included in the final analytical corpus. These encompassed peer reviewed journal articles, systematic reviews, experimental studies, policy analyses, and institutional reports, collectively spanning the principal dimensions of Indonesia's battery technology landscape.

Data Extraction and Thematic Synthesis

Structured data extraction was performed for each included study, capturing: primary research focus, methodology employed, key empirical findings, and relevance to the national battery ecosystem. Data synthesis followed a thematic analysis protocol in which recurring topics, conceptual patterns, and cross study relationships were identified through iterative coding. Nine thematic categories emerged from this process: battery material evolution, manufacturing capacity and investment, charging infrastructure, regulatory and policy frameworks, recycling and circular economy, consumer adoption behavior, environmental impact, SWOT based industrial positioning, and emerging technology trajectories. These categories were subsequently examined not merely as discrete descriptive domains but as structurally interrelated dimensions of a unified ecosystem enabling the cross thematic analytical synthesis that distinguishes this review from prior single topic studies.

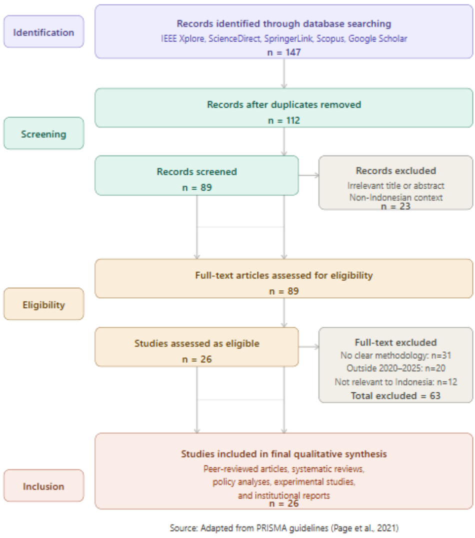

Figure 1. Flowchart PRISMA

Result and Discussions

Thematic analysis of the 26 reviewed studies yielded nine interconnected dimensions characterizing Indonesia's battery technology development between 2020 and 2025.

1. Evolution of Battery Material Technology
   Indonesia's material landscape is dominated by NMC and LFP lithium ion chemistries, structurally anchored in the country's vast nickel, manganese, cobalt, and iron reserves (Latif et al., 2025). Alternative innovations including bio electrolytes (Habibi, 2024), ALD enhanced electrodes (Karimzadeh et al., 2023), and low temperature electrolyte formulations (Hubble; et al., 2022) signal expanding research toward safer and more sustainable battery systems, though translation into commercial deployment remains limited.
2. Manufacturing Capacity and Industrial Investment
   The 2020 nickel ore export ban functioned as a key industrial policy instrument, accelerating foreign direct investment into domestic battery manufacturing (Pandyaswargo et al., 2021). Strategic collaboration between Indonesia Battery Corporation, Hyundai Motor, and LG Energy Solution targets integrated national production capacity of 140 GWh by 2030 (Astuti et al., 2024). However, current expansion remains predominantly technology receiving rather than technology generating (Konewka et al., 2021).
3. Charging Infrastructure and System Integration
   Charging infrastructure expanded significantly following Presidential Regulation No. 55 of 2019, with SPLU, SPKLU, and SPBKLU networks deployed across multiple provinces (Dharmawan et al., 2021) Nevertheless, a supply demand mismatch persists due to low EV adoption rates. BMS standardization and battery swapping protocols remain critical for interoperability and operational safety (Sutopo et al., 2022).
4. Regulatory Framework and Policy Challenges
   Regulatory analysis reveals proactive investment policies but fragmented safety and waste governance. Inconsistencies in TKDN requirements and fiscal incentives persist(Siombo & Adi, 2025), while battery fire safety standards fall substantially below UNECE R100 and UL 2580 international benchmarks (Rudijanto et al., 2025).
5. Battery Recycling and Circular Economy
   Hydrometallurgical processes achieve 90–95% recovery efficiencies for lithium, nickel, cobalt, and manganese (Faizhata et al., 2025) and (Amelia et al., 2023), yet implementation is constrained

by critically low public awareness and underdeveloped reverse logistics infrastructure(Mubarok et al., 2024).

6. Consumer Preferences and EV Adoption Challenges
Purchase price and operational cost are the primary adoption deterrents (Adzhani et al., 2025) compounded by inadequate charging infrastructure density and after sales service networks(Habiburrahman et al., 2024).
7. Environmental Impact and Emission Reduction
EVs can reduce CO_2 emissions by 50–70% compared to conventional vehicles when supported by renewable energy (Widhiyanti; et al., 2025), though environmental risks from upstream mineral extraction require integrated governance (Rakhmawati & Oktaviani, 2023).
8. SWOT Analysis of Indonesia's Battery Industry
Key strengths include nickel endowment and government policy support (Apribowo et al., 2024), while foreign technology dependence and fragmented regulation remain structural weaknesses (Wijaya et al., 2025). Opportunities arise from surging global battery demand (Alfaruqi, 2023), while threats include competition from established manufacturing economies.
9. Emerging Technology Trends and Future Projections
Solid state batteries, sodium ion batteries, and AI driven BMS represent the most strategically significant next generation directions (Latif et al., 2025; Mahandari et al., 2024; Ngurah & Putra, 2024). Vehicle to Grid integration further positions EV batteries as distributed renewable energy storage assets (Habiburrahman et al., 2024).

Discussion

The thematic findings, when examined collectively rather than in isolation, reveal a structural pattern that transcends individual research domains: Indonesia's battery industry is characterized by a fundamental asymmetry between upstream endowment and downstream capability. The country possesses world class natural resource advantages most notably its 21% share of global nickel reserves and has demonstrated growing capacity to attract large scale foreign manufacturing investment. Yet this upstream strength has not been matched by commensurate development in domestic research and development capacity, regulatory coherence, circular economy infrastructure, or consumer facing market conditions (Konewka et al., 2021).

This asymmetry generates a specific vulnerability: Indonesia risks becoming a permanent manufacturing platform for foreign battery technologies executing production processes designed elsewhere rather than evolving into an independent innovator capable of generating proprietary battery technologies and capturing higher value added segments of the global supply chain. Benchmarking against South Korea's development trajectory, where sustained public investment in battery R&D during the 2000s enabled companies such as LG Energy Solution and Samsung SDI to achieve global technological leadership, underscores that manufacturing scale without indigenous R&D investment does not produce long term competitiveness (Konewka et al., 2021).

The identified themes reveal a structural challenge where regulatory fragmentation, including inconsistent TKDN enforcement, limited battery safety standards, and weak waste management systems, reduces consumer confidence and slows EV adoption(Rakhmawati & Oktaviani, 2023) Low adoption rates then weaken the commercial feasibility of charging infrastructure investment, creating a reinforcing regulatory-adoption cycle that cannot be solved through infrastructure expansion alone and instead requires stronger governance intervention.

Similarly, the environmental dimension of Indonesia's battery development cannot be evaluated solely through the lens of vehicle emission reductions. While LCA evidence confirms a 50–70% CO_2 reduction potential for EVs relative to conventional vehicles (Mubarok et al., 2024), this benefit is conditioned on renewable energy integration and is partially offset by the environmental costs of upstream mineral extraction. Indonesia's ambition to be a leading battery producer therefore carries an inherent environmental governance obligation: without robust mining regulation and a functioning circular economy, the ecological footprint of Indonesia's battery industry may undermine the sustainability credentials of its EV ecosystem at a global level.

The emergence of solid-state, sodium-ion, and AI-assisted battery management technologies presents a strategic opportunity for Indonesia (Latif et al., 2025). Unlike lithium-ion batteries dominated by established global patents, these next-generation technologies remain in early commercialization stages, allowing Indonesia to strengthen its position beyond raw material supply and manufacturing. In addition, V2G integration could transform EV batteries into distributed energy storage assets that support national renewable energy resilience (Rudijanto, 2025).

Implications

The findings carry differentiated implications for four principal stakeholder groups: policymakers, researchers, industry practitioners, and civil society. For policymakers, the most urgent priority is resolving regulatory fragmentation that slows industry development and consumer adoption. This can be achieved through cross ministerial harmonization of TKDN regulations, alignment of battery safety standards with UNECE R100 and UL 2580 frameworks, and the establishment of a legally mandated battery end of life management scheme (Pirmana et al., 2023; Puspita, 2024). Beyond regulatory reform, sustained public investment in domestic battery R&D infrastructure analogous to South Korea's government led battery research programs of the preceding decades is essential for reducing structural dependence on foreign technology transfer and enabling indigenous innovation capacity (Ngurah & Putra, 2024).

For the academic and research community, this study highlights a pronounced gap between experimental innovation and industrial translation. Future research should prioritize applied engineering studies that bridge laboratory scale discoveries particularly in bio electrolytes, ALD electrode coatings, and solid state architectures toward pilot scale and commercially viable implementations (Sutopo et al., 2022; Wijaya et al., 2025). Additionally, integrated analytical frameworks that simultaneously examine the material industrial regulatory adoption nexus, rather than single dimension studies, are needed to generate systemic insights that individual disciplinary studies cannot provide.

For industry practitioners, the strategic imperative is to move from technology receiving to technology generating roles. This transition demands investment in proprietary process R&D, domestic workforce development in battery engineering disciplines, and strategic positioning in next generation battery technology domains particularly solid state and sodium ion systems where incumbent competitive advantages are less entrenched (Mahandari et al., 2024; Ngurah & Putra, 2024). The V2G opportunity also merits early mover consideration: companies that develop integrated EV grid management capabilities stand to capture value not only in transportation but across the broader energy storage market (Habiburrahman et al., 2024).

For civil society and public communication stakeholders, addressing the low public awareness of battery recycling is a prerequisite for circular economy implementation. Structured public education campaigns combined with accessible reverse logistics collection infrastructure represent the minimum enabling conditions for translating existing hydrometallurgical recycling capabilities into functional material recovery at scale (Mubarok et al., 2024).

Conclusions

This study constructs the first integrated nine dimensional ecosystem mapping of Indonesia's battery technology development across 2020–2025, revealing a fundamental asymmetry between strong upstream material endowments and persistent structural deficiencies in domestic R&D, regulatory coherence, recycling infrastructure, and consumer adoption. Three key contributions emerge: a causal chain linking regulatory fragmentation to adoption suppression; a benchmark revealing that manufacturing scale without indigenous innovation yields limited competitiveness; and identification of solid state and sodium ion batteries as strategic early mover opportunities. Future research should prioritize longitudinal EV adoption studies and techno economic feasibility analyses, while policy should urgently harmonize safety standards, mandate circular economy regimes, and sustain national battery R&D investment.

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