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Study of battery supply chain optimization resource localization and green manufacturing processes within the emerging electric vehicle industry in the mountainous regions of Southwest China

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Abstract

The study focuses on the economic and environmental assessment of localizing the electric vehicle battery supply chain in the mountainous regions of Southwest China (Sichuan, Yunnan, Guizhou), which host significant lithium reserves and surplus hydropower capacity. Against the backdrop of rising global EV demand and the vulnerability of extended "mine–refining–assembly" chains, the paper examines the extent to which shifting refining and manufacturing closer to the resource base and low-cost clean energy reduces unit cost and carbon footprint. The empirical base spans 2020–2025 and includes official statistics, industry reports, and corporate disclosures; the methodology combines comparative cost analysis with life-cycle assessment, construction of a composite investment attractiveness index (AHP), and project financial modeling (DCF/NPV, scenario and Monte Carlo analyses). Differentiated electricity tariffs, haul distances in mountainous terrain, and shadow carbon charges are computed, and site ranking is conducted (Ya'an, Qujing, Tongren). Quantified effects of full-cycle localization in Sichuan include a 15.53% reduction in the final cost of producing NMC 811 cells relative to the traditional model of placing capacity in coastal provinces, driven by an 83.68% cut in raw-material logistics and a 56.69% reduction in energy costs; shadow carbon charges fall by 91.06%. The environmental impact translates into an 86.99% reduction in CO2e emissions and an 89.35% reduction in transport footprint per 1 GWh of output. The investment attractiveness index identifies the Ya'an area (83.69 points) as the priority clustering hub due to proximity to deposits and accessible hydropower. The base-case NPV of a 50 GWh gigafactory project is estimated at $1.25 billion; the greatest sensitivity is to the price of lithium carbonate (≈±31.6% of NPV for a ±15% price change), whereas the electricity tariff has a moderate effect. The discussion shows that localization simultaneously reduces costs, supply risks, and regulatory costs (CBAM), creating a sustainable competitive advantage and a foundation for the region's green industrial policy.

For citation

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Keywords

Supply chain localization, Sichuan hydropower, electric vehicle batteries, carbon footprint, investment attractiveness.

Introduction

The rapid growth of the global electric vehicle (EV) market, driven by both consumer demand and tighter environmental regulations, has brought to the forefront the industry's critical reliance on battery supply chains. As of the third quarter of 2024, China accounted for over 65% of global lithium-ion battery production, and the domestic EV market exceeded 9 million units, accounting for more than a third of all global sales. However, this hegemony is fraught with internal challenges, primarily related to logistical complexity and environmental sustainability. Traditional supply chains are often geographically fragmented: raw materials (lithium, cobalt, nickel) are extracted in some regions, processed in others, and cell production and battery assembly in others, mainly in coastal industrial clusters. This leads to significant transport costs, a carbon footprint, and vulnerability to geopolitical and logistical disruptions [Al-Ghussain, 2022].

In this context, the mountainous regions of Southwest China, particularly Sichuan, Yunnan, and Guizhou provinces, represent a unique strategic springboard for reconfiguring and optimizing the national battery industry. Sichuan, for example, has more than half of the country's total proven lithium reserves, making it the resource heart of the industry. [Liao, Hu, Luo, 2022] At the same time, this region is China's largest hydroelectric power center, producing more than 850 billion kWh of clean electricity per year. This enormous energy potential creates prerequisites for the organization of a "green" production cycle with a minimal carbon footprint, which is becoming an increasingly important competitive advantage in the global market [Wang, 2022]. Despite these obvious advantages, the development of the region's potential is hindered by a number of factors, including the difficult mountainous terrain, which increases the cost of logistics, insufficiently developed infrastructure compared to the eastern provinces, and the need for significant capital investments.

The aim of this study is to provide a comprehensive economic analysis and simulation of optimizing the supply chain of electric vehicle batteries through the prism of resource localization and the introduction of green manufacturing processes in the mountainous regions of Southwest China. We aim to quantify the economic benefits, investment attractiveness, and environmental benefits of moving from a traditional, extended supply model to an integrated, localized "mine-to-battery" system. The study analyzes how the synergy between rich mineral resources and excess clean hydropower capacity can not only reduce production costs and carbon footprint, but also increase the overall sustainability and competitiveness of the Chinese EV industry [Chen Q., Khattak, 2023]. An analysis of the current situation shows that the average logistics costs for delivering lithium concentrate from Sichuan to processing plants in Jiangsu or Fujian province can be up to 8-12% of its cost, which is a significant financial burden [Gupta, Anand, Tyagi, 2023]. Moving processing and production facilities closer to raw material sources has the potential to reduce these costs by more than half, while creating high-tech jobs and stimulating economic development in the less developed western regions of the country.

Materials and methods of research

This study is based on a comprehensive approach that combines statistical data analysis, econometric modeling, and financial analysis. The empirical basis was an array of data for the period

from 2020 to 2025, covering key economic, production and environmental indicators of the battery industry in China. The main sources of information were official data from the National Bureau of Statistics of China, industry reports from the China Automobile Manufacturers Association (CAAM) and the China Industrial Power Supply Manufacturers Association (CIAPS), as well as financial statements from leading companies in the sector, such as Contemporary Amperex Technology Co. Limited (CATL), BYD Company Ltd. and Tianqi Lithium. Data from regional energy exchanges and logistics operators were used to obtain detailed information on logistics costs and electricity costs [Eid, Mohammed, El-Kishky, 2022]. In total, more than 150 different sources were analyzed, including scientific publications from the Scopus and Web of Science databases, analytical reports from BloombergNEF, S&P Global Market Intelligence, and Wood Mackenzie [Tan, Tian, Xu, Li, 2023].

The methodological tools of the study included several key components. First, a comparative Cost-Benefit Analysis was conducted for two supply chain models: traditional (extended) and localized (integrated in Southwest China). This analysis took into account not only direct costs (transportation of raw materials and components, electricity costs, labor costs), but also indirect costs, such as carbon taxes calculated on the basis of the Life Cycle Assessment (LCA) methodology [Wang, 2025]. This made it possible to obtain a comprehensive assessment of economic efficiency, taking into account the environmental factor. We used data on average tariffs for transportation of goods by rail and road in mountainous areas, as well as differentiated electricity tariffs for industrial consumers in the eastern and southwestern provinces [Zahoor et al., 2023].

Secondly, to assess the investment attractiveness of various sites in the region under study, a composite Investment Attractiveness Index was developed. This index is a weighted assessment that integrates such parameters as proximity to deposits of lithium and other key minerals, the cost and availability of electricity from renewable sources, the level of development of transport infrastructure, the availability of qualified labor, and state policy to support investment [Dhairiyasamy, Gabiriel, Bunpheng, Kit, 2024]. To calibrate the weighting coefficients of the index, the Analytical Hierarchy Process was used, based on expert assessments obtained during interviews with 25 industry representatives, including top managers of manufacturing companies, logisticians, and government officials [Gough, 2023].

Third, scenario modeling and sensitivity analysis of the Net Present Value (NPV) of projects were conducted to assess the financial risks and sustainability of investment projects for the creation of localized production facilities. Global prices for lithium and cobalt, the cost of electricity, and the amount of government subsidies were considered as key variables subject to volatility [Yeo, 2021]. This analysis allowed us to determine the break-even points of projects and identify the most critical risk factors that require hedging strategies. The mathematical apparatus was based on the methods of discounting cash flows (DCF) and Monte Carlo simulation to estimate the probability distribution of financial results [Galati, Adamashvili, 2023]. All data processing and model building was performed using Stata and R software packages.

Results and discussion

The transition to a localized battery production model in Southwest China represents not just a logistical optimization, but a fundamental shift in the region's industrial development paradigm. To quantify this shift, we conducted a multi-pronged analysis covering cost structure, investment attractiveness, financial sustainability, and environmental impact. The choice of these indicators is determined by the need for a comprehensive assessment that reflects the interests of all key

stakeholders: investors who seek to maximize profits and minimize risks; the state, which is interested in sustainable regional development and increasing national competitiveness; and society, for which the environmental consequences of industrial activities are important. The first step was a detailed comparative analysis of operating costs, which allows us to clearly demonstrate the direct economic benefits of reducing logistics leverage and using cheap hydropower.

Comparing the traditional model, where raw materials from Sichuan are transported for processing and production to coastal provinces (for example, Jiangsu), with the localized model, where the entire cycle from mining to battery assembly is concentrated in Sichuan, reveals significant discrepancies in the cost structure. Logistics costs and energy costs are key differentiating factors that directly affect the final profitability (Table 1). The analysis of these data allows not only to state the fact of savings, but also to determine its sources and scale, which is critical information for making investment decisions.

Table 1 - Comparative analysis of the cost structure for the production of 1 kWh NMC 811 battery cells, US $

Cost item	Traditional model (raw materials from Sichuan, production in Jiangsu)	Localized model (full cycle in Sichuan)	Change, %
Raw materials (lithium, nickel, cobalt, manganese)	45.18	45.18	0.00
Transportation of raw materials to the plant	5.82	0.95	-83.68
Energy consumption for processing and production	7.25	3.14	-56.69
Labor costs	6.45	5.98	-7.29
Logistics of finished products to the automobile plant (conventionally in Chongqing)	1.15	0.42	-63.48
Depreciation and other overheads	9.50	9.75	2.63
Carbon tax (notional)	2.35	0.21	-91.06
Total cost	**77.70**	**65.63**	**-15.53**

The data in Table 1 clearly illustrate the economic feasibility of localizing the production cycle. The total cost reduction of 15.53% is a very significant indicator in the highly competitive battery industry. The most dramatic changes are observed in articles directly related to geographical location. Reducing the cost of transporting raw materials by 83.68% is a direct consequence of eliminating the need to transport thousands of tons of lithium concentrate over a distance of more than 2000 km. Logistics costs are being reduced from US $ 5.82 to US $ 0.95 per kWh, reflecting the shift from interprovincial to intraregional transport. An even more significant factor is the 56.69% reduction in energy consumption. This is due to access to cheap hydroelectric power in Sichuan, where the average industrial tariff is about US $ 0.05 per kWh, while in Jiangsu it can reach US $ 0.11 per kWh, and a significant part of it is generated by coal-fired power plants [Yeung, Liu, 2023].

Special attention should be paid to the almost complete levelling of the conditional carbon tax, which falls by 91.06%. Although this indicator is a model, it reflects the real and future risks associated with the tightening of environmental legislation and the introduction of cross-border carbon regulation (CBAM) mechanisms in Europe. Hydropower-based production is gaining a long-term competitive advantage that will only increase as the global transition to a low-carbon economy continues. A slight increase in depreciation costs in the localized model (+2.63%) is explained by the need to build a new, more modern infrastructure, which is a justified investment. The slight decrease in labor costs (-7.29%) reflects the lower level of average wages in the western regions compared to the industrially developed

coast.

However, economic efficiency is not the only criterion for making investment decisions. It is necessary to evaluate and compare the attractiveness of specific sites within the region. For this purpose, an integral index was developed that takes into account the key factors of production placement .

Analysis of the Investment Attractiveness Index shows clear leadership in Zone A (Ya'an City district, Sichuan Province) with a final score of 83.69. This high result is due to the optimal combination of the two most significant factors: maximum proximity to the main lithium mines in Sichuan (score 92.5) and high availability of cheap hydropower (88.4). Despite the fact that Zone B in Yunnan shows the best indicators in terms of energy availability (95.1), and Zone C in Guizhou-in terms of state support (91.0), their significant lag in the main factor – access to raw materials – reduces the overall attractiveness. The weighting factor of 0.35 for the raw material factor reflects its critical importance, since it is the logistics of raw materials that generates the largest costs in the traditional model. Zone A, although inferior to its competitors in some minor parameters, such as infrastructure development (75.3) and labor availability (68.1), provides the best synergy effect, minimizing key operating costs. This makes it the most promising platform for priority placement of large production clusters.

Even with high investment attractiveness, any capital-intensive project is subject to market risks. An analysis of the NPV sensitivity of a 50 GWh plant construction project in Zone A to changes in key variables makes it possible to assess its financial sustainability.

The results of sensitivity analysis identify key risk areas for investors. The price of lithium carbonate has the greatest impact on the project's NPV. A 15% change in the price results in NPV fluctuations of approximately $ 395 million each way, which is about 31.6% of the base value. This highlights the high dependence of the project's profitability on the volatility of commodity markets and dictates the need to use hedging instruments, such as long-term supply contracts or futures transactions. The second most important factor is capital expenditure (CAPEX), which is typical for large infrastructure projects. At the same time, the project demonstrates relative resistance to changes in the electricity tariff. Even with its growth of 15%, NPV is declining only by 11.1%, remaining at a high positive level (1112.35 million US dollars). This confirms the strategic value of placing production in a region with guaranteed low and stable energy costs. The dependence on subsidies is also moderate, which indicates the commercial viability of the project even with reduced government support.

Finally, an integral part of the analysis is the assessment of environmental benefits, which in the modern economy are increasingly translated into direct financial benefits through carbon markets and consumer preferences.

Environmental indicators confirm the transformational nature of localization. The reduction in CO2 emissions by almost 87% is the result of a double effect: the abandonment of long-distance transportation and the use of hydropower instead of coal generation. This allows us to position our products as "green", which opens up access to premium markets, especially in Europe. A reduction in the transport footprint by 89.35% directly correlates with the reduction in logistics costs shown in Table 1. A 15.95% reduction in water consumption is achieved through the introduction of more modern recycled water supply technologies at new enterprises, as well as due to the peculiarities of technological processes for processing local raw materials [Li et al., 2024].

A comprehensive analysis of the data presented in four tables allows you to form a complete picture. The economic benefits shown in table 1 (a 15.53% reduction in production costs) are a powerful incentive for investors. The Investment Attractiveness Index (Table 2) indicates specific geographical locations where this potential can be realized with maximum efficiency, with Sichuan's Zone A being

a clear favorite. The risk analysis (Table 3) shows that, despite the high sensitivity to raw material prices, the project has a significant margin of safety due to the low cost of energy. Finally, environmental indicators (Table 4) not only support the economic case through the carbon tax mechanism, but also create long-term reputational and marketing value. Thus, the localization of the supply chain in Southwest China is a rare case when economic, strategic and environmental goals are completely aligned, creating a powerful synergistic effect. This approach makes it possible to move from simple cost optimization to creating a sustainable, competitive and environmentally responsible next-generation industrial ecosystem.

Conclusions

The study clearly demonstrates that the strategic localization of battery supply chains in the mountainous regions of Southwest China is not just an operational optimization, but a comprehensive solution that can dramatically increase economic efficiency, environmental sustainability and overall competitiveness of the industry. The integration of production facilities in close proximity to the richest lithium deposits and sources of cheap hydroelectric power creates a unique synergistic effect that cannot be replicated in traditional industrial clusters in the east of the country. The obtained quantitative estimates confirm the many-sided advantages of this approach.

The key conclusion is the established fact that it is possible to reduce the total cost of production of battery cells by 15.53%. This result is achieved mainly due to a radical reduction in logistics costs for the transportation of raw materials (by more than 83%) and a twofold reduction in energy costs. In absolute terms, this means savings of more than $ 12 per kilowatt-hour of battery produced, which translates into hundreds of millions of dollars in annual savings on a gigafactory scale. This cost-effectiveness makes localization projects highly profitable and attractive for private investment, which is confirmed by the high base NPV value of $ 1.25 billion for a hypothetical project.

Equally important is the conclusion about environmental benefits. Switching to hydroelectric power and minimizing the transport shoulder can reduce the carbon footprint of production per gigawatt-hour of production by almost 87%. This not only meets the global decarbonization agenda, but also represents a significant commercial advantage that protects producers from the introduction of cross-border carbon tariffs and increases the attractiveness of their products in international markets. The localized model transforms the battery industry from a source of environmental problems to a driver of green growth, which is fully in line with China's national strategic goals.

The prospects for applying the results obtained are diverse. At the macro level, the findings of the study can form the basis of state policy to encourage investment in the industrial development of western regions, helping to equalize regional economic imbalances. For the corporate sector, the presented model and evaluation methodology can serve as a direct guide to action when planning new production capacities. The Sensitivity analysis and Investment Attractiveness Index provide investors with practical tools to assess risks and choose the best investment sites. The implementation of the proposed localized model can transform Southwest China into a global center for the production of "green" batteries, setting a new global standard for the entire industry and ensuring the country's long-term technological and economic leadership in the electric vehicle sector.

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Исследование оптимизации цепочки поставок аккумуляторов, локализации ресурсов и экологически чистых производственных процессов в развивающейся индустрии электромобилей в горных районах Юго-Западного Китая

Сяо Шисюань

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Аннотация

Исследование направлено на экономическую и экологическую оценку локализации цепочки поставок аккумуляторных батарей для электромобилей в горных регионах Юго-Западного Китая (Сычуань, Юньнань, Гуйчжоу), где сосредоточены значимые запасы лития и избыточные мощности гидроэнергетики. На фоне растущего мирового спроса на EV и

уязвимости протяженных цепочек «рудник – переработка – сборка» автор рассматривает, в какой мере перенос переработки и производства ближе к сырьевой базе и дешевой «чистой» энергии снижает себестоимость и углеродный след. Эмпирическая база охватывает 2020–2025 годы и включает официальную статистику, отраслевые отчеты и корпоративную отчетность; методология сочетает сравнительный анализ затрат с оценкой жизненного цикла, конструированием интегрального индекса инвестиционной привлекательности (AHP) и финансовым моделированием проектов (DCF/NPV, сценарный и Монте-Карло анализ). Рассчитаны дифференцированные тарифы на электроэнергию, транспортные плечи в горной местности и условные углеродные платежи, а также проведено ранжирование площадок (Яань, Цюйцзин, Тунжэнь). Получены количественные эффекты локализации полного цикла в Сычуани: снижение итоговой себестоимости производства ячеек NMC 811 на 15,53% относительно традиционной модели с выносом мощностей в прибрежные провинции за счет сокращения логистики сырья на 83,68% и энергозатрат на 56,69%; условные углеродные платежи уменьшаются на 91,06%. Экологический импакт выражается в сокращении выбросов CO2-экв. на 86,99% и транспортного следа на 89,35% на 1 ГВт·ч продукции. Индекс инвестиционной привлекательности выделяет зону Яань (83,69 балла) как приоритетную точку кластеризации благодаря близости к месторождениям и доступной гидроэнергии. Базовый NPV проекта гигафабрики на 50 ГВт·ч оценивается в 1,25 млрд долл.; наибольшая чувствительность связана с ценой карбоната лития (≈±31,6% от NPV при ±15% изменения цены), тогда как тариф на электроэнергию оказывает умеренное влияние. Обсуждение показывает, что локализация одновременно снижает издержки, риски поставок и регуляторные издержки (CBAM), формируя устойчивое конкурентное преимущество и основу для «зеленой» индустриальной политики региона.

Для цитирования в научных исследованиях

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Ключевые слова

Локализация цепочки поставок, гидроэнергетика Сычуани, аккумуляторы для электромобилей, углеродный след, инвестиционная привлекательность.

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