

Business Model for Regional Electric Vehicle Battery Services: A Case Study of Small and Medium Enterprises in the Upper-Northern Thailand

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Abstract

As electric vehicle (EV) adoption accelerates, overcoming infrastructure barriers in non-metropolitan regions remains a critical challenge. While existing literature emphasizes urban charging networks, this study addresses a significant gap by focusing on regional consumers' "service anxiety" specifically concerning the safety and cost of high-voltage battery maintenance post-warranty. This demand-side challenge is compounded by the difficulties traditional garages face in technological transition. Therefore, this study aims to systematically develop and empirically assess a localized EV battery service business model tailored for independent small and medium enterprises (SMEs) in Upper-Northern Thailand.

The study employed a mixed-methods design, Quantitative data were collected from 370 regional EV users to assess market expectations. Subsequently, qualitative insights were gathered through in-depth interviews with a panel of 25 industry experts. The model's strategic architecture was constructed by integrating the CIPP evaluation model (Context, Input, Process, and Product) with the Business model canvas (BMC) and validated through expert evaluation.

Empirical findings reveal that the transition to EV services is constrained primarily by a deficit in certified human capital. Expert evaluation confirmed the model's overall appropriateness at a very high level ($\bar{X} = 4.48$, S.D. = 0.53). Under the resource-based view (RBV), specialized technician competency is the critical asset required to mitigate consumer service anxiety. The framework integrates stakeholder theory by advocating for public-

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private partnerships to support training, alongside circular economy principles to manage battery waste.

Ultimately, this research provides a de-risked blueprint for local SMEs and a strategic framework for policymakers to foster sustainable, decentralized EV ecosystems.

Keywords: Battery Service, Business Model Canvas, Circular Economy, Electric Vehicle Ecosystem, Upper-Northern Thailand

โมเดลธุรกิจบริการแบตเตอรี่รถยนต์ไฟฟ้าในระดับภูมิภาค: กรณีศึกษาธุรกิจขนาดกลาง และขนาดย่อม (SMEs) ในพื้นที่ภาคเหนือตอนบนของประเทศไทย

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บทคัดย่อ

เมื่อการใช้รถยนต์ไฟฟ้า (EV) เติบโตอย่างรวดเร็ว การแก้ไขปัญหาด้านโครงสร้างพื้นฐานในพื้นที่ต่างจังหวัดจึงเป็นความท้าทายที่สำคัญ ขณะทำงานวิจัยส่วนใหญ่เน้นที่เครือข่ายสถานีชาร์จในเขตเมือง งานวิจัยนี้มุ่งเติมเต็มช่องว่างโดยให้ความสำคัญกับ "ความกังวลด้านการบริการ" (Service anxiety) ของผู้ใช้รถในภูมิภาค โดยเฉพาะด้านความปลอดภัยและค่าใช้จ่ายในการซ่อมบำรุงแบตเตอรี่แรงดันสูงหลังหมดประกัน ปัญหาความต้องการนี้ถูกซ้ำเติมด้วยข้อจำกัดของอู่ซ่อมรถดั้งเดิมที่ยากจะเปลี่ยนผ่านเทคโนโลยี การศึกษานี้จึงมีวัตถุประสงค์เพื่อพัฒนาและตรวจสอบความเหมาะสมของโมเดลธุรกิจบริการแบตเตอรี่ EV ระดับท้องถิ่นอย่างเป็นระบบ สำหรับธุรกิจขนาดกลางและขนาดย่อม (SMEs) อิสระในพื้นที่ภาคเหนือตอนบนของประเทศไทย

งานวิจัยนี้ใช้วิธีวิจัยแบบผสมผสาน (Mixed-methods) เก็บข้อมูลเชิงปริมาณจากผู้ใช้งาน EV ในพื้นที่ 370 คน เพื่อประเมินความคาดหวังของตลาด จากนั้นเก็บข้อมูลเชิงคุณภาพผ่านการสัมภาษณ์เชิงลึกผู้เชี่ยวชาญ 25 ท่าน โครงสร้างกลยุทธ์ของโมเดลธุรกิจสร้างขึ้นจากการนำแบบจำลอง CIPP Model (Context, Input, Process and Product) มาผสมผสานกับ Business Model Canvas (BMC) และประเมินความเหมาะสมโดยผู้เชี่ยวชาญ

ผลการศึกษาพบว่า อุปสรรคสำคัญในการเปลี่ยนผ่านไปสู่บริการรถ EV คือการขาดแคลนช่างเทคนิคที่มีใบรับรอง การประเมินโดยผู้เชี่ยวชาญยืนยันความเหมาะสมของโมเดลในระดับมากที่สุด ($\bar{X} = 4.48$, S.D. = 0.53) ภายใต้มุมมองฐานทรัพยากร (RBV) โมเดลชี้ให้เห็นว่าความเชี่ยวชาญของช่างเทคนิคคือทรัพยากรหลักที่สำคัญที่สุดในการลดความกังวลของผู้บริโภค นอกจากนี้ กรอบแนวคิดยังบูรณาการทฤษฎีผู้มีส่วนได้ส่วนเสียผ่านความร่วมมือระหว่างภาครัฐและเอกชนเพื่อสนับสนุนการฝึกอบรม ควบคู่กับหลักเศรษฐกิจหมุนเวียน (Circular Economy) ในการจัดการขยะแบตเตอรี่

ท้ายที่สุด งานวิจัยนี้แนะนำแนวทางที่ช่วยลดความเสี่ยงสำหรับ SMEs ในท้องถิ่น และเป็นกรอบเชิงกลยุทธ์ให้แก่ภาครัฐ เพื่อส่งเสริมระบบนิเวศยานยนต์ไฟฟ้าที่ยั่งยืนและกระจายตัวสู่ภูมิภาคได้อย่างมีประสิทธิภาพ

คำสำคัญ: บริการแบตเตอรี่ ภาคเหนือตอนบนของประเทศไทย โมเดลธุรกิจ ระบบนิเวศยานยนต์ไฟฟ้า เศรษฐกิจหมุนเวียน

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Introduction

The electric vehicle (EV) industry has emerged as a key driver of sustainable transportation, offering a promising pathway toward reducing urban air pollution and greenhouse gas emissions (Casals et al., 2019; Gómez Vilchez & Jochem, 2020; Wang et al., 2017). In Thailand, the EV market has grown rapidly due to strong government support and the need to reduce dependence on fossil fuels. However, the continued expansion of the EV ecosystem faces several structural challenges, including insufficient charging infrastructure, persistent range anxiety, and reliance on imported high-voltage batteries (Engel et al., 2018; Noel et al., 2020). As a result, internal combustion engine (ICE) vehicles remain widely used due to their established infrastructure and lower operational costs (Koojaroenprasit & Pumpinyo, 2023).

These challenges are more pronounced in regions distant from major industrial centers. In Upper-Northern Thailand covering Chiang Mai, Chiang Rai, Lampang, and Lamphun the EV ecosystem is constrained by a significant gap in battery maintenance services. According to data from the Department of Land Transport (2024), new EV registrations in the Northern region surged to 6,208 vehicles in 2023 making it the second-highest region for EV adoption in Thailand with Chiang Mai alone accounting for 3,083 units. Despite this rapid growth, authorized service centers remain limited in number. Geographic isolation leads to logistical delays and high transportation costs for battery repair. Additionally, regional driving conditions may contribute to accelerated battery wear under certain operating conditions, further intensifying consumer concerns regarding service accessibility.

Consequently, regional consumers increasingly experience "service anxiety." In this study, service anxiety is operationally defined as the psychological and practical concerns regarding the availability, reliability, safety, and cost of high-voltage battery maintenance after the manufacturer's warranty expires. Unlike range anxiety, which pertains to charging infrastructure, service anxiety directly threatens the long-term viability of EV ownership.

This demand-side consumer anxiety is directly compounded by a severe supply-side bottleneck: the profound difficulty traditional internal combustion engines (ICE) repair shops face in transitioning to EV services. These local businesses, primarily small and medium-sized enterprises (SMEs), encounter high capital requirements for specialized equipment and lack access to proprietary technical knowledge. Without a structured

support system, SMEs may face difficulties participating in the emerging EV service ecosystem, leaving consumers without localized repair options.

Despite these pressing issues, a notable gap in the literature remains. While existing literature predominantly focuses on mitigating early-stage adoption barriers through urban charging networks, there is limited research exploring integrated business models for post-warranty EV battery services tailored to non-metropolitan SMEs. Specifically, the integration of the business model canvas (BMC) with circular economy (CE) principles for localized hazardous battery management remains relatively underexplored in the context of regional SMEs.

Therefore, this study aims to address this gap by examining both market expectations and operational constraints in Upper-Northern Thailand and translating these insights into a localized BMC. Accordingly, the study addresses two research questions:

1. What are the key demand-side expectations (service anxiety) and supply-side barriers (SME transition challenges) for EV battery services in Upper-Northern Thailand?
2. How can these insights be integrated into a sustainable, expert-evaluated business model for local SMEs?

By addressing these questions, this study seeks to contribute to the literature by extending the resource-based view (RBV) and stakeholder theory into the regional EV aftermarket. Practically, the proposed model offers a structured framework to support SME adaptation, help address consumer service anxiety, and guide policymakers in fostering a sustainable, decentralized EV ecosystem.

Literature Review

1. The EV Service Ecosystem and Regional Adoption Challenges

Recent studies have widely applied frameworks such as BMC (Osterwalder & Pigneur, 2010) to design business strategies for electric vehicle (EV) infrastructure. Much of the existing research focuses on addressing early-stage adoption barriers, particularly by reducing range anxiety through expanding urban charging networks (Axsen & Kurani, 2013; Engel et al., 2018). For example, Willyanto and Iskandar (2023) proposed customer-oriented EV charging solutions, while Rochani et al. (2023) developed a BMC for mobile battery swapping systems. Although these approaches support energy distribution, they are largely designed for urban and infrastructure-intensive environments. In contrast, non-

metropolitan regions, such as Upper-Northern Thailand, face unique geographical and logistical challenges. The limited prior literature regarding regional EV infrastructure indicates a notable gap, particularly concerning how local ecosystems adapt to prolonged usage and environmental factors affecting battery degradation in mountainous terrains. For instance, recent studies indicate that the scarcity of public charging stations in Thailand's non-urban areas significantly heightens consumer range anxiety, while factors such as steep gradients and high road altitudes in mountainous regions have been associated with higher battery energy consumption and the optimal placement of charging infrastructure (Suvittawat & Suvittawat, 2024; Tsai et al., 2024).

2. Post-Warranty Battery Maintenance and "Service Anxiety"

As EV usage expands beyond urban centers, the literature indicates a shift in consumer concerns from "range anxiety" to "service anxiety." In this study, service anxiety is conceptually defined as the psychological and practical apprehension regarding the availability, reliability, safety, and affordability of post-warranty maintenance services. In geographically dispersed areas, reliance on centralized manufacturer service centers leads to higher costs, longer waiting times, and reduced accessibility. Furthermore, literature on post-warranty EV battery services emphasizes that independent EV repair ecosystems must manage complex tasks, including battery diagnostics, module-level repair, safety protocols for high-voltage systems, and reverse logistics for hazardous waste (Meyer et al., 2024; Yu et al., 2025). The absence of localized independent service providers exacerbates service anxiety, highlighting a critical gap in the regional after-sales ecosystem.

3. SME Capability Transition and Theoretical Integration

The transition of SMEs from internal combustion engine (ICE) repair to high-voltage EV services requires substantial capability shifts. Existing literature suggests that SMEs cannot effectively transition independently due to financial, technical, and regulatory constraints. To address this, the proposed study integrates three foundational theories into the BMC framework to establish a coherent conceptual narrative:

1. Resource-Based View (RBV): Aligns with the key *resources*' component of the BMC. RBV posits that competitive advantage relies on valuable and rare resources. In the EV context, specialized human capital appears to be prioritized over physical infrastructure. Thus, certified high-voltage technicians emerge as the critical resource necessary to mitigate service anxiety (Khan et al., 2026; Yu et al., 2025).

2. Stakeholder theory: Maps directly to the *key partners* component. Recognizing SME limitations, Stakeholder theory highlights the necessity of Public-Private Partnerships (PPPs) among government agencies, academic institutions, and private enterprises to facilitate knowledge transfer and reduce training investment risks.

3. Circular Economy (CE): Integrates into the *key activities* and *revenue streams* components. Under a linear economy, degraded batteries are hazardous liabilities. CE principles transform this by establishing reverse logistics for battery module refurbishment and second-life energy storage applications, simultaneously ensuring environmental compliance and generating new revenue (Casals et al., 2019; Meyer et al., 2024).

Together, these three theoretical perspectives provide a complementary analytical foundation for understanding how regional SMEs may develop sustainable EV battery service capabilities under technological, financial, and environmental constraints.

Methodology

1. Population and Sample

The study area was defined as Upper-Northern Thailand, focusing on four key provinces: Chiang Mai, Chiang Rai, Lampang, and Lamphun. These locations were selected via purposive sampling because they are among the major regional centers of EV adoption, characterized by relatively high registration rates (Department of Land Transport, 2024), relatively developed charging infrastructure, and active local policy implementation. It is important to note the limitation of this purposive selection: the findings are geographically bound to the Upper-Northern context and may not be universally generalizable to SMEs in other regions without contextual adaptation. This study employed a sequential explanatory mixed-methods design. The study utilized two distinct sample groups:

1.1 Demand-Side Sample (EV Users): The quantitative phase surveyed a sample of 370 electric vehicle users currently operating within the four target provinces. The data collection was conducted between May and July 2025 utilizing a multi-channel distribution approach, including face-to-face administration, online surveys, mail, and direct questionnaire handouts. To ensure that the study obtained contextually grounded insights, a purposive sampling method governed by specific inclusion criteria was applied (Campbell et al., 2020); all participants were required to have owned and regularly operated an EV for a minimum of one year prior to the survey. This resulted in participation

from respondents with varying genders, age groups, durations of EV use, and EV brand ownership. Crucially, this sample size of 370 respondents was considered adequate for exploratory descriptive analysis and provided sufficient representation of EV users across the target provinces.

1.2 Supply-Side Sample (Industry Expert): For the qualitative model development and verification phases, the researcher employed purposive sampling governed by the "Information-Rich Cases" principle (Patton, 2002). The study engaged a total of 25 experts, categorized by distinct roles:

Phase 1 (Model Construction): An initial panel of 17 experts (including garage owners, certified technicians, and EV suppliers) participated in in-depth interviews to define the structural components of the model.

Phase 2 (Model Verification): An expanded panel comprising the original 17 experts plus an additional 8 independent experts (policymakers and academic specialists) evaluated the finalized model. Expert selection required a minimum of five years of relevant experience across private, academic, and government sectors.

2. Research Instruments

To systematically construct and verify the EV battery service business model, this study utilized two distinct types of research instruments aligned with the mixed-methods design:

2.1 Quantitative Instrument (Structured Questionnaire): Primary data regarding consumer perceptions and service expectations were collected using a structured questionnaire. The survey instrument comprised 37 items and was developed by adapting the service marketing mix (8Ps) framework (Wirtz & Lovelock, 2016).

2.2 Qualitative Instrument (Semi-Structured Interviews) and Framework Integration: Qualitative data were gathered through in-depth, semi-structured interviews. To rigorously guide the model construction, the BMC was integrated with the CIPP Evaluation Model framework. Specifically, Context assessment informed the Value Propositions and Customer Segments; Input assessment defined Key Resources and Cost Structure; Process evaluation shaped Key Activities and Channels; and Product evaluation determined Revenue Streams and overall sustainability. This integration was intended to ensure that the business model components were systematically grounded in contextual needs, operational inputs, implementation processes, and long-term outcomes.

3. Construction and Quality of Research Instruments

Prior to deployment, all instruments were reviewed and validated for content relevance by academic experts to ensure theoretical alignment and minimize measurement errors.

3.1 Content Validity (IOC): The content validity of the survey instrument and the interview/evaluation criteria was assessed by a panel of five independent domain experts utilizing the Index of Item-Objective Congruence (IOC). Only items achieving an IOC score of 0.50 or higher were retained (Rovinelli & Hambleton, 1977).

3.2 Reliability and Qualitative Trustworthiness: The internal consistency of the quantitative measurement scales was confirmed via Cronbach's Alpha, with values ranging from 0.82 to 0.91 (Hair et al., 2019). To enhance qualitative trustworthiness, interview findings were cross-checked across expert groups, and thematic consistency was reviewed by academic supervisors.

Data Analysis

Data analysis followed a mixed-methods approach:

1. Quantitative Analysis: Descriptive statistics (means and standard deviations) were utilized to analyze market expectations and expert evaluations. Because the objective of this study was exploratory model development and appropriateness verification rather than confirmatory hypothesis testing, descriptive statistics were the most appropriate analytical tool.

2. Qualitative Analysis: Data from semi-structured interviews were transcribed verbatim and analyzed. The coding scheme was strictly aligned a priori with the nine blocks of the BMC and the theoretical constructs (RBV, stakeholder theory, CE). To ensure qualitative rigor and trustworthiness, two independent researchers coded the transcripts. Discrepancies were resolved through consensus discussions. The finalized themes were then systematically triangulated with the quantitative survey results to refine the business model.

To provide a comprehensive visual summary of the methodology, Figure 1 illustrates the sequential flow of the entire research process. The study commenced with an in-depth literature review, which established theoretical foundation and guided the identification of research topics. Before deployment, the research instruments were

rigorously validated for content validity (IOC) and internal consistency (Cronbach's alpha). The data collection was conducted through a mixed-methods approach, capturing both quantitative data from the demand-side (370 regional EV users) and qualitative data from the supply-side (industry experts and SMEs). The empirical insights synthesized from these dual perspectives directly informed the design of the EV Battery Service Business Model. Ultimately, the process concluded with a rigorous expert evaluation to verify the developed model, ensuring its structural appropriateness and readiness for real-world implementation.

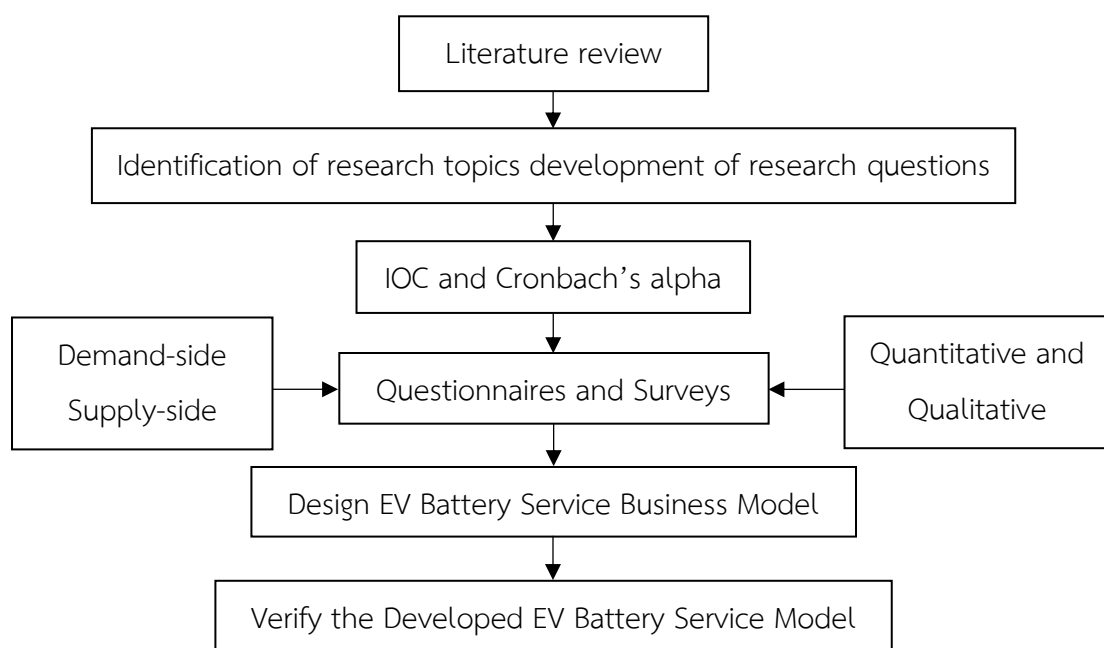


Figure 1: Flow chart of the research

Result

1. Empirical Findings and Structural Requirements for the Upper-Northern Thailand EV Service Model

Before constructing the strategic business architecture, it was imperative to systematically analyze the empirical data gathered from both the demand side (EV users) and the supply side (industry experts). This section details the critical constraints and market expectations in Upper-Northern Thailand. These findings serve as the foundational parameters for the subsequent business model design.

1.1 Demand-Side Insights: The Shift to "Service Anxiety"

Based on the quantitative survey of 370 EV owners across Chiang Mai, Chiang Rai, Lampang, and Lamphun, the data revealed a profound shift in consumer concerns. Analyzed through the Service Marketing Mix (8Ps) framework, the results demonstrate a significant demand for specialized human capital and safety over conventional service attributes. The descriptive statistics, summarized in Table 1, highlight the prioritization of these factors.

Table 1: Descriptive Statistics and Priority Ranking of EV User Service Expectations based on the 8Ps Framework (n=370)

Service Marketing Mix (8Ps)	Mean $\bar{x}$	S.D.	Interpre- tation	Rank
People: Certified high-voltage technicians and expert consultation	4.85	0.42	Very High	1
Process: Rigorous safety protocols and transparent repair procedures	4.78	0.45	Very High	2
Price: Total Cost of Ownership (TCO) and affordable module-level repair alternatives	4.65	0.51	Very High	3
Product: Consistent battery reliability and post-repair warranty	4.60	0.53	Very High	4
Place: Decentralized, localized networks to reduce logistical burdens	4.52	0.58	Very High	5
Productivity & Quality: Fast turnaround time addressing parts shortages	4.45	0.55	Very High	6
Physical Evidence: Specialized diagnostic equipment and safe waiting areas	4.30	0.62	Very High	7
Promotion: Educational campaigns regarding battery health	4.15	0.65	High	8

As shown in Table 1, critical paradigm shifts emerged. Consumers fundamentally value certified high-voltage human capital ($\bar{x} = 4.85$) and rigorous safety protocols ($\bar{x} = 4.78$) above all other factors. Decisions are heavily driven by cost-effective repair solutions rather than full battery replacements. This empirical evidence strongly suggests that resolving service anxiety relies on building trust through specialized technical competence.

1.2 Supply-Side Constraints: The SME Transition Barrier

Concurrently, the deductive content analysis of in-depth interviews with the initial 17 EV experts exposed severe structural bottlenecks preventing local SMEs from meeting this consumer demand.

1) The Human Capital Deficit (Aligning with RBV): Experts consistently emphasized that the primary barrier is not merely the financial cost of tools, but a critical scarcity of certified high-voltage technicians. Unlike the ICE sector, EV maintenance requires rigorous electrical engineering competencies. As one independent garage owner (Expert No. 4) explicitly stated: *"The cost of buying new tools is manageable, but finding a mechanic who understands high-voltage systems without risking their life is nearly impossible. Without certified training, the risk of lethal thermal runaway outweighs the business reward."* Thus, human capital constitutes the rarest and most non-substitutable resource for regional garages.

2) Regulatory and Environmental Liabilities: Standalone garages currently lack the legal framework and logistical networks to handle hazardous end-of-life batteries. An EV component supplier (Expert No. 12) highlighted this constraint: *"If local SMEs touch a degraded battery without proper disposal channels, they face severe environmental fines. They cannot transition independently without a reverse logistics system in place."* This makes independent transition highly risky without a circular ecosystem.

1.3 Translation to the Strategic Framework

The extensive quantitative and qualitative data underscores that a conventional, linear business approach is insufficient for the regional EV aftermarket. To translate these empirically validated operational requirements—specifically the demand for skilled technicians (Table 1) and the supply-side need for risk mitigation—into an actionable blueprint for local SMEs, this study employs the BMC integrated with CE principles, detailed in Section 5.2.

2. Business Model of EV Battery Service Business in the Upper-Northern Thailand Context

The proposed electric vehicle (EV) battery service business model for Upper-Northern Thailand is developed by integrating the BMC with CE principles. The empirical findings reveal a critical service gap driven by a shortage of specialized high-voltage technical expertise. Accordingly, the model is designed to enable local small and medium enterprises (SMEs) to transition into standardized EV service providers.

The empirical analysis directly informs the localized BMC. Based on the demand-side priority (Table 1) and supply-side constraints, human capital plays a more critical role than physical assets; therefore, *certified high-voltage technicians* are identified as the most

important key resource, consistent with the RBV. In addition, to address environmental liabilities, the model incorporates CE principles into key activities and revenue streams by establishing a reverse logistics system in which end-of-life batteries are repaired at the module level or repurposed for second-life energy storage applications.

To address high capital and training requirements, the model emphasizes strategic Key Partnerships with government agencies and academic institutions to support training and reduce investment burdens. The detailed components of the multi-stakeholder framework are presented in Figure 2.

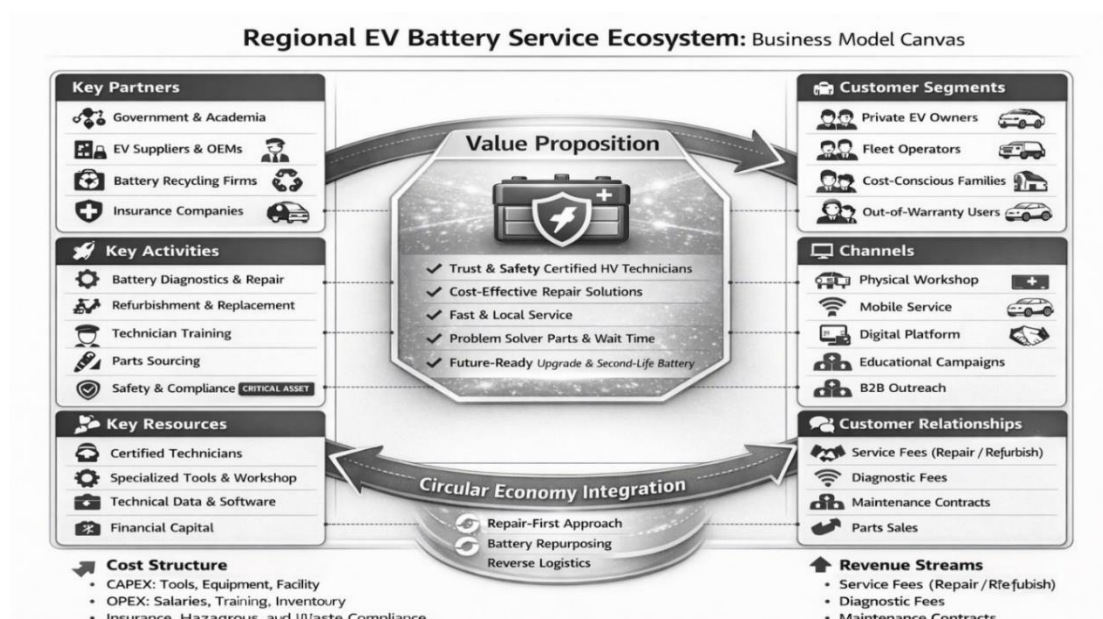


Figure 2: Business Model Canvas for the Regional EV Battery Service Ecosystem.

Figure 2 presents a localized BMC designed to support a sustainable EV battery service ecosystem. At its core, the Value Proposition addresses regional EV users' empirically proven “service anxiety” across five key dimensions: (1) trust through certified high-voltage technicians, (2) cost-effectiveness via repair and refurbishment alternatives to full replacement, (3) convenience through faster, localized service delivery, (4) problem-solving for long wait times and parts shortages, and (5) future readiness via battery upgrades and second-life applications. This reflects a strategic shift from product-centric to service-centric value creation.

On the infrastructure side, the model highlights three elements. First, key partners including government agencies, academic institutions, EV suppliers, recycling firms, and insurers are critical for addressing resource constraints in training, certification, and regulatory compliance. Second, key activities focus on high-voltage battery diagnostics, repair, refurbishment, technician training, and adherence to safety standards. Third, key resources emphasize the strategic importance of certified human capital, supported by specialized equipment and investment. Consistent with the Resource-Based View (RBV), skilled technicians remain the most critical, non-substitutable resource.

On the market interface side, customer segments include regional EV users, fleet operators, and out-of-warranty vehicle owners seeking affordable alternatives to manufacturer service centers. Channels utilize physical workshops, mobile service units, digital platforms, educational campaigns, and direct B2B engagement. Customer relationships are built upon long-term trust, transparent communication, professional service delivery, and value-added maintenance programs, reinforcing retention and loyalty.

The financial structure is divided into cost and revenue components. The cost structure reflects high initial capital expenditures (CAPEX) for specialized equipment and facility upgrades, alongside ongoing operational expenditures (OPEX) such as technician salaries, training, and hazardous waste compliance. Conversely, revenue streams are diversified, encompassing service and diagnostic fees, maintenance contracts, parts sales, and revenue generated from end-of-life batteries through recycling or second-life applications.

Importantly, the entire model is underpinned by a Circular Economy Integration layer. This layer operationalizes a “repair-first” strategy and establishes reverse logistics. By transforming environmental liabilities into economic opportunities, the circular approach enhances both sustainability and long-term financial viability for regional SMEs.

3. Verification of the Developed EV Battery Service Model

To verify the appropriateness and feasibility of the developed EV battery service model, a comprehensive expert evaluation was conducted. The quantitative results confirmed a high level of content validity, all model components achieved IOC values ranging from 0.80 to 1.00, exceeding the acceptable threshold, indicating strong structural alignment with the research objectives. Furthermore, the quantitative assessment of model feasibility yielded an overall mean score of 4.48 (S.D. = 0.53), denoting a very high

level of overall appropriateness. Notably, the criteria evaluating context relevance and sustainability achieved the highest mean scores (4.60 and 4.50, respectively). The evaluation also confirmed the logical linkage from the CIPP needs assessment to the BMC structural design ($\bar{X} = 4.55$). These metrics systematically confirm that the framework aligns tightly with both the regional EV ecosystem's demands and Thailand's broader environmental policies (Table 2).

Table 2: Expert Evaluation of the Appropriateness and Feasibility of the Developed EV Battery Service Model

Evaluation Criteria	Mean ($\bar{x}$)	S.D.	Level	Interpretation
1. Context relevance – Fit with regional EV service ecosystem and policy direction	4.60	0.55	Very High	Strong alignment with EV 3.5 policy and regional demand
2. Operational feasibility – Availability of resources and capacity for implementation	4.40	0.49	High	Feasible if technician training and financial support continue
3. Sustainability – Ability to maintain long-term operations and environmental compliance	4.50	0.52	Very High	Supports circular economy and local workforce development
4. Scalability – Potential to expand to other provinces or business models	4.35	0.58	High	Model adaptable to Chiang Rai, Lampang, Lamphun
5. Policy and stakeholder alignment – Consistency with government and industry objectives	4.50	0.51	Very High	Well aligned with MHESI, DIPROM, and private-sector interests
6. Integrated structure (CIPP → BMC → Systemic) – Logical and comprehensive linkage	4.55	0.50	Very High	Model clear links need assessment to outcome evaluation
Overall Appropriateness (Average)	4.48	0.53	Very High	The model is appropriate, feasible, and sustainable

In-depth qualitative interviews with the expert panel further supported the quantitative findings, confirming the practical relevance and strategic value of the proposed framework. Experts highlighted the model's alignment with Thailand's EV 3.5 policy. They emphasized that its localized "Repair-First" approach can effectively decentralize EV services from major urban centers to regional areas. In terms of operational

feasibility, the panel identified human capital development as the most critical factor. Furthermore, the integration of CE principles was strongly supported as a necessary approach for managing environmental risks and complying with future regulatory requirements. Overall, the expert evaluation confirms that the proposed model is both practical and sustainable.

Discussion and Conclusion

The development of the localized EV battery service business model for Upper-Northern Thailand yields several critical insights. By synthesizing the empirical data with established theoretical frameworks, this study explains not only how local SMEs can transition into the EV aftermarket, but why specific strategic configurations are essential for their survival.

1. Theoretical Alignment and Critical Perspectives: The Synergy of RBV and Stakeholder theory

The findings support the application of the Resource-Based View (RBV) in explaining SME adaptation within the EV service sector. As the industry transitions to high-voltage systems, competitive advantage shifts from physical assets to specialized human capital. However, a critical analysis of the regional context reveals a significant boundary condition to traditional RBV: local SMEs cannot simply "acquire" this resource from the market because the educational infrastructure for EV technology remains nascent.

As evidenced by the quantitative findings (Table 1), where certified high-voltage technicians scored the highest consumer priority ($\bar{X} = 4.85$), the BMC structurally positions human capital as the central Key Resource. Because SMEs cannot overcome this extreme resource scarcity independently, RBV alone is insufficient. This highlights the absolute necessity of Stakeholder theory. Public-Private Partnerships (PPPs) are not merely beneficial; they are structurally mandatory to subsidize training and facilitate knowledge transfer. Together, RBV and Stakeholder theory provide a more comprehensive explanation of SME capability development, leading to the integrated "Business Model Canvas for the Regional EV Battery Service Ecosystem" (Figure 2).

2. Bridging the Literature Gap: Differentiating Service Anxiety from Range Anxiety

This study contributes significantly to the literature by shifting the analytical focus from urban EV infrastructure toward decentralized regional service ecosystems. Existing

studies primarily emphasize "range anxiety"—a spatial infrastructure problem solved by expanding charging networks in metropolitan areas. In contrast, this study clearly differentiates and defines "service anxiety" as a post-adoption psychological barrier rooted in the technical opacity, safety risks, and high replacement costs of EV components after warranty expiration.

The findings confirm that sustaining EV adoption in regional areas depends less on charging infrastructure expansion and more on localized after-sales capability. By directly addressing service anxiety, this study addresses a key gap, demonstrating that regional EV ecosystems require fundamentally different business models focused on technical trust and maintenance affordability rather than energy distribution.

3. The Imperative of the Circular Economy (CE) in SME Viability

A pivotal finding is the non-negotiable role of CE principles. Applying a traditional linear approach to EV batteries introduces immense regulatory and environmental liabilities for provincial SMEs, as end-of-life batteries are hazardous waste. Driven by the quantitative finding that consumers prioritize Total Cost of Ownership and affordable repairs ($\bar{X} = 4.65$), the model embeds CE principles directly into the "Value Propositions" and "Revenue Streams."

The framework dictates a reverse logistics approach: garages perform module-level balancing rather than full-pack replacements, and degraded batteries are repurposed for second-life energy storage. This circular approach serves a dual purpose: it mitigates legal/environmental risks and creates a potentially sustainable, diversified revenue stream, ensuring long-term financial feasibility.

4. Theoretical Contributions

This research advances the existing literature in three distinct ways: First, it extends RBV by demonstrating that in emerging technological shifts within developing regions, non-substitutable human capital must be co-created with state actors rather than simply acquired. Second, it operationalizes Stakeholder theory within the EV aftermarket, proving that SME survival depends on ecosystem-level collaboration. Third, it successfully integrates CE principles into the conventional BMC framework, providing a novel blueprint for transforming hazardous waste liabilities into sustainable revenue streams for SME.

5. Limitations and Boundary Conditions of the Proposed Model

While the proposed model is comprehensive, several limitations must be acknowledged. First, the model assumes a baseline of financial readiness among SMEs to invest in facility upgrades and safety gear; highly undercapitalized garages may still find the transition inaccessible. Second, the framework operates within a transitional regulatory environment; future implementations are highly vulnerable to shifts in national hazardous waste laws and safety standards. Finally, the empirical data was heavily drawn from Chiang Mai, which has a relatively high EV density. The scalability and profitability of this model in other provinces with significantly smaller EV fleets (e.g., Lamphun or Phayao) may require further contextual adaptation, as lower service volumes could extend the return on investment (ROI) period.

6. Conclusion

The transition toward electric mobility presents profound challenges for regional automotive SMEs. This study developed and empirically validated a localized EV battery service business model tailored to the socio-economic context of Upper-Northern Thailand. By integrating the BMC with RBV, Stakeholder theory, and CE principles, the framework offers a structured approach that supports technical feasibility and environmental compliance. The findings highlight that a decentralized, repair-focused ecosystem anchored by certified human capital and PPPs can effectively mitigate consumer service anxiety and ensure the inclusive, sustainable growth of the EV sector beyond major urban areas.

Recommendation

1. Practical Implications for SMEs

For independent garage operators, this research provides a de-risked strategic blueprint. Transitioning to EV service is fraught with financial and safety risks. By utilizing the tailored BMC, SMEs can decisively shift their focus away from competing with authorized dealerships on heavy infrastructure, guiding them instead to invest in high-voltage human capital and localized module-level repairs to capture the out-of-warranty market.

2. Policy and Institutional Implications

For policymakers (e.g., MHESI, BOI, and the Department of Skill Development), this study highlights a critical misalignment in current EV promotion strategies. While policies like EV 3.5 heavily incentivize vehicle purchasing, sustaining adoption requires robust after-sales infrastructure. Public resources must be strategically redirected toward subsidizing high-voltage technical certifications, establishing provincial training centers, and creating regulatory sandboxes for local battery recycling networks. Formulating explicit safety standards for independent garages handling high-voltage systems is recommended.

3. Recommendations for Future Research

3.1 Longitudinal Financial Feasibility (Action Research): Future research should pilot this BMC within actual SME garages. A longitudinal analysis over 12-24 months would provide empirical data on actual CAPEX, OPEX, and profit margins from second-life battery streams.

3.2 National Regulatory Integration: As end-of-life battery volumes scale, future studies must examine the macro-level regulatory frameworks required to safely integrate independent provincial garages into the official national battery recycling supply chain, focusing on safety compliance and waste-tracking logistics.

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