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Carbon Border Barriers and ASEAN Market Adaptation: How Chinese Solar & Storage Firms Redefine Localization Strategies

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Abstract

In response to tightening environmental regulations and carbon border mechanisms such as the EU's CBAM and the U.S. IRA, Chinese solar and energy storage enterprises are accelerating supply chain relocation and production deployment in ASEAN markets. However, this shift intensifies environmental scrutiny and exposes them to fragmented sustainability standards across host countries. This study examines how carbon border barriers reshape localization strategies through an environmental adaptation lens. Using BYD and Trina Solar as core cases, and drawing on policy documents, corporate sustainability reports, and industry narratives, the research applies grounded theory to identify four adaptation pathways: carbon circumvention strategies that mitigate compliance costs through localized production; green-technology localization tailored to host country climate and energy conditions; eco-certification integration to align with both international and domestic standards; and cultural ecologization to strengthen long-term social recognition. Findings reveal that successful localization now hinges on building "ecological legitimacy" across institutional, technological, certification, and cultural dimensions. The study suggests that under regional frameworks such as RCEP, ASEAN-Japan-China cooperation in green technology standard harmonization and ecological responsibility governance can enhance the resilience of regional value chains and provide policy insights for Chinese clean energy firms expanding abroad.

Keywords

Carbon Barriers, Environmental Adaptation, ASEAN, Ecological Legitimacy

1. Introduction

Under the dual pressures of the global climate crisis and the transition toward a

green economy, carbon border barriers, represented by the European Union's Carbon Border Adjustment Mechanism (CBAM) and related green industrial policies such as the United States' Inflation Reduction Act (IRA), are reshaping global trade patterns and supply chain configurations (Böhringer et al., 2022; Fontagné & Schubert, 2023). While the CBAM imposes carbon-related requirements on imports of specified carbon-intensive products (Mörsdorf, 2022; Zhong & Pei, 2024), the IRA influences corporate investment and supply chain decisions through tax credits and subsidies. These policy measures are placing growing pressure on the clean energy industry through upstream material sourcing, supply chain carbon management, and green trade requirements (Cosbey et al., 2019). For China, which is at a critical stage of achieving its "dual carbon" goals, the photovoltaic (PV) and energy storage industries are vital to both emission reduction and energy structure optimization, as well as global low-carbon development and regional green cooperation.

Among overseas markets, the Association of Southeast Asian Nations (ASEAN) has emerged as a strategic hub for Chinese clean energy firms, owing to its abundant renewable energy resources, advantageous geographic location, and substantial market potential (Ratan, 2026). However, significant differences exist among ASEAN member states in terms of environmental regulations, climate conditions, energy structures, and socio-cultural contexts. These differences impose multi-dimensional demands on the environmental adaptability of enterprises. Firms must not only comply with host country environmental policies and low-carbon standards but also achieve deep localization in technological processes, supply chain configurations, and socio-cultural engagement in order to secure long-term environmental legitimacy and green competitive advantages (Chen, 2024; Wang et al., 2024).

Against this backdrop, this study focuses on the environmental adaptation mechanisms of Chinese PV and energy storage enterprises in the ASEAN market under carbon border measures. It seeks to address the core question: How can enterprises, through multi-dimensional localization strategies, build environmental legitimacy within diverse institutional and climatic contexts, thereby supporting regional green transformation? Using BYD and Trina Solar as representative case studies, and integrating grounded theory with multi-case analysis, the research identifies four adaptive pathways—Avoidance Strategy, Green Technology Localization, Ecological Certification Integration, and Cultural Ecologization—and examines their implications for ASEAN' s sustainable development and for China-Japan-Thailand-ASEAN environmental cooperation.

2. Theoretical Foundations

This study draws on Institutional Theory and Legitimacy Theory to examine the internationalization strategies of clean energy firms under carbon border measures. Institutional theory emphasizes the shaping role of external institutional environments on corporate strategy (DiMaggio & Powell, 1983). Within this framework, environmental legitimacy—a key dimension of legitimacy—requires that a company' s environmental performance aligns with societal norms, legal regulations,

and public expectations (Suchman, 1995). Achieving such legitimacy enables firms to gain trust and remain competitive under conditions of low-carbon transition and green regulation (Bansal & Clelland, 2004).

As global climate governance intensifies, multinational enterprises are increasingly required to adjust their strategies in response to evolving environmental regulations and societal expectations across host-country contexts, alongside market and efficiency considerations (Kolk & Pinkse, 2008). This requires firms to become more deeply embedded in host countries' green standards and socio-cultural environments. However, existing research provides limited systematic comparison of ASEAN as a specific region, and there is a particular gap in examining how upstream and downstream enterprises in the clean energy value chain adapt to both institutional and environmental pressures to secure environmental legitimacy through multiple pathways.

In response, this study focuses on the localization practices of Chinese PV and energy storage enterprises in ASEAN. By combining embedded multi-case analysis with grounded theory, it develops a theoretical framework encompassing four adaptive pathways: Avoidance Strategy, Green Technology Localization, Ecological Certification Integration, and Cultural Ecologization. In this framework, carbon border measures are treated as external institutional shocks (Zhen & Wang, 2022), while the localization process is understood as a multi-path adaptation mechanism aimed at jointly achieving environmental legitimacy (Lin & Liu, 2025).

3. Research Design and Methodology

3.1. Research Method

The research design is shown in **Figure 1**.

This study adopts a combined research design, integrating grounded theory with embedded multi-case analysis (Li et al., 2020; Zhu et al., 2024), using BYD and Trina Solar as representative cases. This approach is chosen because the interaction between carbon border measures and environmental governance systems is complex and dynamic (Li et al., 2025). Grounded theory allows for inductive analysis to distill explanatory adaptation pathways, while embedded multi-case analysis facilitates cross-case comparison across different enterprises and market contexts, enhancing the applicability and robustness of the findings.

3.2. Case Selection

BYD and Trina Solar were selected as representative cases of Chinese solar and storage-related enterprises operating in different segments of the broader clean energy industry.

BYD, a global leader in electric vehicles (EVs), has established an integrated vehicle and battery manufacturing base in Thailand, attracting numerous upstream and downstream suppliers and exemplifying a vertically integrated internationalization model. Trina Solar, one of the world's leading PV module manufacturers, has established production capacity in Vietnam, Thailand, and other

ASEAN countries. Its practices in green certification and carbon management reflect a modular and network-based operational model.

Although the two companies operate in different segments of the clean energy value chain, their localization practices provide a basis for examining both commonalities and differences in how Chinese solar and storage-related enterprises respond to environmental policies, technical standards, and local cultural contexts.

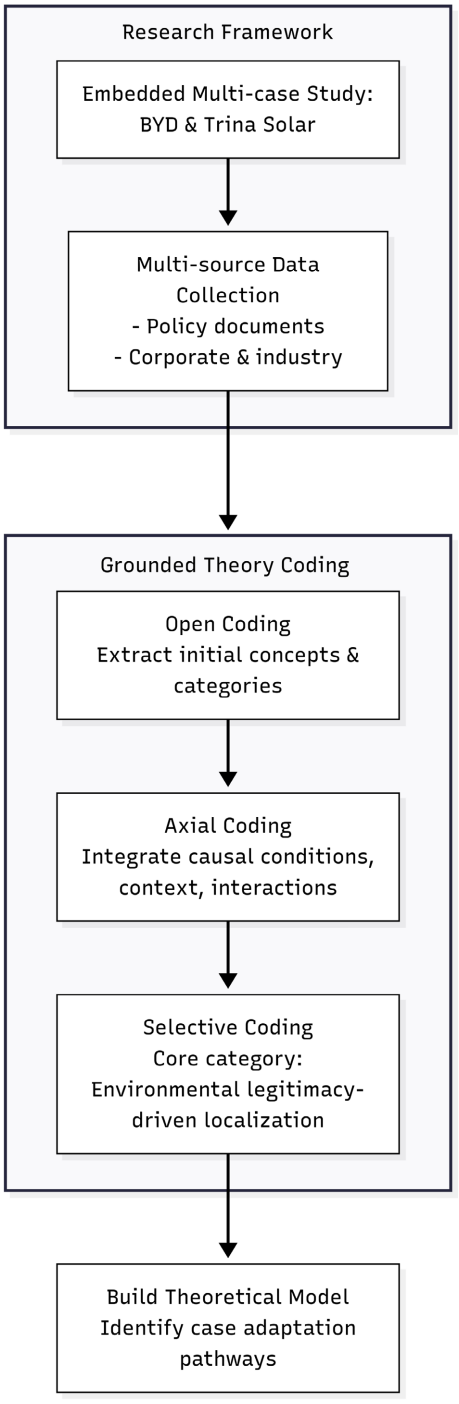


Figure 1. Research design process.

3.3. Data Collection

To strengthen the validity and reliability of the study, a multi-source data system was established, and triangulation was employed to cross-validate key events and findings. Corporate sustainability reporting was treated as a strategic practice rather than a neutral technical record (Ogrean & Herciu, 2022).

In addition to extensive secondary data, this study draws on field visits, informal discussions, and interviews conducted during the author's academic exchange at Chiang Mai University in Thailand. These first-hand experiences provide supplementary contextual insights into ASEAN's economic structure, the clean energy industry, and the localization activities of Chinese enterprises such as BYD and Trina Solar.

Data sources are presented in Table 1.

Table 1. Data sources.

Data Type	Content
Policy Documents	CBAM, IRA, Section 201 trade measures, ASEAN and member state green investment regulations, Thailand's BOI EV3.0/EV3.5 policies, Vietnam and Indonesia carbon investment regulations and industry standards
Corporate & Industry Reports	Annual and ESG reports from BYD and Trina Solar, market analyses by IEA, BNEF, industry associations, and third-party consultancy reports
Interviews & Observations	Informal interviews and secondary materials concerning local distributors, supply chain firms, universities, and community representatives in Thailand, Vietnam, and Indonesia; field notes from exhibitions and research institutions, including visits to the Chiang Mai Branch of the Bank of Thailand and Bank of China in Chiang Mai, as well as informal discussions with a Chiang Mai University faculty member researching China-Thailand cooperation in the EV industry.

3.4. Data Analysis

Following the three-stage coding process of grounded theory (Glaser & Strauss, 1967), qualitative data were systematically analyzed.

3.4.1. Open Coding

Raw data were reviewed line-by-line. Through identifying relevant statements, conceptualization, and constant comparison, 135 initial concepts and 10 initial categories were generated. For ease of comparison, results are presented in a parallel case coding table.

Selected coding examples are listed in Table 2:

Table 2. The example of open coding.

Case Enterprise	Original Data	Initial Concepts	Categories
BYD	BYD used Thailand's FTAs to build a dual-market system for ASEAN localization and EU exports (a1)	Regional agreement utilization (aa1) Dual-market creation (aa2) Trade barrier avoidance (aa3) Export strategy (aa4)	Trade agreement use & market layout (A1)
	Through its Thailand factory, BYD sought to circumvent anti-dumping and countervailing duty (AD/CVD) investigations targeting Chinese products and mitigate certain carbon-related trade barriers (a2)	Carbon barrier avoidance (aa5) Trade strategy adjustment (aa6)	Carbon barrier avoidance (A2)
	BYD's existing battery technology has already far exceeded the requirements of Thailand's new standards (a3)	Technological leadership (aa7) Advanced technology reserves (aa8) Core competitiveness (aa9)	Technology and product adaptation (A3)
	First-generation blade batteries performed excellently in local tropical field tests (a4)	Battery performance advantage (aa10) Localized testing (aa11) Technical validation (aa12) Product iteration (aa13)	
	Launched right-hand-drive models adapted for the Thai market (a5)	Product adaptation design (aa14) Local market demand (aa15) User experience optimization (aa16)	
	Equipped vehicles with localized Thai-language UI (a6)	Software localization (aa17) Language adaptation (aa18) User interface design (aa19)	
	……	……	……
Trina Solar	Established plants in Southeast Asia to avoid EU/US carbon barriers and maintain market share (b1)	Regional agreement utilization (aa1), Dual-market creation (aa2), Trade barrier avoidance (aa3), Export strategy (aa4)	Trade policy use & market layout (B1)
	Withdrew from the China-EU minimum price agreement at the end of 2015, switching to export from overseas manufacturing bases exempt from tariffs (b2)	Avoidance of trade protection measures (bb1) Production layout adjustment (bb2) Market share maintenance (bb3)	

Continued

When the U.S. imposed additional tariffs on four Southeast Asian countries in 2025, accelerated transfer of Vietnam production capacity to Indonesia and the UAE (b3)	Regional capacity transfer (bb7) Third-country transit exports (bb8) Trade barrier response (bb9)	
Products from Rayong Industrial Estate, can be shipped via Lam Chabang port to the ASEAN Free Trade Area; the Kunming-Bangkok Railway will further improve Sino-Thai logistics channels (b4)	Regional logistics network development (bb10) Transportation cost reduction (bb11) Expanded market reach (bb12)	
Used Thailand's "eight-year tax holiday plus five-year 50% reduction" policy to cut manufacturing costs (b5)	Tax policy utilization (bb13) Cost control (bb14) Investment location choice (bb15)	
……	……	……

3.4.2. Axial Coding

On the basis of open coding, this study systematizes initial concepts into multi-dimensional core categories by integrating the causal, conditional, interactive and outcome relationships among categories, and develops the following axial coding, which lays a foundation for theoretical model construction, as shown in Table 3.

Table 3. Axial coding and core category definitions.

Core Category	Definition	Corresponding Initial Categories
Avoidance Strategy	Leverage locational advantages to optimize production and export arrangements, thereby reducing or avoiding the costs and constraints imposed by carbon border barriers and safeguarding market access.	Trade policy utilization and market layout; Carbon barrier avoidance
Green Technology Localization Strategy	Adapt technology, products, processes, and talent to local standards, market needs, and climate.	Technology and product adaptation; R&D and production localization; Policy and standards alignment; Talent cultivation and knowledge transfer
Ecological Certification Integration Strategy	Align with local and international green standards through carbon management and circular economy practices to strengthen compliance and legitimacy.	Carbon management and compliance; Circular economy practices
Cultural Ecologization Strategy	Build trust and recognition by engaging with communities, integrating cultures, and promoting co-existence.	Community relations and trust-building; Cultural integration and brand development

3.4.3. Selective Coding

Building on open coding and axial coding, selective coding integrates all categories and their causal linkages into the core category: the ecological legitimacy-driven localization adaptation mechanism (Du et al., 2025). The corresponding theoretical model is shown in **Figure 2**. This mechanism consists of four mutually reinforcing pathways—Avoidance Strategy, Green Technology Localization, Ecological Certification Integration, and Cultural Ecologization—which can be implemented sequentially or in parallel. Together, they reduce market entry risks and compliance costs, strengthen technological and social foundations, and create sustainable competitive advantages while advancing regional low-carbon cooperation.

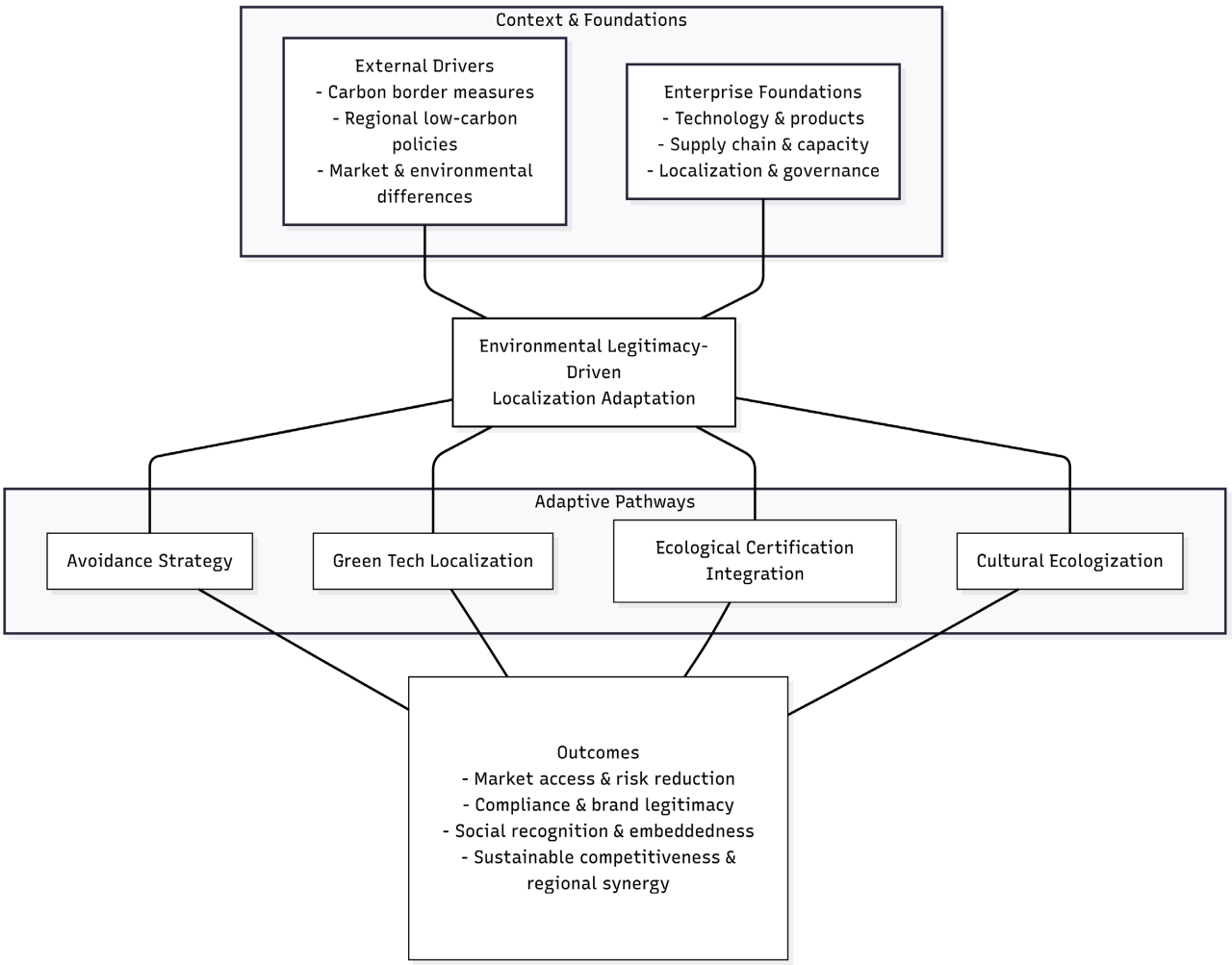


Figure 2. Theoretical model of environmental legitimacy-driven localization adaptation.

4. Case Analysis

4.1. BYD' s Localization Practices in Thailand

Under the pressures of carbon border measures such as the EU's CBAM and the U.S. IRA, BYD has accelerated its overseas expansion since 2022, positioning

Thailand as a pivotal hub in its localization strategy. Thailand, as the core manufacturing center for automobiles in ASEAN, has set a "30/30 Vision" for carbon neutrality and offers a favorable policy environment through measures such as the EV3.0/EV3.5 schemes, which provide tax exemptions, tariff waivers, and purchase subsidies. Leveraging this policy framework and market environment, BYD established a fully automated vehicle plant in Rayong Province. Leveraging Thailand's trade arrangements and the relevant trade regulations governing exports to the EU and the U.S., the company created a "local production-origin shift-European export" model that significantly reduces the risks associated with carbon tariffs and trade barriers.

Faced with higher local content requirements and technology transfer expectations, BYD collaborated with local partners such as Rêver Automotive and AAPICO Hitech to build sales and service networks, launched right-hand-drive models tailored to Thai regulations and driving habits, and established a tropical battery testing laboratory to ensure product reliability in high-temperature, high-humidity conditions. The company also aligned with Thailand' s green standards and circular economy framework through initiatives such as the "RêverLution" carbon credit program, battery recycling and second-life applications, and distributed solar-plus-storage projects.

At the societal and cultural level, BYD actively addressed community concerns regarding water use and environmental impact, participated in local festivals and public events, and partnered with universities to develop vocational training bases for EVs and bilingual education platforms (Wang et al., 2017). These measures not only facilitated technical cooperation and talent development but also enhanced local engagement. Overall, BYD' s localization in Thailand demonstrates the integrated application of avoidance strategies, green technology localization, ecological certification integration, and cultural ecologization, jointly building environmental legitimacy, strengthening sustainable competitiveness, and contributing to regional low-carbon cooperation.

4.2. Trina Solar' s Deployment in Southeast Asia

Trina Solar is one of the leading players in the global PV industry, with the European market historically accounting for around 20% of its revenue. In response to tightening EU carbon regulations and the combined pressures of EU-U.S. trade remedies, the company began proactively establishing operations in Vietnam, Thailand, and Malaysia as early as 2013, later adding a regional headquarters in Singapore and expanding into Indonesia and the Middle East (Li, 2023). This strategy disperses operational risks and avoids carbon pricing tied to origin. Benefiting from ASEAN' s favorable trade agreements, low land costs, and tax incentives, Trina Solar' s Rayong plant in Thailand has developed an efficient logistics network serving the Southern Hemisphere, the Middle East, and Europe, effectively reducing both carbon tariffs and transportation costs.

In adapting to local conditions, Trina Solar has modified technologies for the

region' s high-temperature, high-humidity climate, transferred advanced TOPCon technology to Indonesia via OEM partnerships, and introduced high-automation supply chains in Thailand to localize R&D and production while maintaining flexible capacity and low institutional thresholds (Li, 2024a). In the area of green standards, the company implements full carbon footprint management in its Southeast Asian plants, aligns with international certifications such as those from TÜV, and promotes zero-carbon factory practices (Ding, 2023). Measures include energy-efficient equipment, green packaging recycling, and rooftop solar systems, achieving an 80% packaging recovery rate. Through its "SOLAR Sustainable Development Framework," Trina Solar reinforces the alignment between global and local environmental standards (Li, 2023; Li, 2024b).

On the social and cultural front, Trina Solar has opened its facilities for community visits, addressed environmental concerns transparently, sponsored school-based green projects, and supported clean energy education. It also fosters employee belonging and cross-cultural identity through global digital cultural programs. This approach demonstrates that the company' s Southeast Asian strategy is not merely capacity relocation but a systematic deployment that integrates policy, climate, certification systems, and social structures. By combining avoidance strategies, green technology localization, ecological certification integration, and cultural ecologization, Trina Solar has built a regionally embedded manufacturing network with environmental legitimacy and sustainable competitiveness.

4.3. Cross-Case Comparison and Insights

Table 4. Cross-case comparative analysis.

Pathway	BYD	Trina Solar	Commonalities
Avoidance	Used Thailand-EU/U.S. FTAs to build local production-export route avoiding carbon tariffs.	Multi-country capacity (VN, TH, ID) to spread risk.	ASEAN FTAs & multi-location capacity lower compliance costs.
Green Tech Localization	Tropical battery lab, right-hand-drive models, Thai UI.	TOPCon tech transfer to Indonesia, climate-optimized modules.	Products/tech adapted to local standards & climate.
Ecological Certification	Carbon credit plan, battery recycling & reuse.	Full carbon footprint mgmt, intl certification, zero-carbon plants.	Embedded in regional & global green standards.
Cultural Ecologization	Community events, environmental programs, university partnerships.	Open days, green education sponsorship.	Social engagement boosts public recognition.
Overall Model	Vertical integration, full-chain localization.	Modular, multi-site production.	Four pathways combined, centered on environmental legitimacy.

Both BYD and Trina Solar face the dual pressures of CBAM and the IRA, confronting institutional constraints and environmental market entry requirements

in their overseas expansion. Despite operating in different segments of the PV-energy storage value chain, both enterprises have adopted deep localization strategies in Southeast Asia to address green trade barriers and global environmental governance demands (Ratan, 2026). Their practices reveal four critical adaptation pathways. Avoidance strategies restructure origin and leverage institutional advantages to reduce carbon tariffs and compliance costs, alleviating cross-border carbon pressure. Green technology localization enhances operational efficiency and climate adaptability through technical alignment, product optimization, and supply chain cooperation. Ecological certification integration embeds firms into regional green governance systems via certification, carbon footprint management, and circular economy practices. Cultural ecologization fosters public recognition and sustainable embeddedness through community engagement, environmental education, and cultural participation. Although the specific forms and priorities of these pathways vary between the two companies, they collectively point toward reconstructing environmental legitimacy within the frameworks of global carbon governance and environmental sustainability, offering practical and theoretical guidance for shaping China' s green overseas expansion strategies (**Table 4**).

5. Conclusion and Policy Recommendations

5.1. Research Conclusions

Against the backdrop of global carbon neutrality goals and the escalation of green trade barriers, mechanisms such as the EU' s CBAM and the U.S. IRA are profoundly reshaping global supply chain configurations in the clean energy sector. These developments are prompting Chinese photovoltaic (PV) and energy storage enterprises to restructure their localization strategies in overseas markets, particularly within the ASEAN region.

Using BYD and Trina Solar as representative cases and applying grounded theory, this study distilled four adaptive pathways: the avoidance strategy, green technology localization, ecological certification integration, and cultural ecologization. The findings reveal that these pathways do not operate in isolation; rather, they are often applied in combination and evolve dynamically over time. The avoidance strategy enables firms to gain institutional leeway, reducing cross-border carbon costs and compliance risks. Green technology localization improves the adaptability of technology and products to local environmental conditions and policy requirements. Ecological certification integration enhances compliance and brand legitimacy by embedding enterprises within regional green governance systems. Cultural ecologization fosters long-term public recognition and environmental legitimacy through social embeddedness and public participation.

This multi-pathway collaborative model provides valuable reference for enterprises from China, Japan, and Thailand in advancing regional energy transition and achieving environmental sustainability. Within the RCEP framework and amid the broader trend toward low-carbon transformation, such cross-market en-

vironmental adaptation experiences can help reduce trade frictions, promote mutual recognition of technologies and standards, and offer replicable paradigms for regional low-carbon cooperation and sustainable development.

5.2. Policy Recommendations

Building on the research conclusions, China, Japan, and Thailand hold significant complementarities in the clean energy sector: China excels in large-scale manufacturing and cost control; Japan leads in high-end materials and green standard-setting; Thailand benefits from its role as a logistics hub with strong regional market reach. These advantages should be transformed into actionable cooperation mechanisms.

First, establish a cross-border carbon risk early-warning and response platform. Leveraging RCEP and other regional cooperation mechanisms, develop a risk database and information-sharing system covering carbon tariffs and rules of origin. Use big data to forecast policy changes and deliver timely response strategies to enterprises, ensuring the stability of low-carbon supply chains across production, distribution, and recycling stages.

Second, promote joint cross-border green technology pilots and localized applications. Integrate China' s manufacturing capacity, Japan' s standards, and Thailand' s market advantages to set up joint green technology demonstration plants and localized R&D centers in key ASEAN markets. This would create a closed loop of technology adaptation, product testing, and local talent development.

Third, advance mutual recognition of regional green standards and certifications. Drawing on corporate ecological certification experience, promote the creation of unified or mutually recognized systems for green products and carbon footprint verification. This would lower the cost of duplicate certifications and facilitate cross-border data sharing, improving market access efficiency.

Fourth, strengthen social and cultural dimensions of green cooperation. Use multilateral exchange platforms to jointly conduct environmental education, skills training, and green community development. Cultivate a "China-Japan-Thailand-ASEAN" green cooperation brand to enhance public trust and engagement in clean energy collaboration.

Through institutional coordination, technological collaboration, standard alignment, and cultural co-construction, China, Japan, Thailand, and regional partners can form competitive synergies within the clean energy value chain, offering replicable models for Asia-Pacific green transition and contributing to global environmental governance.

Author Contributions

Jinglin Ouyang conceived and designed the study, collected and analyzed the data, and drafted the manuscript. Qianqing Wei supervised the research, provided critical comments, and revised the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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