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Strengthening the Circular Battery Ecosystem through Sweden-China Collaboration: A Case of Heavy-Duty Vehicle Manufacturer and Universities

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Executive Summary

Enabling battery circularity requires multi-stakeholder collaboration, a deep contextual understanding of market-specific needs, and alignment across technological, business, and policy domains. However, the battery ecosystem is still in its early stages of development. For companies such as heavy-duty vehicle manufacturers with a global presence and headquarters in Sweden, it is crucial to understand how different aspects are progressing in key markets like China—one of the most significant electrification and battery ecosystems. The purpose of this paper is to share our experiences from a project aimed at strengthening collaboration between a Swedish heavy-duty vehicle manufacturer, its facilities in China, a Swedish university, and a Chinese university. The paper discusses the motivations behind this collaboration, the initiatives undertaken so far, the thematic areas identified for future work, and the lessons learned throughout the process. This study contributes to a broader understanding of internationalization and cross-border collaboration within the emerging battery ecosystem.

Keywords: Batteries, Recycle & Re-use, Education, skills and labour market, International networking, Supply and value chain.

1 Introduction

The global transition toward sustainable energy systems has significantly accelerated interest in battery technologies, which are increasingly seen as a cornerstone of clean transportation and energy storage solutions [1]. In this context, there is growing recognition of the need to shift from linear battery value chains toward circular battery ecosystems—systems in which batteries are designed, manufactured, used, repurposed, and eventually recycled, with the aim of minimizing environmental impact and maximizing material recovery [2].

In ecosystem literature, ecosystems are defined as "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" [3, p.40]. Circular ecosystems differ from conventional ecosystems in that their value proposition is rooted in circular economy (CE) principles, and their value delivery emphasizes long-term sustainability [4] [5]. These ecosystems are composed of autonomous but interdependent actors that collectively create and deliver a coherent circular value proposition [5, p.286]. Depending on the focal product or industry, circular ecosystems can take different

forms, each shaped by specific technological, regulatory, and market characteristics [6].

Within this broader context, battery circularity refers to a closed-loop system in which batteries that would otherwise become waste are instead retained within the value chain through reuse, repair, remanufacturing, repurposing, and eventually recycling [7]. However, achieving battery circularity is inherently complex [8]. It demands collaboration across a diverse network of stakeholders, including manufacturers, energy and utility companies, circular integrators, recycling firms, digital technology providers, third-party logistics and service providers, policymakers, research institutions, and emerging startups [9]. These stakeholders must collectively address a wide range of interdependent challenges—including technological limitations, economic viability, and shifting regulatory landscapes [8]. Importantly, these challenges vary across geographical regions, depending on differences in industrial capacity, policy development, market maturity, and cultural approaches to sustainability [10]. This variability makes cross-border collaboration and mutual learning critical for building effective and scalable circular battery ecosystems [2] [11] [12].

For global heavy-duty vehicle and machine manufacturers with a strong presence in Sweden, understanding the nuances of international battery ecosystems is increasingly critical—especially in key growth markets such as China and India. Among these, China stands out as a global leader in battery production, electric vehicle (EV) deployment, and infrastructure for second-life use and recycling [13]. In contrast, Sweden has positioned itself at the forefront of sustainability governance, with strong regulatory commitments to CE principles and public-private cooperation in green transition [14]. Together, Sweden and China represent two distinct but complementary poles in the evolving global battery ecosystem: one emphasizing sustainable regulation and innovation, and the other offering scale, speed, and manufacturing leadership.

Despite their complementary strengths, research on the intersection between the Swedish and Chinese battery ecosystems remains limited. Most studies to date have focused on either the European [7] [10] or Chinese [15] context in isolation. Very few have investigated cross-border collaboration, particularly in the context of heavy-duty vehicles—a segment with unique operational, technological, and lifecycle challenges. The lack of empirical studies that examine international partnerships across regions with differing maturity levels presents a clear research gap [16].

To address this gap, this paper presents insights from a collaborative project involving a Swedish heavy-duty vehicle manufacturer, its subsidiaries in China, and academic partners from both Sweden and China. This cross-border, multi-stakeholder initiative offers a rare opportunity to analyze the interaction of technology development, business model adaptation, and policy coordination across national and institutional boundaries. It provides a grounded case through which to understand how circular battery ecosystems can be built through international cooperation, and how differing national contexts can be leveraged as strengths rather than obstacles.

By sharing insights from this collaboration, the study contributes to the growing literature on the internationalization of CE practices [17] and offers practical lessons for industry actors and policymakers engaged in cross-border battery initiatives [2] [11] [12] [18]. It identifies thematic areas for future research and provides recommendations for strengthening the circular battery ecosystem [9] through coordinated, cross-sectoral, and cross-national collaboration. In particular, the case highlights how such partnerships can foster shared learning, mutual adaptation, and innovation in the heavy-duty vehicle sector.

2 Research method

This study is part of the Eco-Link project, which aims to strengthen collaboration between a Swedish heavy-duty vehicle manufacturer, its facilities in China, a Swedish university, and a Chinese university. The initiative focuses on joint research and development efforts within the broader context of the circular battery ecosystem. The case company is a globally recognized manufacturer in the heavy-duty vehicle and construction equipment industry. It is a world leader in articulated haulers and wheel loaders, and a prominent producer of excavation and compact construction equipment. Headquartered in Sweden, the company also operates a sister company in China, enabling direct collaboration between its European and Asian operations.

Data was collected through a combination of workshops and formal and informal meetings held over the course of the project. In total, five workshops were conducted:

- Two workshops involved five participants from the Swedish manufacturing team
- One workshop included three participants from the Chinese university
- Two joint workshops brought together seven participants representing the Swedish and Chinese manufacturers as well as the Swedish university.

The workshops facilitated continuous dialogue and mutual learning between researchers and practitioners. They were particularly valuable in activities that required diverse perspectives, expert insights, and informed judgment—an approach especially relevant for complex and interdisciplinary topics such as those explored in this study [19]. Joint workshops were structured around specific thematic areas and guided by a series of pre-formulated questions. Each session lasted approximately 120 minutes, allowing sufficient time for in-depth discussion, knowledge exchange, and iterative validation of emerging ideas.

Each workshop was guided by a pre-prepared set of open-ended questions. Participants first responded individually using the brainwriting method (i.e., writing ideas anonymously on post-it notes), which was followed by a group discussion to elaborate and cluster responses. This structure enabled both individual reflection and collective knowledge sharing. The data collected from the workshops were analyzed by the Swedish university research team using a thematic analysis approach [20]. This method facilitated the identification of recurring themes and priority areas for ongoing and future collaboration.

In addition to the workshops, the collaboration included monthly meetings over an 18-month period, involving representatives from all partners. These meetings served several purposes, including:

- Defining and refining topics for new master's thesis projects
- Monitoring progress on ongoing student research
- Addressing operational challenges and collaboration opportunities
- Sharing updates across teams and institutions.

The data collected from workshops and meetings were systematically analyzed using a manual thematic analysis approach [20]. Notes from each session were transcribed and organized in an Excel spreadsheet, where each input—whether from brainwriting or discussion—was reviewed individually. Researchers began by conducting an initial round of open coding, during which similar inputs were grouped by assigning specific color codes. Once all related data points were color-coded, entries with matching colors were clustered together to form preliminary thematic groups. These initial clusters were then reviewed and discussed within the Swedish academic research team. Through a collaborative and iterative process, the team refined and labeled the emerging themes, ensuring conceptual clarity and internal consistency. Thematic names were agreed upon through group consensus. To ensure reliability and validity, the preliminary thematic structure was then shared with representatives from the partner entities—including the company and university teams in both Sweden and China. Feedback from these stakeholders was used to validate the coding scheme and confirm the relevance and accuracy of the identified themes in the context of the ongoing collaboration. This participatory approach to data analysis supported not only research rigor but also enhanced the practical value and collaborative spirit of the Eco-Link initiative.

3 Results

Our analysis produced three key results related to collaboration within the circular battery ecosystem: 1) motivations and drivers for the collaboration, 2) thematic areas of collaboration, and 3) lessons learned from the Sweden-China collaboration. Below we will explain each of these results in detail:

3.1 Motivations and drivers for the collaboration

The collaboration originated from pre-existing personal and academic relationships between researchers at the Swedish university and representatives of the Swedish heavy-duty vehicle manufacturer. These connections laid the foundation for exploring joint research and development opportunities within the broader circular battery ecosystem. Several technological and systemic themes were initially identified as

promising entry points for collaboration. These included emerging technologies such as vehicle-to-grid systems, battery swapping, and business models and policy frameworks relevant to battery circularity.

The importance of this partnership and collaboration was emphasized by one of the Swedish company's managers, who remarked: "*Both academia and industry recognize the challenges facing the world and are determined to seize the opportunities to address them. Our strong relationship and mutual trust enable us to identify common problems and establish a symbiotic collaboration. By joining forces, we create platforms to study and address these issues together. At our company, we acknowledge that learning and finding solutions takes time. By adopting a co-production model, where we collaborate and grow insights together with external partners, we can accelerate the cultural transformation and adoption of the competencies needed for this technological shift. Through our collaborative efforts, we generate knowledge and results that benefit all parties involved - in academia, industry and society at large.*"

This quote reflects a clear recognition of the shared responsibility between academia and industry in tackling systemic challenges such as battery circularity and sustainable innovation. It reveals that the motivation for collaboration goes beyond immediate business or research gains—it is rooted in long-term, strategic alignment toward global sustainability goals. The emphasis on mutual trust and symbiotic collaboration highlights the value of partnerships built on openness, shared learning, and aligned objectives. The concept of co-production is particularly relevant in this context. It positions collaboration not as a transactional exchange of expertise, but as a joint value creation process, where both parties contribute knowledge, resources, and perspectives to develop scalable and practical solutions. For the company, this model supports internal cultural transformation, encouraging openness to external input, fostering innovation, and preparing the organization for the competence shift required by the energy transition. For academic partners, co-production ensures that research remains grounded in real-world challenges, while also expanding the educational relevance of student projects. This quote, therefore, illustrates how the collaboration is motivated by a shared vision for addressing global sustainability challenges and a recognition that such transformation requires deep, ongoing, and trust-based partnerships across institutional and national boundaries.

The Sweden–China collaboration in the circular battery ecosystem is propelled by a combination of strategic, academic, and organizational **drivers**. At its core, the partnership is driven by the mutual goal of identifying high-impact areas within the battery ecosystem where joint innovation can flourish. Comparative analysis of Swedish and Chinese perspectives provides a rich foundation for understanding both shared and context-specific challenges, enabling more tailored and transferable solutions. The collaboration also supports the dual objective of addressing real-world industrial problems while nurturing a talent pipeline equipped with cross-disciplinary and cross-cultural competence. The use of student thesis projects as agile, low-barrier entry points has proven particularly effective in piloting new ideas, while informal student networks help sustain engagement and foster deeper mutual understanding. Together, these drivers create a strong and resilient foundation for long-term, impactful collaboration between Sweden and China in advancing sustainable battery innovation. The primary drivers behind this cross-border collaboration are outlined as follows:

- Identifying target areas within the circular battery ecosystem that are suitable for Sweden–China collaboration.
- Comparing and analyzing cross-cultural perspectives, particularly focusing on both unique and shared challenges between Sweden and China.
- Gaining insights into real-world industry challenges while deepening academic understanding and building a future talent pipeline.
- Leveraging academic and industry networks in both countries to enrich knowledge sharing and generate long-term collaborative opportunities.
- Utilizing thesis projects as a low-threshold entry to explore emerging topics with short-term, low-resource commitments.
- Fostering informal student networks, which support mutual understanding and long-term engagement.
- Maintaining continuity and momentum through regular meetings and open communication channels on emerging issues.

As part of the ongoing collaboration between the Swedish heavy-duty vehicle manufacturer, its China-based operations, and academic partners, several bachelor's and master's thesis projects have been successfully completed. These projects span both technical and business-focused themes relevant to the circular battery ecosystem. Key areas of exploration include vehicle-to-grid (V2G) charging, with studies examining its application in specific operational contexts such as ports and mines, as well as the development of a simulation model for V2G integration. Another major focus has been battery swapping technology, with multiple theses investigating its feasibility, adoption challenges, and enabling conditions in industrial environments. On the technical side, students explored battery pack design for high energy density, supporting innovation in battery architecture. From an economic perspective, total cost of ownership (TCO) analyses was conducted for different construction scenarios, offering insights into the financial implications of various battery strategies. Collectively, these works reflect the collaboration's emphasis on practical, interdisciplinary research and its commitment to advancing sustainable and scalable battery solutions across diverse use cases.

3.2 Thematic areas of collaboration

Based on the workshop data, we identified six thematic areas for strengthening collaboration in the circular battery ecosystem between Sweden and China. These are: 1) Battery life cycle and circularity, 2) Design and optimization of battery systems, 3) Data utilization, analytics, and cybersecurity, 4) Battery simulations, 5) Regulatory compliance, and 6) Knowledge sharing for technological advancement. Detailed descriptions of these six thematic areas are provided below:

3.2.1 Battery life cycle and circularity

This theme focuses on comparing battery usage across first, second, and third life stages between Sweden and China. Understanding lifecycle performance across different regional contexts enables both countries to identify the best practices and optimize reuse and recycling strategies. Collaboration in this area also facilitates joint exploration of battery circularity for mixed cell chemistries, a key concern as product portfolios diversify. Investigating how real-world industrial usage impacts battery components helps align design and maintenance practices, while studies on energy usage and second-life performance can uncover synergies and gaps in circular strategies. These insights are essential for creating adaptable and sustainable battery systems that respond to the needs of both mature and rapidly developing markets.

3.2.2 Design and optimization of battery systems

Differences in product types and operating conditions between the two countries present opportunities for shared learning in battery modularity and portfolio design. Designing a battery portfolio that can accommodate a wide range of products—with differing requirements for power, energy density, spatial constraints, and performance—enables both partners to develop scalable, application-specific solutions. Comparative studies on design trade-offs—such as cooling versus chemistry or power versus material usage—enable engineers to better tailor solutions to specific industrial requirements. Moreover, exploring how to design for flexibility in rapidly changing technological and regulatory environments allows Sweden and China to stay agile while meeting evolving market demands.

3.2.3 Data utilization, analytics, and cybersecurity

Data generated from electric mobility (EMOB) vehicles and machines—particularly battery status and performance data—presents significant opportunities for cross-border innovation. One major area of collaboration between Sweden and China is determining how to effectively use this data, while navigating questions related to regulations, cybersecurity, and ownership. These concerns are especially relevant in contexts where national data policies differ or where cloud-based systems are employed. Partners also emphasized the potential to leverage battery data from EMOB vehicles and machines to improve both product design and real-world usage efficiency. Analyzing usage patterns and health indicators could inform more intelligent design choices, lifespan predictions, and tailored maintenance strategies.

Another key theme is the need to develop robust data analytics tools that can extract actionable insights while also addressing data privacy regulations (DPR) and organizational data protection policies. Ensuring compliance with different regional data standards is a prerequisite for collaborative analytics platforms. In addition, maintaining the cyber-physical security of EMOB vehicles and machines is a growing concern,

particularly given the increasing reliance on cloud-connected components. Partners noted the importance of strengthening cybersecurity architecture and ensuring secure communication and data storage across systems and regions.

Ownership of data emerged as a particularly sensitive issue. Clarifying who owns the data captured from machines and batteries—whether the user, OEM, or third party—is essential for enabling open, collaborative use of that data. Finally, the application of AI tools for aftermarket services, such as predictive maintenance and battery diagnostics, was highlighted. While AI presents clear opportunities, participants stressed the importance of understanding the risks and governance issues associated with AI adoption, including bias, transparency, and decision accountability. Together, these concerns form a comprehensive thematic area that underscores the need for secure, privacy-conscious, and collaborative approaches to battery data utilization across both technical and governance dimensions.

3.2.4 Battery simulations

Battery behavior under industrial use is difficult to generalize, which makes site-specific simulations valuable. This theme explores how multi-physics models can simulate battery performance under varying conditions typical to each region. Developing common datasets for simulations in Sweden and China supports standardized testing environments and fosters a shared understanding of performance metrics. This not only accelerates innovation but also builds alignment in modeling approaches and system optimization.

3.2.5 Regulatory compliance

For a global company, navigating differing regulatory frameworks across markets like Sweden and China poses a major challenge. Joint efforts in this theme can address how to manage regional regulations related to battery production, safety, and usage. Collaborative research can also help anticipate regulatory changes, particularly in the rapidly evolving EMOB sector. Academic platforms can play a proactive role in predicting how legal landscapes might shift, enabling both partners to stay ahead of compliance requirements and maintain competitiveness across regions.

3.2.6 Knowledge sharing for technological advancement

Finally, this theme underscores the importance of mutual learning. By sharing state-of-the-art knowledge from both academic and industrial perspectives, partners can enhance joint understanding of battery diagnostics, safety, and system performance. The theme also includes exploring the role of autonomous systems in construction machinery, a domain with growing relevance in both countries. Evaluating the potential of creating a shared electromobility platform within the company's global operations can help align efforts, avoid duplication, and foster cohesive development strategies across business units.

3.3 Lessons learned from the Sweden-China collaboration

Cross-border collaboration within complex, fast-evolving sectors like the circular battery ecosystem brings unique opportunities—alongside real challenges. Drawing on experiences from this project, several important lessons have emerged that can guide future joint initiatives. These lessons highlight not only what contributed to the effectiveness of the Sweden–China partnership, but also how specific strategies can help deepen trust, improve alignment, and generate long-term value across institutional and national boundaries.

Lesson 1: Trust and personal connections are essential catalysts for collaboration

One of the most significant enablers of the Sweden–China collaboration was the existence of strong personal and professional relationships early in the project. These connections, particularly between researchers and industry partners, created a foundation of trust that made it easier to initiate open conversations, align goals, and explore new areas of interest. In cross-cultural contexts—where communication styles, expectations, and norms often differ—trust is not merely an outcome but a prerequisite. Investing in informal networking and personal relationship-building strengthens the social foundation of the collaboration. For Sweden and China, where collaboration cultures differ, early trust-building helps bridge institutional gaps and ensures more fluid, respectful, and productive interactions.

Lesson 2: Thesis projects are valuable low-risk entry points for exploring emerging topics

The use of student thesis projects—particularly at the master's level—proved to be a convincing mechanism for initiating collaboration in emerging or uncertain research areas such as battery swapping or vehicle-to-grid applications. These projects offered a low-risk, low-resource method to test new ideas, develop insights, and pilot potential solutions. Importantly, they also served as a means of developing future talent equipped with cross-cultural and interdisciplinary experience. For Sweden and China, integrating student work into the collaboration not only enhances knowledge creation but also supports long-term talent development and institutional capacity building, particularly in areas where innovation is rapidly evolving.

Lesson 3: Thematic focus areas help sustain direction and depth in collaboration

Clearly defined thematic areas—such as data utilization, battery simulation, and regulatory alignment—helped the project stay focused and ensure that all parties contributed meaningfully. These themes acted as common reference points for planning, resource allocation, and setting research priorities. In large, multi-stakeholder collaborations like this one, thematic alignment is critical to avoid fragmentation and to ensure complementary contributions. For international partnerships between countries like Sweden and China, such a shared strategic structure provides a navigational tool to manage complexity, evolving interests, and institutional diversity over time. It also enables more coherent knowledge translation into policy, technical solutions, and industry practices.

Lesson 4: Connecting collaborative activities to relevant organizations ensures long-term impact

One important insight from the Sweden–China collaboration is the need to go beyond project-level engagement and actively anchor ongoing activities within the core structures of participating institutions. While workshops, thesis projects, and informal exchanges create immediate value, lasting impact depends on integrating these efforts into the strategies, operations, and innovation agendas of the relevant departments—both in academia and industry. Establishing formal touchpoints with R&D, sustainability, or product development departments on the company side, and with faculty groups or research centers on the university side, creates continuity beyond individual projects or participants. For Sweden and China, this alignment helps institutionalize collaboration, supports knowledge retention despite staff turnover, and builds a stronger foundation for scaling outcomes and co-developing long-term innovation pathways in the circular battery ecosystem.

4 Discussion

This study makes several significant contributions to the field of cross-border collaboration within the circular battery ecosystem, specifically through a detailed case study of the Sweden-China partnership. Lastly, by identifying and analyzing key challenges, this research provides actionable insights into the structural and cultural adjustments required for effective international partnerships. As the battery ecosystem continues to develop, cross-border initiatives like this Sweden-China project will play a crucial role in fostering technological advancements, supporting regulatory alignment, and nurturing future talent essential for achieving global circularity goals.

First, the study illustrates the importance of shared motivations and drivers in initiating and sustaining cross-border partnerships. While the initial collaboration was rooted in personal connections, it quickly evolved into a strategic relationship guided by a shared interest in addressing complex technological, environmental, and policy challenges associated with battery circularity. Drivers such as comparative analysis of market conditions, leveraging academic and industrial networks, and engaging students through thesis projects created both strategic alignment and operational momentum. Second, the identification of six thematic collaboration areas—from battery life cycle management to regulatory compliance and data analytics—provides a structured lens through which partners can align resources and co-create knowledge. These themes not only reflect the core challenges of battery circularity but also offer platforms for addressing them through interdisciplinary, transnational cooperation. Thematic clarity emerged as a critical factor for maintaining focus, deepening engagement, and translating joint efforts into long-term value.

Third, the study identified several challenges that must be addressed to fully realize the potential of such collaborations. Differences in educational systems, collaboration styles, and learning expectations required

adaptive strategies and continuous dialogue. Additionally, the need to connect activities with the relevant departments and institutional strategies on both sides emerged as a crucial lesson for ensuring long-term impact. Moreover, the use of student-driven thesis projects as low-risk pilots proved to be a highly effective strategy. These initiatives enabled agile exploration of new topics while building a future talent pipeline. Finally, this case reinforces the value of co-production models, where knowledge is created jointly between academia and industry, across national contexts. It demonstrates that even amid structural differences, strategic alignment and cultural adaptability can yield a productive and future-oriented collaboration.

5 Conclusions

This study makes several significant contributions to the growing body of research on cross-border collaboration in the context of circular economy and battery innovation. By analyzing the Sweden–China collaboration, it shows how shared motivations and clear thematic priorities can bring together diverse actors in a complex and evolving ecosystem. The six thematic areas identified in this project offer a roadmap for future cooperation and knowledge co-creation, while the lessons learned from operational and cultural challenges provide practical guidance for other international initiatives. Importantly, the findings emphasize that collaboration must go beyond ad hoc interactions. Long-term impact depends on institutional integration, cultural awareness, and the strategic use of tools such as student theses and regular joint workshops. These practices enable continuous learning and build organizational capacity on both sides. As the global battery ecosystem continues to mature, such cross-border partnerships will play an increasingly vital role in achieving sustainable and circular outcomes. They can help harmonize regulatory frameworks, accelerate technological advancement, and foster globally connected talent. The Sweden–China case thus offers valuable insights and a replicable model for other countries and sectors aiming to address complex sustainability challenges through international collaboration.

6 Limitations and Future work

While this study provides valuable insights into cross-border collaboration within the circular battery ecosystem, it also has several limitations that should be acknowledged. First, the findings are based on a single case study involving specific institutions in Sweden and China. Although this partnership provides contextual insights, the results may not be fully generalizable to other countries, industries, or collaboration models without adaptation to local conditions. Second, data collection primarily relied on qualitative methods, including workshops, thesis project tracking, and informal discussions. While these approaches enabled deep engagement with stakeholders, they may also be influenced by participant availability, and interpretation biases that were not fully captured or standardized across settings. Third, the scope of the study focused largely on the collaborative process, thematic focus areas, and institutional experiences. It did not assess the quantifiable outcomes of collaboration, such as technological advancements, policy impact, or environmental benefits. Future research could benefit from a more empirical assessment of these outcomes over time.

Looking ahead, future work should pursue several directions. First, there is a need to expand the collaboration model to additional contexts, involving a broader set of countries and actors across the battery value chain to test the scalability and adaptability of the lessons learned. Second, future studies should explore institutionalization mechanisms—how outcomes from such collaborations can be formally embedded into company R&D strategy, university curricula, and long-term innovation planning. Third, a mixed-methods approach combining qualitative insights with quantitative assessments (e.g., technology performance, policy alignment, stakeholder engagement metrics) would provide a more comprehensive evaluation framework. Finally, a key area for future research is to continue the development and application of the six thematic areas identified in this study—such as battery design, data use, and regulatory compliance—and to assess how ongoing work in these domains directly contributes to building a circular battery ecosystem within the case company. Tracking these developments over time will provide valuable evidence of how cross-border collaboration can translate thematic focus into operational impact.

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