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# *Supply Chain Design and Optimization Strategies under Carbon Tariffs*

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***Abstract.*** As the EU Carbon Border Adjustment Mechanism (CBAM) moves into force, green and low-carbon transformation has become a question Chinese supply chains can no longer postpone. This transformation is shifting trade competition from "cost competition" into "green competition." This paper builds a supply chain analytical framework covering Scope 1/2/3 emissions and, through case and comparative analysis of Apple and BYD, proposes strategies along four dimensions. The study finds that CBAM brings heavy compliance cost pressure but also strategic opportunity: Apple pushed 320 suppliers to commit to 100% clean electricity and made selected products carbon neutral, while BYD cut supply chain emission intensity by 25-30% through vertical integration. Even so, Chinese enterprises still struggle with data acquisition, Scope 3 accounting, cost balancing, collaborative reduction mechanisms, and the fragmentation of green trade rules.

***Keywords:*** Carbon Tariff, Supply Chain Design, Green Supply Chain, Carbon Emission Management, CBAM

## 1. Introduction

Green development has moved from the margins of policy debate to the center of global economic competition. As climate pressures intensify, the international trade regime is being reshaped by a new generation of green trade barriers, among which the EU Carbon Border Adjustment Mechanism (CBAM) is the most consequential [1]. For China, the world's largest manufacturer and exporter, this shift from "cost competition" to "green competition" is not a distant scenario but an immediate constraint on its trade structure. At its core, CBAM is designed to prevent "carbon leakage": the EU charges imported products a carbon tariff linked to its own carbon market price, hoping to push trading partners toward low-carbon production. Leading multinationals have moved early. Most Chinese firms, however, have not yet built systematic carbon management into their supply chains; data collection, Scope 3 accounting, and joint emission reduction with suppliers remain weak points.

This paper takes Apple and BYD as typical cases and examines their supply chain carbon management practices in detail. By integrating supply chain management research with carbon emission research, a comprehensive analysis framework covering scope 1/2/3 is constructed. The analysis draws on literature review, case studies, quantitative analysis, and comparative research. The analysis helps Chinese exporters make sense of CBAM's policy logic and compliance requirements, points to the carbon data systems they need to build, distills workable optimization

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strategies from benchmark cases, and offers reference points for policymakers designing supporting measures.

## 2. Literature review and theoretical foundation: carbon tariff policy framework and supply chain carbon management

### 2.1. Literature review and theoretical evolution

Research on carbon tariffs has grown quickly. Jordan and Bleischwitz examined the compliance difficulties carbon tariffs face under WTO rules [1]. Dechezleprêtre traced how CBAM transmits along supply chains and concluded that it will reshape where multinationals procure and produce [2]. Zhang et al. quantified CBAM's impact on China's key industries and proposed phased responses [3]. On supply chain carbon management, Seuring and Müller laid the early conceptual foundation for sustainable supply chain management, arguing that environmental standards must be built into supplier relationships rather than bolted on afterwards [4]. Taken together, the literature still leaves several gaps: carbon tariffs and supply chain strategy are rarely studied together; Scope 3 management lacks distilled best practices; case work seldom compares across industries; and the strategies proposed are often too abstract to implement.

Carbon tariffs are a new external constraint, and they push supply chain management theory in a greener direction. Four theoretical lenses help to see how. Global value chain theory treats carbon tariffs as a new kind of "environmental standard" [5]. The resource-based view suggests that low-carbon supply chain capabilities meet the VRIN criteria and can therefore turn a compliance burden into a competitive resource [6]. Stakeholder theory reminds us that emission cuts depend on core firms building collaborative governance with suppliers rather than acting alone. Institutional theory, finally, reads CBAM as coercive pressure that combines with normative and mimetic pressures to speed the diffusion of green practices [7]. Drawing on these perspectives, this paper builds a "policy constraint-strategic response-value creation" analytical framework.

### 2.2. EU CBAM policy analysis

CBAM is a centerpiece of the European Green Deal. By tying the carbon cost of imports to EU carbon market prices, it aims to prevent carbon leakage and push global production toward lower emissions. The policy has moved quickly and was officially launched for collection on January 1, 2026. The transitional phase covers six industries—steel, cement, fertilizer, aluminum, hydrogen, and electricity. Once collection is fully phased in, free allowances will fall from 97.5% in 2026 to zero by 2034. From 2028, the mechanism is expected to widen to over 180 product categories.

The payable CBAM charge is calculated as max{0, (product embedded emissions - free allowances - carbon price already paid in the third country)} × the EU ETS carbon price, and it covers both direct and indirect emissions. China is among the largest suppliers of CBAM-covered goods to the EU, so the additional bill for Chinese exporters could run into billions of euros a year.

### 2.3. Supply chain carbon emission accounting framework

Under the Greenhouse Gas Protocol (GHG Protocol) and ISO 14064, corporate emissions fall into three scopes. Scope 1 covers direct emissions from stationary and mobile combustion, industrial processes, and fugitive sources; these sit at the heart of CBAM's embedded-emission calculations. Scope 2 covers indirect emissions from purchased energy, which CBAM has already brought into

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scope for some industries. Scope 3 covers the wider value chain, and in consumer electronics and automobiles it typically represents 70% to more than 90% of total emissions. CBAM does not yet reach Scope 3 directly, but as EU carbon footprint requirements broaden, transparency about upstream emissions will matter more and more.

## 3. Case studies: Apple and BYD supply chain carbon management

### 3.1. Apple supply chain carbon management practices

Apple runs one of the most dispersed supply chains in the world. The structure is "globally dispersed, centrally coordinated". This lets Apple exploit comparative advantages wherever they arise, but it also makes carbon management extraordinarily complicated. Apple's emissions are heavily concentrated in Scope 3. In fiscal year 2023 its total carbon emissions were about 25 million tons of $CO_2$ equivalent; Scope 1 contributed only around 1%, Scope 2 about 5%, and Scope 3 roughly 94% [8]. Within Scope 3, purchased goods and services—mainly component manufacturing and raw material processing—accounted for 70% to 80% [8]. The implication is clear: Apple's carbon management has to focus upstream, working through supplier empowerment and procurement strategy rather than its own operations.

Apple's response rests on three pillars, anchored in the Supplier Clean Energy Program. The first is the program itself. By 2024, 320 suppliers had committed to using 100% clean electricity, accounting for over 95% of Apple's direct manufacturing expenditure [8]. If fully decarbonized, it could cut product embedded carbon emissions by about 50% to 60%, corresponding to CBAM tax savings of hundreds of millions of euros a year [8]. The second pillar is a circular strategy for materials, recycled aluminum alone can cut carbon emission intensity by roughly 95%. The third pillar is product-level carbon footprint optimization. Apple has pledged carbon neutrality across its entire value chain by 2030 [8].

None of this is without limits. Suppliers' progress on clean energy depends on national renewable infrastructure and policy environments, and it has been slow in some developing countries. Carbon management at sub-tier suppliers remains a weak spot. And Apple's model is built on high profit margins, which lower-margin manufacturers cannot simply copy.

### 3.2. BYD supply chain carbon management practices

BYD sits at the opposite extreme: a highly vertically integrated supply chain, with in-house research, development, and production for core components such as batteries, motors, electronic controls, and chips, and a self-production rate above 95% for the "three electric systems." This "vertically integrated, independently controllable" model gives BYD tight control over quality and cost—and, less obviously, a structural advantage in carbon management. Its total emissions in 2023 were about 15 million tons of $CO_2$ equivalent, split roughly 5% Scope 1, 15% Scope 2, and 80% Scope 3 [9]. The battery supply chain is the largest emission source, responsible for 40% to 50% of a vehicle's lifecycle carbon emissions [9].

BYD's strategy has two pillars. The first is to exploit vertical integration for decarbonization. Because it produces the three electric systems itself, BYD can act directly on the carbon intensity of core components: process optimization and energy substitution have cut the carbon intensity of battery production by 25% to 30%. The second pillar is a 2045 carbon neutrality roadmap for the entire value chain [9]. BYD plans to extend carbon neutrality to the whole value chain from 2040 to 2045.

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Vertical integration pays off directly under CBAM. Producing core components in-house makes carbon data far easier to gather and verify; fewer supply chain tiers mean lower tracing and management costs; and tight control over key suppliers lets decarbonization measures land quickly. Should CBAM expand to the new energy vehicle sector, BYD could save an estimated 600 million to 1 billion euros a year in carbon tariffs. The model has real costs, though: heavy fixed-asset investment, and concentrated exposure to technology shifts.

### 3.3. Comparative case analysis

The two cases differ on nearly every dimension. In structure, Apple's global dispersion captures local comparative advantages but makes carbon management complex and data hard to obtain, whereas BYD's vertical integration gives it controllability and transparency at the price of heavy fixed-asset investment and concentrated technology risk. In strategy, Apple practices "supplier empowerment," an approach suited to dispersed supply chains where the focal firm holds strong bargaining power. BYD practices "autonomous control," cutting emissions through internal management and technology upgrades, which works where core components can be self-produced and technology barriers are high. In CBAM response potential, Apple's supplier decarbonization, if carried through, could reduce embedded carbon emissions by 50% to 60%; BYD's integration-driven cuts of 20% to 30% would save 600 million to 1 billion euros a year once CBAM reaches its sector. What the comparison shows is that there is no single optimal model for supply chain carbon management under carbon tariffs. Still, the two models converge on the same foundations: both maintain full-scope carbon emission data systems, both write carbon constraints into supplier management and procurement decisions, both achieve substantive reductions through technological innovation and energy substitution, and both work to clear carbon neutrality roadmaps and timelines. These shared elements form the backbone of the supply chain design and optimization framework developed below.

## 4. Challenges facing Chinese enterprise supply chains under carbon tariffs

Apple and BYD show what good practice looks like. Most Chinese enterprises, however, are still at an early stage of responding to carbon tariff pressures, and four challenges stand out.

### 4.1. Supply chain carbon emission data acquisition and accounting challenges

Accounting for the embedded carbon emissions of CBAM-covered products means tracing back to raw material extraction and processing. Chinese manufacturing supply chains, however, tend to be "multi-tier, small-batch, and dispersed," and many suppliers are SMEs with no carbon data collection capability at all. Industry surveys suggest that fewer than 10% of Chinese manufacturers have set up supplier carbon emission data collection mechanisms [3]. CBAM requires the EU methodology, while Chinese firms have long worked with domestic guidelines, which increases the learning cost. China's verification and certification market is not yet mature, and supplier data may contain false reporting or concealment.

### 4.2. CBAM compliance cost and competitiveness balance dilemma

The steel industry is a typical example: China exported roughly 5 million tons of steel to the EU in 2024, and once CBAM is fully implemented the annual carbon tariff bill could reach 800 million to 1 billion euros, which is sufficient to erode profits, in a low-margin industry [3]. On the indirect

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side, firms must also pay for data management systems, consulting and verification, and process transformation, which adds further financial strain. For SMEs these fixed costs may simply exceed what they can bear, creating "compliance barriers" that accelerate market concentration. CBAM significantly raises the cost of China's high-carbon exports to the EU. Enterprises are caught in a dilemma between abandoning the EU market and staying while bearing heavy costs. China's carbon market currently covers only the power sector, and its carbon price sits far below EU levels, so exporters cannot offset CBAM charges through the domestic market and end up bearing "dual carbon costs."

### 4.3. Barriers to building supply chain collaborative emission reduction mechanisms

Power is asymmetric: core firms may transfer reduction costs downstream without offering incentive support—a "unilateral pressure" model that easily breeds supplier resistance and broken partnerships. Benefit sharing is missing: core firms may keep the brand premiums and market advantages that emission cuts bring while suppliers carry the bulk of the investment. Supplier capabilities lag: SMEs generally lack carbon management professionals, access to clean energy, and funds for low-carbon technology upgrades.

### 4.4. Global green trade rule fragmentation risks

Finally, the rules themselves are fragmenting. The UK plans to implement a similar mechanism in 2027, the US is discussing a "Clean Competition Act". Because these schemes differ in coverage scope, accounting methods, and carbon price benchmarks, enterprises must respond to several rule systems at once, and compliance costs multiply. Green trade rules are increasingly becoming a powerful tool for major power competition, and "green protectionism" poses a threat to the global supply chain layout of Chinese enterprises. The new battery regulations of the European Union have set strict requirements for aspects such as carbon footprint and the content of recycled materials, which has created technical barriers for Chinese enterprises.

## 5. Strategies for supply chain design and optimization under carbon tariffs

### 5.1. Building full-scope carbon emission data governance systems

Enterprises should build a "Green Ledger" system that integrates carbon emission data into core management information systems, and makes emissions "measurable, traceable, and verifiable." This calls for unified data collection templates and processes, quality control mechanisms, and integration of carbon data with production and financial data. An MRV (Monitoring, Reporting, Verification) system should underpin all of this. At the supply chain level, firms should share a carbon data platform. Firms should also take an active part in formulating industry carbon data standards and promote shared emission factor databases and platforms, which reduce compliance costs and raise the whole industry's data governance.

### 5.2. Optimizing supply chain structure and green technology innovation

Layout decisions should be re-examined through a carbon lens. Energy-intensive production belongs where renewable energy is abundant; final assembly belongs near end markets; and "nearshoring" or regionalized production deserves serious evaluation. On energy, firms can lock in long-term clean electricity through PPA power purchase agreements, and push suppliers toward renewable energy as

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well. On materials, procurement should prioritize low-carbon inputs and make carbon footprint a purchasing criterion, and raise the share of recycled and recyclable materials.

### 5.3. Establishing multi-level collaborative emission reduction mechanisms

Suppliers can be managed in ABC tiers. Class A suppliers (high emission, high impact) become strategic partners with joint reduction targets; Class B suppliers (medium emission) are managed through standardized procedures, reduction guidelines, and technical support; Class C suppliers (low emission) mainly need compliance and data collection. Carbon constraints should be written into contracts, and carbon performance should be integrated into the supplier evaluation system. Empowerment matters as much as pressure. Drawing on Apple's Supplier Clean Energy Program experience, core firms can train suppliers in carbon accounting and low-carbon production techniques [8]. Dynamic assessment should link carbon performance to procurement volume and cooperation depth, and publish regular supply chain carbon reports to keep stakeholders informed.

### 5.4. Actively participating in global carbon governance rule formulation

Enterprises should join the ISO, GHG Protocol, and other international standard-setting processes, convey their concerns to government through industry associations and chambers of commerce, giving negotiators practical grounding. Government, for its part, should expand the national carbon trading market to quickly bring in CBAM-covered industries such as steel, cement, and aluminum, promote international mutual recognition of carbon markets, and set up a dedicated carbon tariff response fund to ease the transition for affected enterprises. Multilaterally, China should press for transparency and non-discrimination in green trade rules under the WTO framework.

## 6. Conclusion

This paper has examined how supply chains should be designed and optimized under carbon tariffs. CBAM imposes real compliance cost pressure on Chinese exporters, but it also opens strategic room for firms that move early. Apple's experience shows that even a globally dispersed supply chain can be decarbonized when the focal firm invests in supplier empowerment [8]. BYD demonstrates the alternative path—vertical integration has reduced the emission intensity of its supply chain [9]. The two models differ in almost every respect, yet they rest on the same foundations: full-scope carbon emission data, carbon constraints embedded in procurement, technology- and energy-driven reduction, and clear carbon neutrality roadmaps. Chinese enterprises should build carbon data governance before regulators demand it, redesign supply chain layouts around carbon costs, replace unilateral pressure on suppliers with shared investment and shared benefits, and take part in shaping the rules. Government support remains indispensable. This study relies on publicly disclosed data from two companies, and its quantitative estimates are approximate; future research could extend the comparison to more industries and test the proposed framework with firm-level micro data. Supply chain design under carbon tariffs is a systematic project, and firms that treat carbon as a design variable rather than a tax bill can turn green transition pressure into industrial upgrading momentum and secure a favorable position in the green competition ahead.

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