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Circular Battery Value Chains, Green Industrial Governance, and Sustainable Competitiveness: Comparative Business Systems Evidence from the European Union and China

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ABSTRACT

This article examines how circular battery value chains reshape green industrial governance, business systems, market competitiveness, and sustainable socio-economic development. Using a comparative case study of the European Union and China, the study argues that battery circularity is not merely an environmental waste-management agenda but a strategic economic governance problem involving industrial policy, technological innovation, supply-chain resilience, market regulation, corporate accountability, and resource security. The European Union represents a regulatory-market model that seeks to create sustainable battery competitiveness through lifecycle standards, carbon-footprint disclosure, recycled-content requirements, battery passports, critical raw material diversification, and circular economy regulation. China represents a strategic developmental production model characterized by large-scale electric vehicle deployment, dominant battery manufacturing capabilities, industrial policy coordination, extended producer responsibility, power-battery traceability systems, and rapid recycling-sector expansion. The findings reveal that circular battery competitiveness depends on the institutional capacity to coordinate material flows, innovation systems, corporate governance, recycling infrastructure, energy systems, and international trade. The comparison demonstrates that the European Union is stronger in regulatory standard-setting and sustainability-oriented market governance but weaker in manufacturing scale and upstream resource security, while China is stronger in industrial scale, battery deployment, and recycling capacity but faces challenges of market disorder, governance fragmentation, and environmental accountability. The article contributes to comparative business systems, green industrial policy, circular economy, and sustainable development scholarship by developing propositions on circular industrial governance and resource-based competitiveness.

Keywords: circular economy; battery value chains; green industrial policy; European Union; China; electric vehicles; critical raw materials; sustainability governance; business systems; resource security

INTRODUCTION

The global transition toward electrified mobility, renewable energy storage, and digitalized industrial systems has transformed batteries from a technological component into a strategic economic infrastructure. Lithium-ion batteries now sit at the intersection of industrial competitiveness, climate policy, resource security, trade governance, innovation systems, and sustainable development. Electric vehicles, stationary storage, digital devices, smart grids, and advanced manufacturing increasingly depend on secure and sustainable battery value chains. This creates a central paradox for contemporary business and economic governance: the technologies required for decarbonization depend on minerals, energy-intensive manufacturing, global supply chains, waste-management systems, and industrial capabilities that themselves must be governed sustainably.

The scale of this transformation is substantial. The International Energy Agency reports that almost half of China's car sales were electric in 2024, and that China accounted for almost two-thirds of global electric car sales in that year. In Europe, about one in five new cars sold in 2024 was electric, although growth stagnated as policy support weakened in some major markets (IEA, 2025a). In 2025, global electric-vehicle battery deployment reached 1.2 TWh, an increase of almost 30% compared with 2024 and more than seven times the level in 2020; China accounted for around 60% of global EV battery deployment, while the European Union accounted for almost 15% (IEA, 2026). These figures indicate that the battery transition is no longer an experimental clean-technology market but a core industrial system shaping the future of automobiles, energy, mining, logistics, finance, and trade.

Battery value chains are also central to geopolitical economic governance because they depend on critical minerals whose processing remains highly concentrated. The IEA reports that the average market share of the top three refining countries for key energy minerals increased from approximately 82% in 2020 to 86% in 2024, and that around 90% of supply growth came from the top single supplier, including China for cobalt, graphite, and rare earths. The same assessment notes that two-thirds of global battery recycling capacity growth since 2020 has occurred in China (IEA, 2025b). This concentration means that circular economy policy is no longer merely a sustainability instrument. It has become a strategic response to mineral dependency, trade vulnerability, industrial competition, and climate-policy credibility.

The European Union and China provide analytically powerful cases for examining this issue. Both are central actors in the global battery economy, yet they approach battery circularity through distinct institutional and business-system logics. The European Union represents a regulatory-market governance model. Its battery strategy is embedded in the European Green Deal, Circular Economy Action Plan, Critical Raw Materials Act, industrial strategy, due-diligence regulation, and product lifecycle governance. The EU Batteries Regulation, which entered into force on 17 August 2023, aims to make batteries sustainable across their lifecycle, from material sourcing to collection, recycling, and repurposing, while strengthening strategic autonomy and supporting a competitive sustainable battery industry (European Commission, 2025a). The EU Critical Raw Materials Act sets 2030 benchmarks of at least 10% of annual EU strategic raw material consumption from extraction, 40% from processing, 25% from recycling, and no more than 65% dependence on a single third country at any relevant processing stage (European Commission, 2025b).

China represents a strategic developmental production model. It has built the world's largest electric-vehicle market, dominant battery manufacturing capacity, expanding recycling infrastructure, and an increasingly formalized policy framework for battery traceability and extended producer responsibility. China's 14th Five-Year Plan on Circular Economy aims to improve resource productivity, build a resource recycling industrial system, produce 20 million tonnes of recycled non-ferrous metals, and increase the output value of the resource recycling industry to RMB 5 trillion by 2025; the plan explicitly includes recycling waste power batteries from new energy vehicles as a key task (NDRC, 2021; IEA, 2024). China's New Energy Vehicle Industry Development Plan for 2021–2035 also establishes measures for power-battery recycling, including extended producer responsibility, traceability platforms, cascade utilization, residual-value assessment, and efficient extraction of valuable materials (State Council of China, 2020).

The academic problem addressed in this article is that battery circularity is frequently studied through fragmented perspectives. Environmental management research often treats battery recycling as a technical waste problem. Strategic management studies frequently focus on firm capabilities, electric-vehicle competition, and supply-chain strategy. Innovation studies examine battery chemistry, gigafactories, and industrial ecosystems. Political economy research analyzes industrial policy, resource nationalism, and geopolitical competition. Sustainability transition scholarship studies mobility electrification and energy-system decarbonization. While each literature contributes important insights, current scholarship remains limited in explaining how institutional structures connect circular economy policy, business-system transformation, market governance, economic performance, and sustainable socio-economic development.

This limitation matters because circular battery value chains require coordination across multiple economic domains. Mining, refining, cell manufacturing, module assembly, electric-vehicle production, charging infrastructure, second-life applications, collection systems, recycling technologies, data traceability, and secondary-material markets are deeply interdependent. A circular battery economy cannot emerge simply because firms discover profitable recycling opportunities. It requires regulatory standards, producer responsibility, industrial finance, digital traceability, consumer participation, technological innovation, cross-border trade rules, environmental safeguards, and credible demand for recovered materials. In this sense, circularity is an institutional coordination problem rather than a downstream waste-management activity.

The literature provides several important but incomplete foundations. Porter (1990) explains how national competitive advantage depends on firm strategy, factor conditions, demand conditions, and related industries, but the framework must be extended to account for circular resource flows and regulatory sustainability standards. North (1990) shows that institutions structure incentives and reduce uncertainty, yet battery circularity demonstrates that institutions also structure material recovery, lifecycle accountability, and environmental traceability. Teece (2007) argues that dynamic capabilities enable firms to sense, seize, and reconfigure resources, but circular battery markets require system-level capabilities beyond individual firms. Geels (2019) explains socio-technical transition through interactions between regimes, niches, and landscape pressures, yet circular battery systems show that resource security and industrial policy are not peripheral but central to sustainability transitions. Mazzucato (2021) and Juhász, Lane, and Rodrik (2023) revive mission-oriented and modern industrial policy, but battery circularity shows that missions must govern not only innovation and production but also end-of-life recovery, standards, and secondary markets.

Existing research on circular economy also requires deeper institutionalization. Kirchherr, Reike, and Hekkert (2017) show that circular economy is often defined through reduction, reuse, recycling, and recovery, but business implementation remains uneven because circularity challenges linear production incentives. Geissdoerfer et al. (2020) emphasize circular business models, yet circular models depend on market rules, consumer behavior, infrastructure, finance, and regulation. Recent studies on electric-vehicle battery recycling highlight technical recovery potential and policy instruments, but often insufficiently analyze the comparative business systems through which different economies translate policy into industrial capability. As a result, scholarship still lacks an integrated framework explaining how institutional structures shape circular battery competitiveness.

The empirical gap is equally important. The European Union has created one of the world's most advanced sustainability-oriented regulatory frameworks for batteries, yet it remains dependent on imported raw materials, imported cells, and external processing capacity. China has achieved extraordinary scale in electric vehicles, batteries, and recycling capacity, yet its circular economy faces challenges related to informal recycling, regional policy variation, competitive disorder, and environmental enforcement. The European Union is attempting to use regulation to create future markets for sustainable batteries. China is attempting to use industrial scale and state coordination to formalize circular material flows. The comparison therefore allows the study to examine whether regulatory leadership and industrial scale represent complementary or competing pathways to sustainable competitiveness.

This article identifies six research gaps. First, the theoretical gap concerns insufficient integration of comparative business systems, circular economy, industrial policy, and sustainability transition theory. Second, the empirical gap concerns limited comparative evidence on how the EU and China govern battery circularity as an economic development strategy. Third, the institutional gap concerns inadequate analysis of how different governance architectures shape business implementation. Fourth, the market-structure gap concerns the under-explained role of firms, recyclers, automakers, battery producers, and digital traceability platforms. Fifth, the policy-coordination gap concerns the difficulty of aligning climate policy, resource policy, trade policy, industrial policy, and waste regulation. Sixth, the sustainability gap concerns whether circular battery systems genuinely reduce environmental harm and increase socio-economic resilience or simply shift extraction and waste burdens across regions.

The novelty of this article lies in conceptualizing circular battery value chains as a form of green industrial governance. The article argues that circular competitiveness emerges when institutional structures create credible rules for material recovery, firms build dynamic capabilities for lifecycle business models, governments coordinate industrial and environmental policy, and markets reward low-carbon and traceable products. The article's analytical framework links institutional structures → circular business systems → policy implementation → economic performance → sustainable socio-economic development. The causal logic is that institutional design shapes circular value-chain coordination; coordination affects firm investment and innovation; business-system transformation influences competitiveness and resilience; and resilience contributes to sustainability only when material recovery, labour standards, environmental accountability, and inclusive industrial development are integrated.

The research objective is to explain how the European Union and China use different institutional and business-system architectures to govern circular battery value chains, and what this comparison reveals about the conditions under which green industrial transformation generates sustainable competitiveness and socio-economic development.

METHODOLOGY

This study employs a comparative institutional business systems methodology integrating comparative economic analysis, circular economy governance, green industrial policy, and sustainability transition theory. The European Union and China are selected through a most-different systems logic because both are structurally important to the global battery economy but differ in institutional authority, regulatory design, market structure, industrial organization, corporate governance, environmental enforcement, and state-business coordination. The European Union is analyzed as a regional regulatory-market system that uses binding product rules, lifecycle standards, due diligence, strategic autonomy instruments, trade partnerships, and circular economy legislation to shape market behavior across member states. China is analyzed as a strategic developmental production system that combines national planning, industrial subsidies, manufacturing scale, extended producer responsibility, traceability systems, and state-guided industrial upgrading. The comparison is theoretically aligned with comparative capitalism, institutional economics, circular economy theory, dynamic capabilities, and socio-technical transition theory because it treats battery circularity not as an isolated recycling technology but as an institutionally embedded transformation of firms, markets, resource flows, and policy systems.

The empirical basis consists of triangulated secondary evidence from international organizations, government policy documents, regulatory materials, and academic literature. The study draws on International Energy Agency data on electric vehicles, battery deployment, and critical mineral concentration; European Commission materials on the Batteries Regulation and Critical Raw Materials Act; Chinese circular economy and new energy vehicle policy documents; WTO, UNCTAD, OECD, and World Bank reports on trade, industrial transformation, digital and green transition, and sustainable development; corporate governance and industrial policy literature; and peer-reviewed research on circular economy, battery recycling, electric mobility, innovation systems, and comparative business systems. The analysis applies structured focused comparison, institutional mechanism tracing, and cross-case analytical mapping. Reliability is strengthened by triangulating empirical indicators across official and multilateral sources, distinguishing documented evidence from analytical inference, and evaluating each case through the same comparative variables: institutional architecture, industrial scale, regulatory design, business-system coordination, innovation capability, recycling infrastructure, resource security, market competition, digital traceability, sustainability governance, and socio-economic implications. No interview data are used, and no respondent quotations are fabricated. The limitation is that the study does not estimate econometric effects; its contribution is explanatory and theory-building, appropriate for identifying institutional mechanisms and developing propositions for future empirical testing.

Findings and Discussion

1. Institutional Architectures of Circular Battery Governance

The first major finding is that the European Union and China both treat battery circularity as a strategic economic issue, but they govern it through different institutional architectures. The European Union relies primarily on regulatory market-making. Its battery policy seeks to shape the conditions under which firms can sell batteries into the European market. The Batteries Regulation introduces lifecycle governance by requiring sustainability, safety, labelling, information, due diligence, waste management, and battery-passport obligations. The European Commission frames the regulation as a key instrument for making batteries sustainable across the entire lifecycle and for supporting clean-energy transition and industrial independence (European Commission, 2025a). This reflects a regulatory theory of competitiveness: the EU seeks to convert high sustainability standards into market discipline, technological upgrading, and strategic autonomy.

China's institutional architecture is more production-centered and developmental. Circular battery governance is embedded in national industrial planning, new energy vehicle policy, extended producer responsibility, manufacturing scale, and resource-security strategy. The 14th Five-Year Plan on Circular Economy identifies the construction of a resource recycling industrial system as a national priority, while the New Energy Vehicle Industry Development Plan explicitly links battery recycling to traceability platforms, cascade utilization, valuable-material extraction, and industry ecosystem development (NDRC, 2021; State Council of China, 2020). This reflects a production-systems theory of circularity: circular battery governance is not only about environmental compliance but about securing inputs for continued industrial expansion.

The cross-case comparison reveals a fundamental institutional divergence. The European Union seeks to govern circularity through rules that apply to products placed on the market, regardless of where they are produced. This gives the EU extraterritorial regulatory influence because non-European battery producers must comply with

EU lifecycle standards if they want market access. China seeks to govern circularity through integration of producers, recyclers, platforms, industrial parks, and state-led planning mechanisms. This gives China operational advantages because it can coordinate production, deployment, collection, and recycling within a large domestic market.

This divergence extends institutional economics. North (1990) argues that institutions structure incentives and reduce uncertainty, but battery circularity shows that institutions also define material responsibility across time. The key institutional question is not only who owns a battery when it is sold, but who is responsible for its embedded minerals, carbon footprint, residual value, second-life application, safe collection, and end-of-life processing. The European Union addresses this through legal obligations and market-entry standards. China addresses it through producer responsibility, administrative coordination, and traceability systems.

For business systems, the implications differ. EU firms must build compliance capabilities: lifecycle assessment, supplier due diligence, digital product passports, recycled-content documentation, carbon accounting, and waste-management partnerships. Chinese firms must build operational circularity capabilities: battery collection networks, cascade utilization, recycling technologies, producer-recycler coordination, and compliance with evolving traceability rules. The EU model rewards firms that can document sustainability performance. The Chinese model rewards firms that can integrate circular processes into large-scale production systems.

The policy implication is that circular economy governance must be designed as industrial governance, not merely environmental law. The EU's strength is its ability to define market rules that may become global standards. China's strength is its ability to mobilize industrial systems at scale. The weakness of the EU model is that regulation may outpace domestic production and recycling capacity. The weakness of the Chinese model is that scale may outpace environmental accountability and market order. Sustainable competitiveness requires both credible rules and operational capabilities.

2. Industrial Scale, Market Structure, and Circular Business Transformation

The second finding is that industrial scale strongly shapes circular economy feasibility. China's electric-vehicle and battery market provides an enormous material base for future circularity. With electric vehicles representing almost half of new car sales in China in 2024 and China accounting for almost two-thirds of global electric car sales, the country is creating the world's largest stock of future end-of-life batteries (IEA, 2025a). In 2025, China accounted for around 60% of global EV battery deployment, compared with almost 15% for the European Union (IEA, 2026). These figures demonstrate that China's future recycling potential is structurally linked to its present deployment scale.

The European Union faces a different scale problem. It has a large automotive market and strong regulatory ambition, but EV market expansion has been uneven. The IEA reported that around one in five new cars sold in Europe was electric in 2024 and that EV sales stagnated as policy support weakened in several major markets (IEA, 2025a). This matters because recycling ecosystems depend on predictable material flows. If domestic EV adoption is slower or more uneven, recycling investment becomes riskier, particularly when energy prices, financing costs, and global competition are high. The EU can mandate recycled content, but firms need sufficient volumes of waste batteries, local processing capacity, and economically viable recovery technologies.

The comparison demonstrates that circular business models require both regulatory demand and material supply. The EU is strong in creating regulatory demand for circularity through recycled-content rules, carbon-footprint disclosure, and battery passports. China is strong in generating material supply through massive EV deployment and battery manufacturing. However, neither strength is sufficient by itself. Regulation without industrial scale may create compliance dependence on foreign producers and recyclers. Scale without stringent governance may create informal recycling, environmental leakage, and inefficient material recovery.

This finding extends the circular business model literature. Geissdoerfer et al. (2020) emphasize value retention, reuse, remanufacturing, and recycling, but battery circularity shows that business models depend on timing and volume. A battery circular economy cannot mature until enough batteries reach end-of-life, but firms must invest before end-of-life volumes fully materialize. This creates a temporal coordination problem. Governments must provide credible long-term rules, financing support, and market signals so firms can invest ahead of material flows.

China's market structure creates both advantages and risks. Large battery manufacturers, automakers, and technology firms can coordinate battery design, collection, and recycling at scale. Firms such as CATL, BYD, and other major actors can potentially integrate recycling into upstream and downstream strategies. Yet China also faces disorderly competition in parts of the battery sector. Reports of policy concern over irrational competition and overcapacity suggest that scale can create price pressure and consolidation risks. When competition becomes excessively price-driven, firms may underinvest in environmental compliance, safety, and high-quality recovery.

The European Union's market structure creates different risks. European automakers, battery start-ups, recyclers, and energy firms operate in a fragmented multi-country regulatory and investment environment. The EU single market provides scale in principle, but member-state differences in permitting, energy prices, infrastructure, industrial policy, and fiscal capacity affect implementation. Battery recycling plants require stable feedstock, low-carbon energy, permitting certainty, and financing. If these conditions are not aligned, the EU may set advanced circular standards while importing circular-compliant batteries from firms with stronger production scale elsewhere.

The business implication is that firms must shift from linear product strategy to lifecycle resource strategy. Battery producers must design for disassembly, traceability, second-life use, and material recovery. Automakers must treat batteries as long-term asset systems rather than components sold with vehicles. Recyclers must become strategic partners in supply-chain security. Digital platforms must verify battery histories, ownership, chemistry, carbon footprint, and residual value. Financial institutions must develop instruments for recycling infrastructure, secondary-material contracts, and circular supply-chain finance.

The development implication is that circular battery value chains can generate new industries, employment, and regional upgrading, but only if policy supports capability diffusion. China's recycling industry can create new industrial clusters, but environmental quality and labour conditions must be monitored. The EU's circular battery agenda can support regional industrial renewal, but it must avoid becoming an administrative burden that only large firms can manage. Circular competitiveness should therefore be evaluated not only by recycling volume but by the distribution of value across firms, regions, workers, and communities.

3. Critical Raw Materials, Resource Security, and Trade Governance

The third finding is that circular battery governance has become a resource-security strategy. The IEA's critical minerals analysis shows that refining concentration has intensified rather than diversified in recent years, with the top three refining countries increasing their average share of key energy mineral refining from around 82% in 2020 to 86% in 2024 (IEA, 2025b). The same report notes that China's influence extends beyond refining because two-thirds of global battery recycling capacity growth since 2020 has occurred in China. This creates a strategic asymmetry between the European Union's dependency-reduction ambitions and China's existing industrial position.

The European Union's Critical Raw Materials Act is a direct response to this asymmetry. Its 2030 benchmarks seek to build domestic capacities across extraction, processing, and recycling while limiting dependence on a single third country. The Act also includes monitoring, stress testing, strategic projects, shorter permitting timeframes, supply-risk preparedness, and measures to improve circularity and sustainability (European Commission, 2025b). This is a clear example of economic governance moving beyond market liberalization toward resilience-oriented industrial policy.

China's resource-security strategy is different. It combines domestic industrial scale, overseas investment, mineral processing capacity, battery manufacturing, recycling expansion, and policy-guided circularity. The country's battery recycling policy cannot be separated from its broader position in global mineral processing and battery supply chains. Recycling reduces pressure on primary mineral imports, supports domestic industrial continuity, and strengthens strategic control over secondary materials. The State Council's NEV plan explicitly encourages power battery value-chain development and improvement of capacity in key resources such as lithium, nickel, cobalt, and related materials (State Council of China, 2020).

The comparison reveals that circularity is becoming a form of strategic autonomy. For the EU, recycling is a way to reduce external dependency and strengthen resilience. For China, recycling is a way to reinforce industrial leadership and resource control. These two motivations overlap but are not identical. The EU emphasizes diversification, sustainability standards, and supply-chain accountability. China emphasizes industrial ecosystem integration, material security, and production continuity. This reflects different positions in the global value chain: the EU is a rule-maker seeking capacity; China is a capacity-holder strengthening rule compliance and recycling systems.

This finding contributes to international business theory by showing that location advantages now include circular resource access. Dunning's eclectic paradigm traditionally emphasizes ownership, location, and internalization advantages, but battery industries add lifecycle resource advantages. Firms may locate production not only near consumers or low-cost inputs, but near recycling infrastructure, low-carbon electricity, compliant supply chains, and strategic raw material networks. In this context, circularity becomes part of global value-chain strategy.

Trade governance is also affected. Battery passports, recycled-content requirements, carbon-footprint rules, and due-diligence obligations can reshape market access. Producers outside the EU must document compliance, while European firms must secure reliable inputs and verify supply chains. China's battery firms may be technologically and cost competitive, but EU regulatory requirements can increase the importance of traceability, carbon intensity, and recycled material sourcing. The result is a hybrid competitive arena in which price, technology, compliance, and sustainability interact.

The policy challenge is to prevent circular economy policy from becoming either disguised protectionism or ineffective aspiration. The EU must ensure that sustainability rules are transparent, scientifically grounded, and supported by domestic investment. China must ensure that recycling expansion meets environmental and social standards rather than merely increasing material recovery volume. International cooperation remains necessary because battery minerals, components, vehicles, and waste streams cross borders. A fragmented trade regime could reduce efficiency and increase costs, while unregulated globalization could reproduce environmental harm.

The sustainability implication is that recycling cannot eliminate the need for responsible mining in the short and medium term. Battery demand is growing too rapidly for secondary materials to meet all needs immediately. However, circular systems can reduce long-term pressure on primary extraction, improve supply resilience, and lower lifecycle emissions if powered by clean energy and governed with strong standards. Circularity is therefore not a substitute for mineral governance but a complement to it.

4. Digital Traceability, Corporate Governance, and Market Trust

The fourth finding is that digital traceability is becoming a core governance mechanism in circular battery value chains. Batteries are complex products containing materials from multiple jurisdictions, production stages, and suppliers. Circularity requires information about chemistry, origin, carbon footprint, recycled content, state of health, ownership history, safety status, and end-of-life options. Without reliable data, secondary markets cannot function efficiently, regulators cannot verify compliance, and firms cannot manage lifecycle value.

The European Union's battery-passport agenda reflects this logic. The Batteries Regulation links sustainability governance to information disclosure, labelling, lifecycle documentation, and future digital data systems. From a business perspective, the battery passport is not merely a compliance document; it is a market infrastructure that can support used-battery valuation, second-life applications, recycling efficiency, consumer trust, and responsible sourcing. The European Commission's battery policy emphasizes lifecycle sustainability from sourcing to recycling and repurposing, while related implementation rules focus on calculating and verifying recycling efficiency and material recovery rates (European Commission, 2025a).

China's traceability approach is more administrative and production-system oriented. The NEV Industry Development Plan calls for strengthening the power battery traceability management platform and supporting cascade utilization and residual-value assessment (State Council of China, 2020). This indicates that China recognizes battery data as essential to formalizing recycling markets. Traceability can reduce leakage into informal recycling channels, support producer responsibility, and improve safety management. However, the effectiveness of traceability depends on enforcement, data accuracy, inter-firm cooperation, and local administrative capacity.

The comparison shows that digital traceability creates market trust through different mechanisms. The EU uses transparency to support regulatory compliance and market accountability. China uses traceability to support administrative coordination and industrial control. Both models require firms to develop data-governance capabilities. Battery producers must collect and share technical information without exposing commercially sensitive data. Automakers must manage ownership and use-phase data. Recyclers must verify material recovery. Regulators must audit information. Consumers and investors must trust the system.

This finding extends corporate governance literature. Traditional corporate governance focuses on shareholders, boards, disclosure, and accountability. Circular battery governance expands accountability across product lifecycles and supply chains. Firms become responsible not only for financial performance but also for carbon footprint, mineral sourcing, recyclability, safety, and end-of-life outcomes. ESG governance therefore moves from corporate reporting to product-level verification. This is a significant shift because it links sustainability claims to physical material flows.

The theoretical implication is that market trust increasingly depends on data credibility. In linear markets, trust may be based on brand reputation, certification, and contractual enforcement. In circular markets, trust also requires traceable product histories and verifiable material claims. This introduces new institutional risks: data manipulation, fragmented standards, cyber vulnerabilities, confidentiality conflicts, and unequal digital capacity among SMEs. If only large firms can comply with battery-passport and traceability requirements, circular governance may unintentionally increase market concentration.

The business implication is that companies need digital circular capabilities. These include lifecycle data collection, supplier data integration, blockchain or secure database systems, carbon accounting, materials informatics, recycling analytics, and compliance management. Firms that develop these capabilities early may gain competitive advantage in regulated markets. Firms that fail to do so may face market-access barriers, financing disadvantages, and reputational risk.

The policy implication is that digital traceability should be interoperable, auditable, and proportionate. Governments should avoid creating incompatible data systems that increase compliance costs. They should also support SMEs through technical assistance, shared platforms, and standardized reporting tools. In both the EU and China, traceability will determine whether circular economy governance becomes an inclusive market infrastructure or a complex compliance burden.

5. Sustainability Outcomes, Social Development, and Limits of Circular Competitiveness

The fifth finding is that circular battery value chains can support sustainable development, but only if circularity is connected to broader socio-economic and environmental objectives. Recycling valuable materials such as lithium, nickel, cobalt, manganese, graphite, and copper can reduce primary extraction pressures, lower supply risk, and create new industrial activity. Second-life applications can extend battery value in stationary storage, microgrids, and renewable-energy systems. Better battery design can reduce waste, improve safety, and increase recyclability. Yet circularity can also be limited by technical losses, energy-intensive recycling processes, hazardous waste, informal dismantling, and unequal distribution of environmental burdens.

The European Union's sustainability model is legally comprehensive. It links batteries to zero pollution, circular economy, strategic autonomy, and lifecycle responsibility. The strength of this approach is that it embeds sustainability into market entry conditions. The weakness is that implementation may be slow, costly, and uneven across member states. If European recycling capacity develops too slowly, EU firms may rely on imported compliant materials or outsource circular processes. This would weaken the developmental benefits of circular industrial policy.

China's sustainability model is materially expansive. It benefits from large domestic material flows, manufacturing capacity, and policy coordination. The strength of this approach is that China can rapidly build recycling capacity and integrate circularity with industrial upgrading. The weakness is that rapid expansion can produce regulatory fragmentation, local enforcement variation, and competition between formal and informal recyclers. Reuters reported in 2025 that China's cabinet approved an action plan to improve the recycling system for new energy vehicle power batteries as the sector entered a large-scale decommissioning stage, indicating official recognition that battery retirement had become a major governance issue (Reuters, 2025).

The comparison indicates that sustainability outcomes depend on institutional quality, not only recycling volume. High recycling volume without environmental safeguards can reproduce pollution. Strict standards without industrial capacity can shift recycling abroad. Circular systems must therefore be evaluated through material recovery rates, lifecycle emissions, labour conditions, safety, local pollution, economic inclusion, and industrial resilience. Sustainable competitiveness requires that circularity improve both environmental performance and socio-economic welfare.

This finding extends sustainability transition theory by emphasizing resource feedback loops. Electrification is often presented as a transition from fossil fuel dependence to clean mobility. Yet battery systems show that low-carbon transitions generate new material dependencies. A sustainable transition must therefore govern both energy flows and material flows. The circular economy is the institutional mechanism through which material dependency can be moderated over time.

The social development implications are significant. Circular battery industries can create skilled jobs in recycling technology, logistics, testing, digital traceability, materials science, and remanufacturing. However, they can also produce hazardous work if safety standards are weak. The EU's challenge is to ensure that circular industrial policy supports regional employment and skills formation rather than simply creating compliance markets. China's challenge is to ensure that recycling expansion improves labour safety, environmental quality, and local development rather than reinforcing low-margin hazardous processing.

For emerging economies, the EU–China comparison offers important lessons. Countries rich in lithium, nickel, cobalt, graphite, or rare earths should not remain mere suppliers of raw materials. They can use circular economy policy to negotiate technology transfer, local processing, recycling partnerships, and sustainability standards. However, they must avoid becoming destinations for waste or low-standard processing. International battery circularity must therefore be governed through fair trade, responsible investment, environmental justice, and development partnerships.

The broader economic implication is that circularity changes the meaning of competitiveness. Competitive advantage in the battery economy will not depend only on lower production cost, larger factories, or better chemistry. It will increasingly depend on the ability to prove low carbon intensity, secure responsible materials, recover valuable inputs, comply with evolving rules, and maintain trust across global value chains. Circular capability is therefore becoming a core dimension of business strategy and national economic governance.

Table 1. Analytical Matrix of Comparative Business and Economic Development

Variable	**Case 1: European Union**	**Case 2: China**	**Empirical Evidence**	**Analytical Interpretation**
Institutional governance model	Regulatory-market governance based on lifecycle standards, due diligence, battery passports, and circular economy law	Strategic developmental production governance based on industrial planning, manufacturing scale, EPR, traceability, and recycling systems	EU Batteries Regulation entered into force in 2023; China's 14th Five-Year Circular Economy Plan and NEV Plan prioritize battery recycling	EU governs through market-entry rules; China governs through production-system coordination
Industrial scale	Large automotive market but uneven EV adoption and weaker battery manufacturing scale than China	World's largest EV and battery market with dominant deployment and manufacturing capacity	China accounted for almost two-thirds of global electric car sales in 2024; EU EV sales were about one-fifth of new car sales	China has stronger material-flow foundations for recycling; EU has stronger regulatory demand for circularity
Resource-security strategy	Diversification, strategic partnerships, domestic extraction, processing, recycling, and import-dependency reduction	Control of processing, manufacturing, recycling expansion, and integrated industrial ecosystems	EU Critical Raw Materials Act sets 2030 benchmarks of 10% extraction, 40% processing, 25% recycling, and maximum 65% single-	EU seeks autonomy through diversification; China reinforces leadership through scale and circular capacity

			country dependence	
Circular business architecture	Compliance-oriented circularity involving lifecycle assessment, recycled content, carbon footprint, and product data	Operational circularity involving collection, cascade utilization, residual-value assessment, and material recovery	EU battery rules emphasize lifecycle sustainability; China's NEV plan strengthens traceability and cascade use	EU firms must build compliance capabilities; Chinese firms must build integrated circular operations
Digital traceability	Battery passport and product information systems as tools for transparency, market trust, and regulatory verification	Power-battery traceability management platform as tool for administrative coordination and producer responsibility	EU regulation requires information and lifecycle documentation; China's NEV plan calls for traceability strengthening	Traceability becomes a core market infrastructure for circular value chains
Market structure	Fragmented multi-country market with strong regulation but uneven industrial capacity and energy-cost pressures	Highly scaled but competitive and sometimes disorderly industrial ecosystem	IEA shows EU battery deployment below China; China has major recycling-capacity growth	EU risks regulatory dependence; China risks overcapacity, price pressure, and uneven enforcement
Sustainability governance	Strong legal standards, circular economy rules, zero pollution, and strategic autonomy agenda	Large-scale recycling policy, resource recovery, EPR, and carbon-neutrality goals	EU rules cover lifecycle sustainability; China's circular plan targets RMB 5 trillion resource recycling industry output by 2025	EU has stronger formal accountability; China has stronger operational scale
Economic performance pathway	Uses sustainability rules to create future competitive markets and reduce strategic	Uses manufacturing dominance and recycling growth to reinforce	EU CRMA and Batteries Regulation shape market access; China dominates EV deployment and battery	Sustainable competitiveness requires combining standards with scale

	dependencies	battery value-chain competitiveness	recycling growth	
Development and social implications	Potential for regional industrial renewal, skills formation, and green jobs if capacity grows	Potential for industrial upgrading and resource security but risks informal recycling and local environmental burdens	China approved further action on NEV battery recycling as large-scale decommissioning emerged	Circularity must be judged by environmental quality, labour safety, and inclusive development

The table demonstrates that circular battery transformation is shaped by institutional complementarities. The EU's regulatory architecture is coherent in its sustainability objectives, but it depends on industrial investment, energy affordability, permitting, and supply-chain diversification to become economically effective. China's production architecture is powerful in scale and operational integration, but it depends on stronger enforcement, formal recycling channels, environmental safeguards, and market discipline to become sustainably credible. The central comparative insight is that circular competitiveness requires both rules and capacity. Rules without capacity may generate dependency; capacity without rules may generate environmental and social risk.

The table also clarifies the causal mechanism linking institutions to development outcomes. Institutional structures define responsibility for battery lifecycles. Policy implementation creates incentives for firms to invest in traceability, recycling, and circular design. Business systems translate those incentives into industrial capabilities. Economic performance emerges through reduced material dependency, improved supply-chain resilience, new market opportunities, and compliance-based competitiveness. Sustainable socio-economic development occurs only when these outcomes reduce environmental burdens, create decent work, support regional upgrading, and strengthen long-term resource security.

Theoretical Propositions

Proposition 1: Circular battery competitiveness depends on the institutional integration of lifecycle regulation, industrial capacity, and resource-security strategy.

The EU–China comparison shows that circularity cannot be achieved through recycling policy alone. It requires coordination between product standards, mineral policy, industrial finance, manufacturing systems, digital traceability, and end-of-life markets. Regulatory ambition must be matched by operational capacity, while industrial scale must be disciplined by sustainability governance.

Proposition 2: Digital traceability mediates the relationship between circular policy and market trust.

Battery passports, traceability platforms, lifecycle data, and material documentation convert sustainability claims into verifiable market information. Without credible traceability, recycled-content claims, carbon-footprint declarations, and second-life valuation remain uncertain. Traceability therefore functions as an institutional infrastructure for circular markets.

Proposition 3: Strategic industrial policy improves sustainable competitiveness when it links production scale with material recovery and environmental accountability.

China demonstrates that manufacturing scale can accelerate circular capability, while the EU demonstrates that regulation can define sustainability expectations. The strongest model combines industrial investment, recycling infrastructure, clean energy, and enforceable accountability.

Proposition 4: Circular economy policy contributes to socio-economic development only when value retention is distributed across firms, workers, regions, and communities.

Circular battery industries can create jobs, reduce dependency, and support regional renewal, but they can also concentrate value or shift environmental risks. Sustainable development requires inclusive industrial upgrading, labour protection, environmental justice, and SME participation.

Proposition 5: In green technology sectors, resource circularity is becoming a source of geopolitical and business-system advantage.

As critical minerals become strategically constrained, firms and economies with credible access to secondary materials, recycling capacity, and lifecycle compliance will gain competitive resilience. Circularity therefore becomes part of national competitiveness, corporate strategy, and international economic governance.

CONCLUSION

This article examined how the European Union and China use different institutional and business-system architectures to govern circular battery value chains, and what this comparison reveals about the conditions under which green industrial transformation generates sustainable competitiveness and socio-economic development. The direct answer to the research objective is that circular battery transformation depends on the institutional capacity to align lifecycle regulation, industrial scale, resource security, business innovation, digital traceability, and sustainability accountability.

The main analytical finding is that the European Union and China represent two distinct but incomplete pathways. The European Union is a regulatory leader. It uses lifecycle standards, carbon-footprint requirements, battery passports, recycled-content rules, critical raw material benchmarks, and circular economy policy to reshape market incentives. Its strength lies in legal accountability, sustainability-oriented market governance, and standard-setting power. Its weakness lies in uneven industrial capacity, external material dependency, energy-cost pressures, and the risk that regulation may outpace domestic production and recycling capability.

China is an industrial-scale leader. It has created the world’s largest electric-vehicle and battery ecosystem, substantial recycling-capacity growth, and policy mechanisms for producer responsibility, traceability, cascade utilization, and resource recovery. Its strength lies in manufacturing scale, rapid deployment, coordinated industrial policy, and operational circularity. Its weakness lies in market disorder, informal recycling risks, enforcement variation, environmental accountability, and potential overcapacity.

The theoretical contribution of the article is to conceptualize circular battery value chains as green industrial governance systems. The article integrates comparative business systems, institutional economics, circular economy theory, dynamic capabilities, and sustainability transition scholarship. It shows that circularity is not merely an environmental practice but a strategic economic capability. Firms, states, and regions compete not only through cost, technology, and market access but also through lifecycle accountability, secondary-material access, traceability, and compliance credibility.

The empirical contribution lies in the structured comparison of two central actors in the global battery economy. The EU demonstrates how regulation can create demand for sustainable products and redefine market access. China demonstrates how industrial scale can create material flows and recycling opportunities. The comparison shows that sustainable competitiveness requires combining the EU's strength in standards with China's strength in operational capacity, while avoiding the weaknesses of both models.

The business implications are substantial. Battery producers, automakers, recyclers, and investors must move from linear supply-chain management to lifecycle resource strategy. Competitive firms will need capabilities in carbon accounting, product passports, recycling partnerships, second-life business models, supplier due diligence, and circular design. The policy implications are equally significant. Governments should coordinate battery regulation with industrial finance, clean energy, infrastructure, skills, trade policy, and environmental enforcement. Circular economy policy must be designed as a competitiveness strategy and a development strategy.

The sustainability implications are clear. Battery circularity can reduce long-term mineral dependency, improve resource efficiency, lower environmental pressure, and support green industrial employment. However, circularity is not automatically sustainable. Recycling processes must be clean, workers must be protected, communities must not bear disproportionate environmental burdens, and global trade in battery materials must avoid reproducing unequal extraction relationships.

This study has limitations. It relies on secondary evidence and comparative institutional interpretation rather than firm-level interviews or econometric estimation. Future research should examine firm-level circular capabilities, recycling economics, battery-passport implementation, regional employment impacts, and the role of emerging economies in battery mineral and recycling value chains. Further research should also compare additional cases, such as the United States, Japan, South Korea, Indonesia, Chile, and the Democratic Republic of Congo.

The broader conclusion is that circular battery governance will become a defining frontier of twenty-first-century business and economic policy. The economies that succeed will not be those that merely produce more batteries or impose more rules. They will be those that create coherent institutions linking innovation, production, accountability, resource recovery, and sustainable development..

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