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**Carbon Cost Information Collection and Consolidation from an ESG Perspective: A
Case Study of Kingfa**

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Abstract

Purpose: To examine how carbon cost information is collected and consolidated from an Environmental, Social, and Governance (ESG) perspective, using Kingfa Science & Technology as a case study. Specifically, the study aims to address the fragmentation of carbon-related physical and financial data across corporate systems and to construct a practical framework for carbon cost classification, attribution, and consolidation, thereby supporting the "dual-carbon" goals and responding to external pressures such as the Carbon Border Adjustment Mechanism (CBAM).

Methodology: This study adopts a single-case study approach based on publicly available secondary data, including Kingfa's annual reports (2022–2025), sustainability reports (2022–2025), and the China Carbon Market Development Report (2025). Data analysis employs trend comparison to track the co-movement of green business expansion and carbon intensity changes, and monetary conversion estimation using market reference prices to bridge physical energy consumption data with financial cost information. The analysis covers Scope 1 (direct emissions) and Scope 2 (energy indirect emissions), with Scope 3 addressed qualitatively by materiality, since public reporting provides it only as an unverified group-level aggregate that cannot be attributed to a cost object.

Findings: The study reveals that Kingfa's carbon cost information is highly fragmented across ESG, energy, production, R&D, and financial systems, with no effective mapping between physical emission data and financial cost data. Three major gaps are identified: (1) inconsistent classification and accounting boundaries of carbon costs; (2) lack of mapping between physical and monetary data; and (3) unclear cost objects and cost drivers. To address these gaps, the study proposes a carbon cost collection and consolidation mechanism comprising: (a) a three-tier classification framework dividing carbon costs into carbon emission costs, carbon abatement costs, and carbon risk costs; (b) a tripartite "cost object–cost driver–responsibility center" consolidation structure that clarifies cost attribution, allocation basis, and accountable entities.

Unique Contribution to Theory, Practice and Policy: The proposed mechanism enhances the traceability and managerial relevance of carbon cost information, filling the research gap on front-end information collection and consolidation from an ESG perspective. For practice, it provides Kingfa and similar manufacturing enterprises with a structured approach to integrating fragmented carbon data into managerial decision-making. For policy, the study offers empirical insights for regulators and standard-setters to consider enterprise-level carbon cost accounting frameworks that align with both domestic "dual-carbon" targets and international mechanisms such as CBAM.

Keywords: ESG, Carbon Cost Management, Carbon Information, Green and Low-Carbon

JEL Classification: Q56, Q52, M41, Q54

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INTRODUCTION

In September 2020, at the 75th session of the United Nations General Assembly, China pledged to the international community to strive to achieve carbon peaking before 2030 and carbon neutrality before 2060 (Chen & Luo, 2025). The announcement of this "dual-carbon" goal has exerted direct and urgent transformation pressure on chemical new material enterprises characterized by high energy consumption and high emissions. These firms feature complex production processes, large-scale energy consumption, and diversified carbon emission sources; their low-carbon transition performance affects not only their own competitiveness but also profoundly influences the overall carbon reduction process of the manufacturing sector. The ESG (Environmental, Social and Governance) concept provides an important management framework for corporate low-carbon governance. Within this framework, the environmental dimension requires firms to strengthen resource efficiency and carbon emission management, while the governance dimension requires the establishment of a sound information management system (Chen & Zhang, 2023).

Carbon cost management identifies, collects, consolidates, and allocates carbon costs including allowances, trading, taxes, and abatement investments for integration into business decisions and performance evaluation. From an ESG perspective, carbon cost management performs a key function: it connects carbon activity data with cost information and serves as the foundation for both ESG disclosure quality and carbon performance improvement. Empirical evidence from heavily polluting listed companies in China shows that an improved ESG disclosure level can significantly enhance carbon performance (Yin et al., 2023), and further confirms that better ESG performance can substantially reduce corporate carbon emission intensity (Xie et al., 2024). Therefore, integrating the ESG concept into carbon cost management can shift enterprises from passive compliance-based accounting to proactive, strategic management, simultaneously increasing the information content of ESG reports while unlocking abatement and cost-saving potential, thereby achieving a unity of environmental and economic benefits.

To date, academic research on carbon cost management has yielded notable results. Kaplan & Ramanna (2021) proposed the E-liability accounting system, advocating the use of cost accounting principles to measure carbon emissions and allocate them along the value chain to each product stage. Carbon accounting management issues in complex manufacturing supply chains have also attracted attention (Kaur et al., 2022). Existing studies have examined the implementation mechanisms of carbon accounting in daily enterprise operations (Carrión et al., 2025), while research on carbon sustainability disclosure continues to accumulate (Sharaf-Addin, 2024). Chinese studies mainly focus on corporate ESG performance, carbon information disclosure quality, and green transition outcomes, offering extensive exploration of enterprise carbon management practices.

Thus, while prior literature predominantly concentrates on accounting methods, disclosure systems, and ESG performance, carbon accounting is essentially "a process system for collecting, recording, and analyzing carbon-related information to serve stakeholders' decision-making" (Liew & Cao, 2024). However, the front-end information collection and consolidation

stage remains insufficiently studied. This gap is widest at the value-chain level. Scope 3 emissions which for manufacturing firms typically account by far the largest share of the total inventory originate from suppliers, logistics providers and product users, so the underlying activity data lie outside the reporting firm and can rarely be obtained, verified or expressed in monetary terms by the firm itself. Difficulties in Scope 3 data collection and verification still constitute a major barrier to corporate carbon accountability. This macro-level barrier shapes the empirical design of the present study rather than being set aside by it. Because the constraint is informational rather than conceptual, the tractable response is not to abandon Scope 3 but to investigate, at a level where evidence is obtainable, how a firm organises the carbon cost information it actually controls and where that information ceases to flow. Accordingly, this paper narrows its focus to the front-end stage of information collection and consolidation within carbon cost management and examines this stage within a single firm. Although this stage does not encompass the entire content of carbon cost management, it bridges carbon emission information and accounting information management, serving as a critical foundation for subsequent carbon cost measurement, control, and evaluation, and thus holds significant research value.

Kingfa Science & Technology is selected for this purpose because it exhibits the tension described above in an observable form. As a leading chemical new material enterprise, it publicly reports a group-level emission inventory in which Scope 3 accounts for the overwhelming majority of total emissions while Scope 1 and Scope 2 together account for a minor share, and it has set out explicit "dual-carbon" targets, green-product plans and environmental investment programmes. Its public reporting nevertheless remains concentrated on physical and ratio indicators, with little monetary measurement of carbon costs and limited category-level detail on value-chain emissions. Therefore, through the reports the company discloses, the boundary between what carbon cost information is collected, what is consolidated, and what is left uncollected can be observed directly. From an ESG perspective, we examine how that boundary is drawn. Prior research has made substantial progress in three respects: the standardization of accounting methods (for example, the establishment of product carbon footprint accounting standards such as ISO 14067 and GB/T 24067); data quality control (for example, data quality control schemes and traceability requirements covering the whole process of monitoring, collection, recording and review); and the design of disclosure systems (for example, the categorized disclosure requirements for Scope 1, 2 and 3 emissions under corporate sustainability disclosure standards, and the product carbon footprint labelling and certification system). Whereas prior research has largely resolved how emissions are inventoried and disclosed, it leaves open how that inventory is turned into cost information a manager can act on. The framework of "carbon cost classification–cost object–cost driver–responsibility center" supplies that procedure: each element answers one question disclosure rules do not what counts as a carbon cost, which object bears it, what drives it, and which unit answers for it, so that emission and cost data can be matched to the same object and charged to the same accountable unit.

LITERATURE REVIEW

This paper is primarily grounded in pollution cost internalization theory and strategic cost management theory. Pollution cost internalization theory is an economic theory based on externality theory, which holds that the social costs caused by negative externalities such as environmental pollution should be transformed into private costs borne by enterprises (Pigou, 2017). For market mechanisms to function effectively, institutional arrangements such as carbon trading and carbon pricing are required to convert external environmental costs into internal enterprise costs (Zhu et al., 2022). This theory provides the theoretical basis for enterprises to identify carbon-emission-related costs and transform them into measurable and manageable information. Strategic cost management theory achieves the coordination of cost systems with corporate strategy through structural cost management (organizational, product, and process design) and executional cost management (cost driver analysis and performance evaluation) (Anderson & Dekker, 2009).

These two theories provide a complementary analytical framework for the case analysis in this paper. Pollution cost internalization theory clarifies why carbon costs "need to be" incorporated into enterprise management—that is, external environmental costs should be transformed into internal cost constraints. Strategic cost management theory indicates how carbon costs "should be" systematically identified and managed—namely, by tracing them to the activities that cause them rather than by aggregating them at the corporate level. For Kingfa Science & Technology, carbon costs are closely related to its energy use, emission reduction, and low-carbon R&D activities, which makes the firm an appropriate setting in which to apply that logic. What the two theories jointly establish is therefore the direction of the analysis: carbon cost information must be traced to its source before it can support either management or governance. The mechanism through which this is accomplished is defined and applied in the sections that follow, and is consequently not anticipated here.

ESG governance and the informational basis of transparency. The two theories above explain why carbon costs should be internalized and how they should be managed, but neither addresses the governance dimension invoked by the title of this study. Within ESG frameworks, that dimension turns on the quality of the underlying information system rather than on the volume of disclosure (Chen & Zhang, 2023): disclosed environmental figures carry governance value only to the extent that they can be verified against the corporate activities that produced them. This condition is created by information systems rather than by reporting standards, since no standard can supply accountability that the underlying records do not contain. Treating collection and consolidation as a governance mechanism therefore closes the gap between the two theories and the ESG framing of the study: the procedure supplies the verifiable link between a reported emission and the corporate activity and organizational unit behind it. Transparency of this kind is produced upstream of disclosure, in the design of the information system, and is what allows ESG governance to operate on evidence rather than on assertion.

METHODOLOGY

Case Enterprise and Data Context

Kingfa Science & Technology (stock code: 600143. SH; hereinafter referred to as "Kingfa") was founded in 1993 and listed on the Shanghai Stock Exchange in 2004. It is the world's largest modified plastic manufacturer (Report, 2026). The company engages in the R&D, production, and sales of chemical new materials, with products covering, among others, modified plastics, fully biodegradable plastics, and eco-friendly high-performance recycled plastics, featuring a multi-variety and multi-base structure. Carbon emission sources include direct fuel combustion, purchased electricity, steam, and supply chain activities, giving the firm significant research value for decomposing carbon costs from the corporate aggregate level down to product-level cost objects. In terms of carbon strategy, the company aims to reduce greenhouse gas emissions per unit of product by 30% by 2030 compared with the 2022 baseline, and continuously advances its "Three 10-Million-Ton" circular economy plan. By 2025, green plastics, waste plastic recycling, and recycled plastics had respectively reached 30.94%, 27.20%, and 37.90% of their targets, while the use of clean energy such as photovoltaic power and green electricity was expanded. Although the publicly disclosed indicators have formed a relatively clear environmental target system, they mostly remain at the level of physical and ratio indicators, with a relative lack of monetary measurement of carbon costs, which needs further deepening.

Research Design and Analytical Techniques

This study adopts a single-case study approach (Yin, 2014) to investigate the collection and consolidation of carbon cost information from an ESG perspective. The case enterprise, Kingfa Science & Technology, is selected through purposive sampling: as the world's largest modified plastic manufacturer with complex production processes, multi-source carbon emissions, and a publicly disclosed "dual-carbon" target system, it offers high research value for decomposing carbon costs from the corporate aggregate level down to product-level cost objects. The case study design enables an in-depth examination of how carbon-related physical data and financial information are currently managed and where the gaps lie.

Data sources. This research is a secondary-data-based study. The data are drawn entirely from publicly available sources, including: (1) Kingfa's annual reports (2022–2025); (2) Kingfa's sustainability reports (2022–2025); (3) the China Carbon Market Development Report (2025); (4) market reference prices published by national and local government agencies, industry associations, electricity trading platforms, and other publicly accessible sources. All data used are at the aggregate corporate or business-segment level; no internal accounting records or non-public operational data were accessed.

Analytical techniques. Two principal analytical techniques are employed:

First, trend comparison analysis. Using the disclosed physical indicators (e.g., green plastic output, recycled plastic output, carbon emission intensity per unit of modified plastic) from 2022 to 2025, this study tracks the co-movement of Kingfa's green business expansion and

carbon intensity changes, and examines whether these physical trends align with the company's monetary investments in R&D and environmental governance.

Second, monetary conversion estimation. To bridge the gap between physical carbon data and financial cost information, this study converts energy consumption data (Scope 1 and Scope 2) into monetary terms using contemporaneous market reference prices for each energy type (natural gas, electricity, steam, coal water slurry, photovoltaic power, and green electricity). Since the actual procurement prices and transaction contracts for various energy types are not fully disclosed, the estimated energy costs do not represent actual transaction prices but serve as a reasonable proxy for assessing the order of magnitude of energy-related carbon costs. Similarly, implicit carbon costs are estimated using the national carbon price range of 69–105.65 CNY/tCO_{2e} to gauge potential future cost exposure under carbon pricing mechanisms.

One precaution follows from the use of proxy prices. Reference prices differ across energy types and may shift over the period covered, so the estimates may diverge from transacted values in a direction that public data cannot establish; for the same reason, the monetary split between Scope 1 and Scope 2 should not be expected to reproduce their physical emission shares.

The same treatment is not extended to Scope 3. Kingfa's public reporting discloses Scope 3 only as an aggregate physical quantity at the group level, without category-level detail, activity data, or monetary measurement, so it cannot be attributed to an identifiable cost object; any monetary conversion of it would rest on allocation assumptions that the underlying disclosure does not support. Scope 3 is therefore addressed qualitatively by materiality, entering the proposed framework as carbon risk cost rather than as a measured cost object. Under this criterion, Scope 3 is analysed by identifying those emission items that bear on the enterprise's cost management and by examining how these items are organised into carbon cost information.

Limitations. In addition to the boundaries set out above, the specific allocation of cost objects and cost drivers lacks verification from internal enterprise data, so the allocation rules proposed here remain untested against the firm's own records. Future research could incorporate internal business, financial and energy data, together with supplier-level Scope 3 primary data, to validate the proposed consolidation mechanism and to extend quantitative consolidation into value-chain carbon costs.

RESULTS

Analysis of the Current State of Carbon Cost Management

Green Business Expansion and Changes in Product Carbon Intensity

Table 1 shows that Kingfa's green business exhibits a continuous expansion trend rather than a short-term fluctuation. From 2022 to 2025, green plastic output increased by 129.87% and recycled plastic output by 104.31%, indicating that green products have gradually entered the business structure adjustment from isolated environmental initiatives. For carbon cost

management, this change implies that the company's carbon cost objects are shifting: traditional high-carbon products and green products may share R&D, equipment, and energy resources. If carbon costs are still accounted for at the overall corporate level, the cost transfer and abatement benefits brought by product structure adjustment cannot be identified.

Table 1: Output Trends of Kingfa's Green and Low-Carbon Products (2022–2025)

Year / Indicator (10,000 tons)	2022	2023	2024	2025
Green plastic output	13.46	21.92	27.41	30.94
Waste plastic recycled	20.00	21.80	26.85	27.20
Recycled plastic output	18.55	28.02	34.81	37.90

Data source: Compiled from Kingfa's 2022–2025 Sustainability Reports.

Table 2 further shows that the carbon emission intensity per unit of modified plastic decreased from 0.1847 tCO₂/t in 2022 to 0.1305 tCO₂/t in 2025, a cumulative decline of 29.36% over four years. The decrease was 28.70% in 2023, followed by a brief rebound of 1.60% in 2024, and a further decline of 2.47% in 2025. This change better reflects the improvement in resource efficiency of the production process than total emissions alone. However, the rebound in 2024 also suggests that carbon intensity does not decline monotonically, but is jointly affected by operational factors such as product mix, output, and production load. Therefore, carbon cost evaluation cannot rely solely on annual emission intensity as a result indicator; rather, it requires matching abatement investments with corresponding production objects.

Table 2: Changes in Carbon Emission Intensity per Unit of Modified Plastic (2022–2025)

Year	Carbon Emission Intensity (tCO ₂ /t)	Year-on-Year Change
2022	0.1847	—
2023	0.1317	-28.70%
2024	0.1338	1.60%
2025	0.1305	-2.47%

Data source: Compiled from Kingfa's 2022–2025 Sustainability Reports

Growth of Green Investments and the Foundation of Cost Information Formation

As shown in Figure 1, the scale of Kingfa's green investments increased in parallel with business expansion. R&D investment in 2025 grew by 90.15% compared with 2022, and environmental investment grew by 305.36%. While this set of changes cannot directly prove an improvement in carbon cost management efficiency, it reveals a fact of greater managerial value: the enterprise has invested substantial resources in R&D, environmental governance, and green transition, yet these investments have not been uniformly collected and consolidated according to abatement objects. According to Sharaf-Addin (2023), the effectiveness of a carbon management accounting system depends on its ability to systematically integrate carbon-related monetary and non-monetary information and track it across value chain stages.

Currently, Kingfa's green R&D expenditures remain only within the R&D cost system, and environmental investments only within the environmental statistics system. A carbon cost collection and consolidation mechanism that links ESG investments with specific abatement objects has not yet been formed. As a result, the enterprise only knows "how much has been invested," but cannot answer "how much abatement has been achieved" or "how much resource consumption corresponds to each unit of abatement."

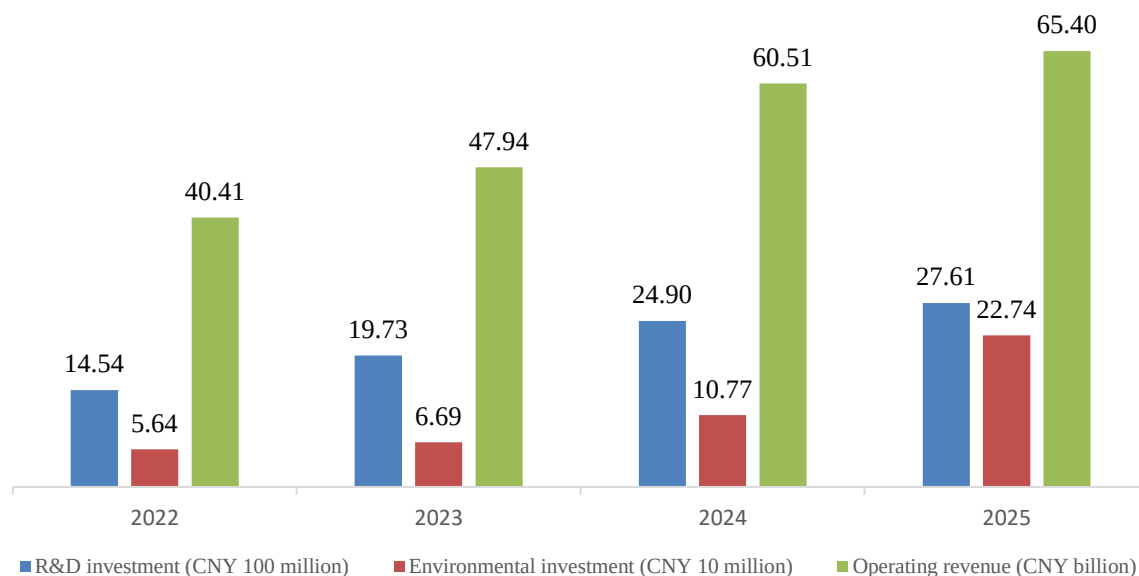


Figure 1: Statistics on Kingfa's R&D Investment, Environmental Investment, and Operating Revenue (2022–2025)

Data source: Compiled from Kingfa's 2022–2025 Sustainability Reports

The Cost Attributes of Energy Consumption

Physical data alone are difficult to directly support product cost control and business decision-making. Carbon cost management in the management accounting sense requires further linking the carbon emission formation process with enterprise resource consumption, cost expenditure, and business activities. Based on Kingfa's existing information, the company has disclosed greenhouse gas emissions by scope and obtained data related to energy consumption such as natural gas, electricity, steam, and coal water slurry. This means that the enterprise actually possesses the foundation for carrying out the transformation of carbon cost information.

Table 3: Monetary Measurement of Kingfa's Energy Consumption (2025)

Emission Scope	Emissions / tCO ₂ e	%	Energy Category	Consumption	Unit	2025 Market Reference Price	Estimated Cost (CNY)
Scope 1 Direct emissions	975,816.39	5.54%	Natural gas	193,250,876.62	standard m ³	4.2 CNY/m ³	811,653,681.80
			Diesel	724.76	ton	7100 CNY/ton	5,145,796.00
			Coal water slurry	281,400.75	ton	1000 CNY/ton	281,400,750.00
Scope 1 subtotal	975,816.39	5.54%					1,098,200,227.80
Scope 2 Energy indirect emissions	2,158,935.39	12.25%	Purchased electricity	324,775.55	10,000 kWh	0.46 CNY/kWh	1,493,967,530.00
			Purchased steam	873,260.74	ton	260 CNY/ton	227,047,792.40
			PV power (self-generated & self-used)	8,334.33	10,000 kWh	0.24 CNY/kWh	-20,002,392.00
			Green electricity procurement	7,015.10	10,000 kWh	0.39 CNY/kWh	27,358,890.00
Scope 2 subtotal	2,158,935.39	12.28%					1,768,376,604.40
Scope 3 Value chain emissions	14,483,619.81	82.18%					
Total emissions	17,618,371.59	100.00 %					

Data source: Compiled from national and local government agencies, industry associations, electricity trading platforms, relevant publicly available market data, Kingfa's 2025 Annual Report, and Kingfa's 2025 Sustainability Report. Note: PV power (self-generated & self-used) has no actual external purchase price. This paper uses the upper bound of the typical levelised cost of electricity (LCOE) of ground-mounted centralised photovoltaic power as the reference price to estimate its value in substituting for purchased electricity.

As Table 3 shows, in 2025, Kingfa's Scope 3 emissions accounted for 82.18% of total emissions, while Scope 1 and Scope 2 combined accounted for only 17.82%. This structure shifts the focus of carbon cost management: on-site production energy is a cost source directly controllable by the enterprise, whereas value chain emissions constitute a larger potential risk source (Wang & Hao, 2024; Wang & Liu, 2023). The former is suitable for inclusion in cost measurement by product, process, and responsibility center; the latter is more appropriate for gradual inclusion of risk information and supply chain management based on the materiality principle. Applying the procedure set out above, these estimates indicate order of magnitude rather than actual transaction prices.

$$C_i = Q_i \times P_i \quad (1)$$

Where Q_i , P_i and C_i correspond respectively to the Consumption, Market Reference Price and Estimated Cost columns of Table 3, with scope-level totals obtained by summation over the energy types within each scope.

Based on existing energy consumption data, the estimated Scope 1 energy cost totals approximately CNY 10.98 million, and the Scope 2 related energy cost is about CNY 1.768 billion, summing to approximately CNY 2.867 billion. Thus, the main management target of Kingfa's energy costs is the energy portfolio formed by electricity, natural gas, steam, coal water slurry, PV power, and green electricity procurement, and the pressure of energy expenditure is substantial. Among these, electricity remains the cost source most worthy of

priority attention. Therefore, PV self-generation and self-use and green electricity procurement should not be disclosed merely as ESG indicators, but should enter the joint evaluation of energy costs and abatement effects. In short, the main management target of energy costs is the energy portfolio formed by electricity, natural gas, steam, coal water slurry, PV power, and green electricity procurement.

(4) Carbon Emission Monetization and Carbon Cost Information Gaps

To further determine whether carbon emissions have acquired cost attributes, this paper estimates the implicit carbon cost pressure using a carbon price range of 69–105.65 CNY/tCO_{2e}.

$$ICC = E \times p_c \quad (2)$$

Where E is the emission volume of the scope concerned in tCO_{2e} and p_c the carbon price. Because p_c is a range rather than a point value, the result is reported as the interval [$E \times 69$, $E \times 105.65$] CNY, as set out in Table 4.

The implicit carbon cost corresponding to the combined Scope 1 and Scope 2 emissions is approximately CNY 216 million to 331 million, while that corresponding to total emissions is approximately CNY 1.216 billion to 1.861 billion. The fact that the Scope 3 amount is significantly higher than that of Scope 1 and Scope 2 further indicates that although value chain emissions may not directly generate current financial expenditures, they can create substantial future cost exposure.

Table 4: Estimation of Kingfa's Implicit Carbon Costs (2025)

Emission Scope	Emissions (tCO _{2e})	Carbon Price Range (CNY/ton)	Lower Bound of Implicit Carbon Cost (CNY 10,000)	Upper Bound of Implicit Carbon Cost (CNY 10,000)
Scope 1 Direct emissions	975,816.39	69-105.65	67,331,330.91	103,095,001.60
Scope 2 Energy indirect emissions	2,158,935.39	69-105.65	148,966,541.91	228,091,523.95
Scope 1 + 2	3,134,751.78		216,297,872.82	331,186,525.56
Implicit carbon cost		69-105.65		
Scope 3 Value chain emissions	14,483,619.81	69-105.65	999,369,766.89	1,530,194,432.93
Total implicit carbon cost	17,618,371.59	69-105.65	1,215,667,639.71	1,861,380,958.48

Data source: Compiled from the China Carbon Market Development Report (2025) and Kingfa's 2025 Sustainability Report

The transformation from carbon emission information to carbon cost information is not simply a matter of monetizing emissions; it also requires clarifying the formation sources, cost objects, and allocation bases of carbon costs. However, due to different data generation logics across systems—the ESG system centers on emission boundaries and performance indicators, the energy system on consumption volumes, the financial system on accounting items and cost centers, and the production system on products and processes the enterprise as a whole lacks a

unified coding scheme. Without a unified caliber for carbon cost information, data cannot be matched to the same cost object.

Problems in Kingfa's Carbon Cost Management

Unlike traditional production costs, carbon costs also include costs arising from energy consumption, green R&D, equipment upgrades, and resource recycling. Therefore, establishing a systematic carbon cost collection and consolidation system is an important foundation for enterprises to achieve refined carbon cost management (Christensen et al., 2021). Existing studies point out that current corporate carbon accounting practices still face the problem of separation between carbon emission data and financial data, making it difficult for enterprises to accurately evaluate the economic effects of abatement measures (Huang, 2024). In practice, enterprises face several problems in carbon cost management, which are prominently manifested in the following three aspects.

First, carbon cost information is fragmented and the accounting caliber has not been unified. Kingfa is able to disclose multiple types of group-level data emissions, energy, R&D, environmental protection, and green products yet struggles to further derive unit carbon costs for products. The reason is that these data are not generated according to the same cost logic. Taking green products as an example, from 2022 to 2025, green plastic and recycled plastic output increased by 129.87% and 104.31%, respectively, but the simultaneously increased R&D and environmental investments (with growth rates of 90.15% and 305.36%, respectively) remain scattered across their respective systems and have not been allocated down to the product level along with output. The ESG department focuses on emission boundaries and target achievement; the energy department focuses on physical consumption of electricity, natural gas, and steam; the R&D department focuses on project investment; the finance department recognizes expenses according to accounting standards; and the production department organizes data by production line and product. Since various data lack a unified carbon cost coding scheme, a single abatement activity may appear in different statistical systems simultaneously, yet cannot be consolidated into a complete cost object. Research on the lack of unified methods for measurement and reporting in carbon management accounting implementation suggests that for a multi-product chemical enterprise like Kingfa, simply collecting more data will not automatically improve cost information quality without establishing a unified classification and coding system.

Second, there is no effective mapping channel between physical carbon emission data and financial cost data. Although the enterprise already has the capability to disclose total emissions and energy consumption, the existing information hardly supports attribution analysis of abatement effects for specific energy-saving and technology-transformation projects, nor can it accurately measure unit carbon costs at the specific product level. In 2025, the monetized energy costs of Scope 1 and Scope 2 are estimated to have reached CNY 2.867 billion, and the corresponding physical consumption (natural gas, electricity, steam, etc.) has also been disclosed. However, because the two types of data belong to different statistical calibers and have not been broken down by production line or process, they cannot be matched to the same cost object. The deep-seated root of this dilemma is that the "physical measurement system" and the "monetary measurement system" operate independently without coupling. Existing international research in carbon accounting also shows that if carbon information cannot achieve the same granularity as financial information and be embedded at the transaction level, it is difficult for it to truly integrate into the management decision-making process (Distler et

al., 2025). In other words, if physical data cannot be effectively embedded in the value creation logic, its managerial relevance will be greatly reduced.

Third, the cost objects and cost drivers corresponding to carbon information are unclear. By compiling Kingfa's disclosed data, the carbon emission intensity per unit of modified plastic decreased from 0.1847 tCO₂/t in 2022 to 0.1305 tCO₂/t in 2025, while green plastic output increased by 129.87% and recycled plastic output by 104.31% over the same period, indicating a significant product mix change. It can be seen that Kingfa has many business segments and product types, and differences in raw materials, energy structure, and process routes across products result in marked heterogeneity in carbon costs. Allocating carbon costs evenly by operating revenue or output would compress the true resource consumption differences of different products into a single average; conversely, allocating entirely by functional department would leave joint investments such as R&D, technology transformation, and environmental protection facilities without clear beneficiary objects. Therefore, unclear cost objects and cost drivers are the direct reason why carbon cost information cannot enter product- and process-level management.

Corporate carbon management tools do not operate independently of traditional management control systems; rather, they need to be adjusted, linked, and reconfigured in organizational practice. For Kingfa, this means that carbon cost management should not start from scratch, but should be embedded by leveraging existing cost centers, project management, and energy metering systems. Only when cost objects are clearly defined, cost drivers are explainable, and responsibility centers can obtain corresponding information does carbon cost truly acquire management control attributes.

Optimization Pathways for Kingfa's Carbon Cost Management from an ESG Perspective

(1) Clarifying Carbon Cost Classification and Accounting Boundaries

The first level concerns carbon cost classification. Given that Kingfa's existing data mainly come from different systems finance, energy, production, R&D, and ESG a unified classification with a principle of layered boundaries should be adopted as a starting point. The mainstream academic approach classifies carbon costs into carbon emission costs and carbon abatement costs. However, existing research points out that the social cost of carbon is insufficient to address the systemic risks of climate change, and proposes "risk cost of carbon" (RCC) as an external cost that needs to be internalized (Chen & vanderBeek, 2019). Therefore, this paper first divides carbon costs into carbon emission costs, carbon abatement costs, and carbon risk costs. The fundamental purpose of this classification is to accurately match the financial accounting caliber: emission costs are recognized in current profit or loss (income statement); abatement costs are recognized as capital expenditures or R&D expenses (balance sheet / cash flow statement); and risk costs enter stress testing and impairment provisions (information disclosure). Second, costs that can be directly traced to products, processes, or projects should be prioritized for direct allocation, while indirect costs that cannot be directly traced should be allocated based on reasonable cost drivers. Specifically, carbon emission costs mainly record cost information formed by energy use and carbon compliance. Carbon abatement costs focus on recording investments directly related to emission reduction, such as green R&D, energy-saving retrofits, green energy, environmental governance, and resource recycling. Carbon risk costs serve as scenario information in management accounting, reflecting potential future cost exposure arising from carbon prices, green trade rules, and value

chain constraints. These three types of information are distinct yet can be consolidated under the same cost object, providing a unified caliber for subsequent cost analysis.

The second level concerns accounting boundaries, that is, determining which carbon costs should be included in product- and process-level accounting. In terms of emission boundaries, Scope 1 and Scope 2 have high data availability and should be prioritized for cost allocation. Due to the dispersed data sources of Scope 3, it should be gradually incorporated by selecting key raw materials, transportation, and product use stages based on the materiality principle. This approach avoids over-precision caused by insufficient Scope 3 data quality, while preventing enterprises from focusing solely on their own production and neglecting value chain risks.

(2) Establishing a Tripartite "Cost Object–Cost Driver–Responsibility Center" Consolidation Mechanism

Two concepts underpin the rules that follow. A cost object is the entity to which a cost is ultimately charged; a cost driver is the factor that causes the cost to be incurred and therefore supplies the basis on which it is allocated. Costs are thus identified through their drivers and then allocated to objects according to those drivers, which is what allows a consolidated figure to remain traceable to the activity that produced it.

Carbon costs from energy should be allocated using actual energy consumption as the cost driver (Zhang et al., 2022). Direct energy sources such as natural gas and coal water slurry are allocated according to actual consumption at the production line or process level; purchased electricity and steam can be allocated to production lines based on metering or allocation coefficients. Energy-saving retrofit costs can be allocated based on equipment operating hours, beneficiary output, or pre- and post-retrofit energy consumption changes. Green R&D costs are directly allocated to R&D projects; when project outcomes can be clearly traced to specific products, they are further allocated to those products. Transportation carbon costs can be allocated based on shipment weight, distance, and transport mode.

Compared with allocation by revenue or output, the value of the cost driver approach lies in explaining why costs are incurred. This is particularly important for Kingfa, as the same ton of product may have different carbon emission levels due to differences in process routes and energy structures. Only when allocation rules match the reasons for resource consumption do unit product carbon costs become meaningful for internal comparison.

Carbon cost management also requires further clarifying responsibility boundaries and establishing the mapping among cost objects, cost drivers, and responsibility centers, as shown in Figure 2, so that carbon costs scattered across production, procurement, R&D, and environmental governance can be consolidated according to actual resource consumption. The production and operation responsibility center mainly corresponds to production objects such as production lines, processes, and equipment. Using actual energy consumption, output, and equipment operating hours as primary cost drivers, it consolidates energy carbon costs such as natural gas, electricity, and steam into specific production stages, and further measures product carbon costs. The procurement and supply chain responsibility center corresponds to cost objects including raw materials, products, suppliers, and transportation tasks. Using purchase volume, material volume, and "shipment weight $\times$ distance $\times$ transport mode" as primary cost drivers, it consolidates carbon costs from raw material procurement and transportation, providing the basis for Scope 3 carbon cost accounting. The R&D innovation responsibility center corresponds to green R&D projects and their outcomes. Using R&D hours and project

investment amount as cost drivers, it attributes green R&D expenditures to specific projects; when outcomes can be clearly traced to products, costs are further collected into those products. The investment and environmental governance responsibility center corresponds to energy-saving retrofits, environmental governance, and carbon emission monitoring projects. Using project investment, operating hours, beneficiary output, and abatement volume as cost drivers, it consolidates related investments into specific projects or beneficiary production stages. Thus, a collection mechanism of "clear attribution of cost objects, explanatory allocation by cost drivers, and control undertaken by responsibility centers" is formed, further generating carbon cost information across dimensions such as products, production processes, and projects, providing a basis for internal reporting, cost comparison, and abatement decision-making.

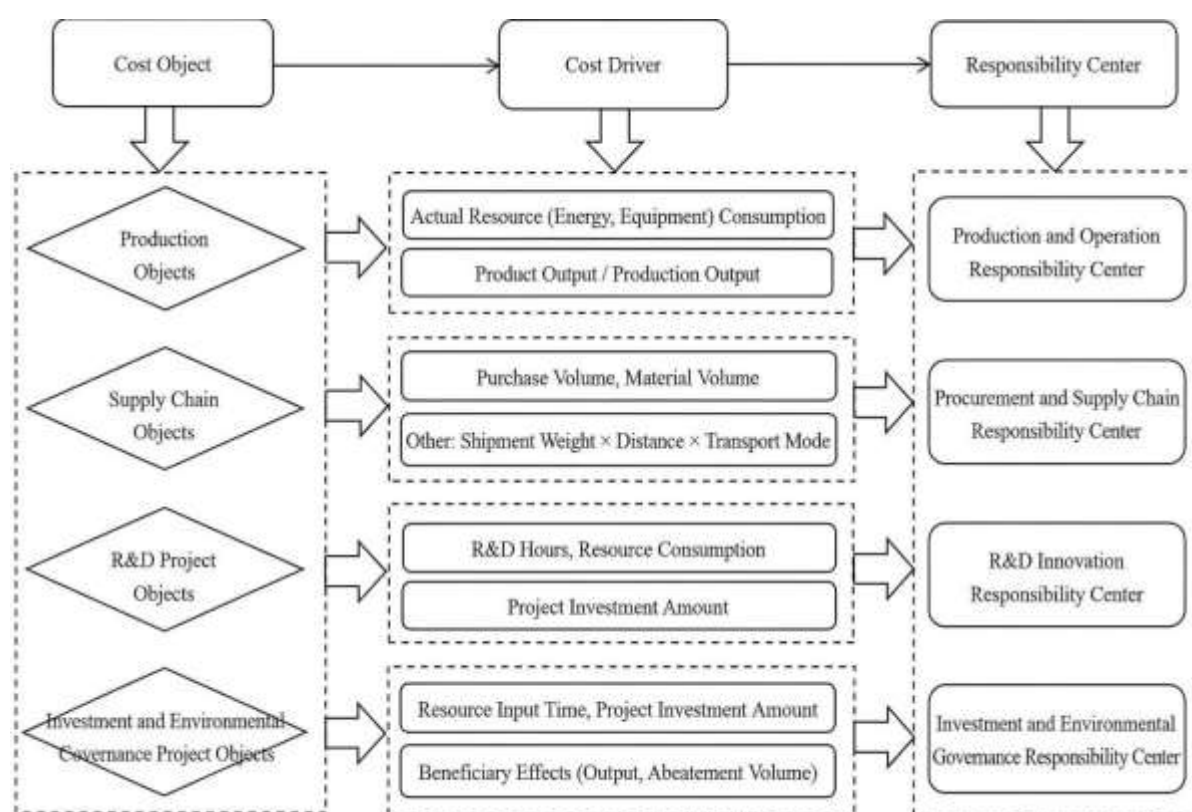


Figure 2: Carbon Information Consolidation Framework of "Cost Object–Cost Driver–Responsibility Center"

The finance department and the ESG management department do not act as independent responsibility centers, but instead undertake accounting and governance support functions, responsible for cost amounts, coding, and reporting, as well as emission boundaries, emission factors, and data quality, respectively. Each responsibility center conducts cost accounting and allocation based on unified cost objects and cost drivers, forming a responsibility chain of "clear attribution of cost objects, explanatory allocation by cost drivers, and control undertaken by responsibility centers," as shown in Figure 2, providing a basis for subsequent internal reporting, performance evaluation, and abatement decision-making.

CONCLUSION AND IMPLICATIONS

Taking Kingfa Science & Technology as a case, this paper focuses on the information collection and consolidation stage within carbon cost management. The study finds that Kingfa has established a sound foundation in ESG governance and green low-carbon practices, with certain achievements in carbon emission management, green R&D, and environmental investment. However, carbon emission, energy, production, R&D, and financial information remain scattered across different management systems. Physical and monetary measurements lack effective linkage, making it difficult for carbon costs to be allocated down to the product, production line, and project levels. Therefore, what the enterprise needs to address at present is not simply increasing carbon information disclosure, but establishing a unified carbon cost information processing logic.

To address these problems, this paper constructs an information collection and consolidation mechanism of "carbon cost classification–cost object–cost driver–responsibility center." Taking production lines, processes, products, and R&D projects as cost objects, and energy consumption, output, R&D hours, shipment weight and distance as cost drivers, it sets up four types of responsibility centers—production and operation, procurement and supply chain, R&D innovation, and investment and environmental governance so that carbon costs can be clearly attributed, reasonably allocated, and assigned to management control. This mechanism not only helps improve Kingfa's existing carbon cost management, but also provides a reference for manufacturing enterprises with multiple production links and complex energy structures.

This paper still has certain limitations. As it mainly relies on publicly disclosed information, the quantitative analysis is restricted to Scope 1 and Scope 2, with Scope 3 addressed only as risk exposure rather than consolidated cost; the specific allocation of cost objects and cost drivers also lacks verification from internal enterprise data, and some carbon cost estimates are constrained by data availability. Future research could combine actual business, financial, and energy data, together with supplier-level Scope 3 primary data, to further verify the carbon cost allocation results across different cost objects, and continuously improve the linkage mechanism between carbon cost information and business decision-making.

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