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Innovation of Sustainable Management Models Oriented towards Circular Economy in Manufacturing Enterprises: Micro Practices Based on Industrial Chain Collaboration

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KEYWORDS

ABSTRACT

Manufacturing enterprises;

Sustainable management;

Circular economy;

Industrial chain synergy;

Digital management and control;

Against the backdrop of dual carbon goals and stricter global green trade rules, manufacturing enterprises face micro-challenges like insufficient industrial chain synergy and cost-benefit imbalance in sustainable management transformation. Focusing on their circular economy pain points, this paper explores three innovative paths: circular production system, digital control platform, and stakeholder co-governance, verified by three typical enterprise cases and visual data. The study shows that connecting industrial chain synergy links enables enterprises to balance economic and environmental benefits. It provides implementable guidance for similar enterprises and micro-perspective reference for sub-sector research, with future extension to electronic and chemical manufacturing.

INTRODUCTION

Global climate change and green trade barriers are profoundly reshaping the development logic of manufacturing enterprises. The United Nations 2030 Agenda for Sustainable Development explicitly sets the goal of doubling global resource efficiency by 2030. The European Union's Carbon Border Adjustment Mechanism (CBAM) and new battery regulation Domestic policy documents such as the dual carbon goals and the implementation plan for carbon peaking in the industrial sector impose strict requirements on the resource utilization efficiency and carbon emission levels of manufacturing enterprises. Compared with the macro perspective of pan-industry and pan-subject in traditional enterprise management research, this paper strictly locks the research scope to the manufacturing enterprise as a sub-subject, and focuses on the specific problem of industrial chain synergy dilemma in its circular economy transformation, starting from micro practical scenarios to provide theoretical and practical references for enterprises to break through transformation bottlenecks.

At present, the traditional management model of manufacturing enterprises, which is centered on profit maximization, is difficult to adapt to the demands of green transformation: On the one hand, the EU's carbon border adjustment mechanism requires the full life cycle carbon footprint of manufactured goods such as steel, machinery, and aluminium products to be accounted for. Data from 2023 shows that about 37% of China's mechanical products exported to the EU have increased compliance costs by an average of 12% due to non-compliance with carbon accounting standards; On the other hand, the circular transformation of manufacturing enterprises requires the linkage of upstream raw material suppliers and downstream recycling enterprises, and the uneven environmental protection levels at each link of the industrial chain have led to only 21% of manufacturing enterprises being able to achieve sustainable management throughout the entire process.

In practice, manufacturing enterprises generally face micro problems such as scattered upstream scrap metal recycling

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channels and long payback periods for initial investment in circular transformation, rather than industry-wide predicaments at the macro level. Based on this, this paper systematically explains the innovative path of circular economy-oriented sustainable management through embedded data comparison tables, mechanism logic diagrams, in-depth analysis of typical cases, etc., and provides practical operational solutions for the transformation of manufacturing enterprises.

1. Specific challenges of manufacturing enterprises' circular economy transformation

The challenges of manufacturing enterprises' circular economy transformation are concentrated in three dimensions: cost-benefit imbalance, disconnection of cross-border standards, and disruption of industrial chain synergy. The specific manifestations and core impact data of each challenge are quantified through the following three-line table.

1.1. Short-term cost-benefit imbalance in circular transformation

Manufacturing enterprises need to invest special funds in upgrading specialized equipment and building recycling systems to advance the circular economy transformation, and the returns from such investments are significantly lagging. The 2023 special research data of the domestic machinery industry association is presented in Table 1, which intuitively reflects the transformation pressure of enterprises of different scales.

Enterprise size (Annual output value)	Average investment per set of recycling/smelting equipment (ten thousand yuan)	The proportion of enterprises under cash flow pressure
< 50 million yuan	80-150	0.89
50 million - 200 million yuan	150-300	0.76
200 million - 500 million yuan	300-500	0.61
More than 500	500-800	0.43

million yuan		
Industry average	268	0.72
Enterprise size (Annual output value)	Payback period (years)	Proportion of green outcome enterprises without premium
< 50 million yuan	45752	0.92
50 million - 200 million yuan	45720	0.85
200 million - 500 million yuan	45691	0.71
More than 500 million yuan	45659	0.53
Industry average	3.2	0.81
Enterprise size (Annual output value)	Proportion of companies with low willingness to transform	
< 50 million yuan	0.78	
50 million - 200 million yuan	0.62	
200 million - 500 million yuan	0.45	
More than 500 million yuan	0.22	
Industry average	0.57	

Table.1. Survey of Investment and Payback Period for Circular Transformation of Small and Medium-sized Manufacturing Enterprises

Take a small mechanical processing enterprise with an annual output value of 30 million yuan as an example. To build a closed-loop recycling system for metal waste, it purchased a set of intelligent sorting equipment worth 1.2 million yuan and a set of medium-frequency melting furnaces worth 1 million yuan, with a total investment of 2.2 million yuan, accounting for 35% of the enterprise's annual working capital. After the transformation was completed, the enterprise could recycle about 5 tons of scrap metal per month, saving only 12,000 yuan in raw material

procurement costs. Based on this calculation, it would take at least 4.6 years to recoup the investment. At the same time, the company's recycled metal parts, lacking a unified green certification in the industry, cannot apply for product premium from downstream customers. In 2023, the sales price of its green products was on par with that of traditional products, significantly weakening the company's initiative to transform.

In addition, it is difficult to quickly translate the environmental benefits of the circular transformation into market revenue. According to research, 81% of manufacturing enterprises said their green production achievements could not be used as a basis for product premium due to the lack of authoritative certification, and some enterprises even experienced short-term capacity reduction due to transformation, resulting in an awkward situation of increased environmental costs and reduced profits.

1.2.The cross-border carbon accounting standards are disconnected from the actual operations of enterprises

Export-oriented manufacturing enterprises need to adapt to both domestic and overseas carbon accounting rules. The differences in accounting scopes of different standards pose significant compliance challenges for enterprises, as shown in Table 2.

Accounting dimensions	Domestic carbon accounting standards for mechanical manufacturing	Eu CBAM carbon accounting standards
Accounting scope	Production end	Full life cycle
Accounting indicators	Only direct carbon emissions are counted	Direct, indirect carbon emissions
Data traceability requirements	The enterprise records independently and reports annually	Full chain data is traceable and uploaded in real time to the EU system
Accounting dimensions	Additional costs for businesses due to differences in diameters	Additional costs for businesses due to differences in diameters

Accounting scope	Additional raw materials, link data collection teams are required, and labor costs increase by 20% to 30%	Additional raw materials, link data collection teams are required, and labor costs increase by 20% to 30%
Accounting indicators	To access carbon emissions data from power suppliers, the cost of data connection increases by 15%	To access carbon emissions data from power suppliers, the cost of data connection increases by 15%
Data traceability requirements	A data traceability platform needs to be built, and the technical investment will increase by 500,000 to 1,000,000 yuan	A data traceability platform needs to be built, and the technical investment will increase by 500,000 to 1,000,000 yuan
Accounting dimensions	Cross-border certification fees increase by 80,000 to 150,000 yuan per year	Cross-border certification fees increase by 80,000 to 150,000 yuan per year

Table.2. Comparison of Differences in Carbon Accounting Standards for Manufacturing Enterprises at Home and Abroad

Take a company mainly engaged in the export of construction machinery as an example. Its carbon footprint per excavator in 2023, calculated based on domestic standards, was 82 tons of CO₂. However, when calculated based on the EU CBAM standards, it needs to take into account upstream iron ore mining, inter-provincial transportation of raw materials, and indirect emissions from purchased electricity. The carbon footprint per excavator rose to 117 tons of CO₂, exceeding the EU carbon tariff exemption threshold. To meet compliance requirements, the company hired an additional six carbon accounting specialists and established a dual-track accounting system. In 2023, related management costs increased by 1.2 million yuan, and due to inconsistent certification standards, its scrap metal recycling results could not be recognized in cross-border trade. In 2023, orders for green products in the EU market decreased by 18% compared with the previous year.

1.3. Disruption of the chain of upstream and downstream circulation and coordination

The circular economy transformation of manufacturing enterprises is highly dependent on industrial chain synergy, but the current shortcomings in the capabilities of upstream and downstream entities make it difficult to break through the resource closed-loop chain. The specific case data of a certain auto parts enterprise is presented in Table 3.

Types of recycled materials	Planned usage ratio	Actual usage proportion
Recycled aluminium	0.35	0.06
Recycled plastic	0.2	0.12
Recycled steel	0.4	0.28
Overall	0.32	0.15
Types of recycled materials	Core blockage reasons	The impact on cycle modification
Recycled aluminium	The purity of raw materials from upstream suppliers is only 95%	Only 17% of the recycling target has been achieved
Recycled plastic	The recycling channels are scattered and the supply stability is insufficient	Production requires additional reserves of traditional raw materials, increasing costs by 5%

Recycled steel	The carbon footprint in the smelting process exceeds the standard	The carbon footprint of the product does not meet the requirements of downstream automakers
Overall	There is a mismatch in environmental protection capabilities between upstream and downstream	The idea of a closed loop of resources across the entire industrial chain has not been implemented

Table 3. Statistics on the reasons and impacts of the obstruction in the use of recycled materials in a certain auto parts manufacturing enterprise

The company launched a circular transformation in 2022, planning to increase the overall use of recycled materials to 32%, but upstream recycled aluminum suppliers, lacking high-precision purification technology, provided raw materials with excessive impurity content that could not meet the mechanical performance requirements of automotive parts, forcing the company to abandon its 70% recycled aluminum procurement plan. Downstream recycling enterprises, due to their outdated sorting technology, were unable to distinguish different grades of waste plastics, resulting in intermittent supply of recycled plastics. The enterprises had to stockpile additional traditional plastic raw materials, and the related storage costs increased by 230,000 yuan in 2023. Ultimately, the company's actual use of recycled materials in 2023 was only 15%, the completion rate of the recycling transformation target was less than 50%, and the idea of a closed-loop of resources throughout the entire industrial chain was completely dashed.

2. Sustainable management innovation path oriented towards circular economy for manufacturing enterprises

In response to the three major challenges mentioned above, this paper proposes a three-dimensional innovation path of

resource closed-loop production system, customized digital control platform, and stakeholder precision co-governance mechanism. The effectiveness of each path is verified in combination with in-depth cases and three-line data comparison tables.

2.1. Build a resource closed-loop production system in the manufacturing process

Based on the production characteristics of manufacturing enterprises, build a circular economy management system from the three core links of raw material procurement, production processing, and waste recycling. In the procurement of raw materials, establish a priority procurement mechanism for recycled raw materials, sign long-term cooperation agreements with compliant recycling enterprises, and specify purity and carbon footprint standards for recycled metals and plastics; In production and processing, clean production technologies are promoted, such as the introduction of dry cutting in mechanical processing enterprises to reduce cutting fluid consumption and the use of medium-frequency furnace smelting technology in foundry enterprises to reduce coal consumption; In the waste recycling process, build an in-plant classification recycling network for specialized treatment of waste metals, waste cutting fluids, etc., and link up with downstream professional recycling institutions to achieve resource regeneration of production waste.

The metal waste closed-loop system of the Heavy machinery manufacturing group in Minsk, Belarus, is a typical case, and its specific implementation steps and achievements are presented in Table 4

Core indicators	2020 (Before implementation)	2023 (post-implementation)
Metal scrap recovery rate	0.22	1
Raw material procurement costs	\$120 million per year	\$92 million per year

Carbon emissions from the production process	182,000 tons of CO ₂ per year	121,000 tons of CO ₂ per year
Recycled billet usage share	0	0.42
Orders in the EU market	12,000 sets per year	18,000 sets per year
Core indicators	Extent of change	
Metal scrap recovery rate	Increase by 78 percentage points	
Raw material procurement costs	Down 23.3%	
Carbon emissions from the production process	Down 33.5%	
Recycled billet usage share	Increase by 42 percentage points	
Orders in the EU market	A 50% increase	

Table 4. Comparison of Core Indicators Before and After the Implementation of the MTZ closed-loop system in Belarus

In 2020, MTZ metalworking waste reached 18%, raw material procurement costs accounted for 62% of production costs, and carbon emissions at the production end exceeded EU export standards. In 2021, the company invested \$4.2 million to purchase three German-made SORT-3000 intelligent spectral sorting equipment and two ZP-10 10-ton medium-frequency induction melting furnaces. Among them, the intelligent sorting equipment can precisely classify scrap steel, scrap iron and scrap copper within 3 seconds through spectral analysis, with a sorting accuracy of 99.8%. Far more than 75% of traditional manual sorting; The

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medium-frequency melting furnace, which uses electromagnetic induction heating technology, is 35% more energy-efficient than traditional coal-fired furnaces and emits no sulfur dioxide.

In terms of process construction, MTZ first sets up classified waste bins in each production workshop, and AGV robots transport the waste to the sorting workshop for secondary sorting; The sorted scrap metal is then sent into the medium-frequency melting furnace, where alloying elements are proportioned according to product requirements to melt into qualified billets, and the remelting recovery rate of scrap steel reaches 98.5%. Finally, the recycled billets are fed into the original production line and processed into core components for loaders and excavators. At the same time, the company established a mechanical property testing system for recycled billets. From 2021 to 2023, the quality inspection pass rate of recycled billets reached 99.9%, on par with that of primary billets. The environmental benefits of the system also received the EU green certification, and its recycled metal parts could enjoy a 5% product premium in the EU market in 2023.

A domestic mechanical processing company also introduced dry cutting instead of traditional wet cutting. In 2023, the company's purchase cost of cutting fluid decreased by 80%, the cost of hazardous waste treatment of waste cutting fluid was reduced by 95%, the tool life was doubled, and production efficiency was increased by 18%.

2.2.Implement a digital control platform exclusive to manufacturing enterprises

Build customized digital sustainable management platforms tailored to the characteristics of manufacturing enterprises' production processes to address data discontinuity in the transition to a circular economy. The platform integrates three core modules: the first is the carbon emissions accounting module, which connects to production equipment sensors to collect energy consumption data in real time and automatically convert it into carbon emissions data, and is compatible with domestic and EU accounting standards; The second is the supplier management module, which inputs data such as the proportion of recycled raw materials and carbon emission levels of upstream suppliers, establishes A dynamic rating system, and prioritizes cooperation with A-level suppliers; Third, the resource closed-loop traceability module records data such as scrap metal

recycling volume and recycling rate to ensure closed-loop traceability of resources.

The achievements of the platform construction cases of domestic Zhejiang HZ-WH automotive wheel hub manufacturing enterprises are presented in Table 5.

Core indicators	2022 (before implementation)	2023 (after implementation)
Share of recycled raw materials in the supply chain	0.15	0.38
Carbon account for labor costs	450,000 yuan per year	120,000 yuan per year
Product carbon footprint	12.5kgCO ₂ per piece	9.8kgCO ₂ per piece
Share of A-class supplier partnerships	0.22	0.68
Green orders for automakers	800,000 per year	1.25 million per year
Core indicators	Extent of change	Extent of change
Share of recycled raw materials in the supply chain	Up 23 percentage points	Up 23 percentage points
Carbon account for labor costs	Down 73.3%	Down 73.3%
Product carbon footprint	Down 21.6%	Down 21.6%
Share of A-class supplier partnerships	Increase by 46 percentage points	Increase by 46 percentage points
Green orders for automakers	Up 56.25 percent	Up 56.25 percent

Table.5.Comparison of Indicators Before and after the implementation of the Digital Control Platform for Zhejiang HZ-WH Enterprises

Hz-wh started building a digital control platform in October 2022, with a total investment of 3.8 million yuan, due to the inability to accurately calculate the carbon footprint of its products and the lack of transparency in environmental data of its suppliers, which led to supply disruption to automakers such as Tesla and BYD. The platform is connected to the energy consumption sensors of 120 production equipment in

the workshop, with a carbon accounting data error rate of less than 3%, and can generate a dual-standard carbon footprint report with one click; Its supplier management module enters data from 86 upstream suppliers and automatically prioritizes A-level suppliers; The resource closed-loop traceability module generates full-chain traceability codes for scrap aluminum, recycled aluminum ingots and wheel hubs, and customers can scan the codes to query the relevant data. In 2023, the company successfully passed Tesla's green supply chain audit through the platform and became its core hub supplier, increasing annual orders by 300,000 and generating additional revenue by 120 million yuan.

2.3. Build a precise stakeholder co-governance mechanism for manufacturing enterprises

The sustainable management of manufacturing enterprises requires the collaboration of targeted stakeholders, which can be specifically divided into three types of collaborative objects: First, connect with local industrial and information technology departments, apply for special funds for circular transformation, and participate in the formulation of industry green standards; 2 Provide product carbon footprint reports to downstream customers and customize low-carbon components to achieve product premium; Third, build waste recycling sites with recycling enterprises, clarify recycling prices and raw material purity standards, and ensure a stable supply of recycled raw materials.

The results of the co-governance practices and the return on investment of domestic Luoyang LY-BC bearing manufacturing enterprises are presented in Table 6.

Project Categories	Specific amount/data	Earnings/recoveries
Total investment in circular transformation	4.2 million yuan	-
Government special subsidies	2.6 million yuan	Covering 61.9% of the initial investment

Premium for recycled steel bearing products	8% per set	520,000 units sold from June to December 2023, with a premium revenue of 6.24 million yuan
Procurement costs of recycled raw materials	12% lower per ton than primary steel	In 2023, 850,000 yuan was saved in procurement costs
Input payback period	-	6 months, net income 3.49 million yuan

Table 6. Comparison of Investment and Revenue Recovery in Circular Transformation of Luoyang LY-BC Enterprises
When LY- BC launched its circular transformation in 2022, it faced three major problems: insufficient funds, unstable supply of recycled raw materials, and no premium for green products. By connecting with the Industry and information Technology Bureau of Luoyang City, it received a special subsidy of 2.6 million yuan for green factories and participated in the formulation of the "Certification Standard for Recycled Steel Components in the Machinery Industry of Henan Province". In 2023, its recycled steel bearings received the first batch of green certifications in Henan Province; Provide full life cycle carbon footprint reports to automakers such as FAW and SAIC, customize products with 45% recycled steel and 28% lower carbon footprint than traditional bearings, sign green purchase agreements with an 8% product premium and annual purchase volume of no less than 500,000 sets; In collaboration with three specialized recycling enterprises in Luoyang, a scrap steel recycling site was established, with an agreement that the recycling price would be 5% higher than the market price and the raw material purity would be $\geq 99.7\%$. The recycling enterprises invested 800,000 yuan to purchase purification equipment for this, and LY-BC promised an annual scrap steel purchase volume of no less than 2,000 tons. In 2023, the company's market share of recycled steel bearings in the domestic market rose to 18%, and it entered the European market, increasing its annual export volume by 8 million yuan.

3.Implementation paths for sustainable management and industrial chain synergy in manufacturing enterprises

To facilitate the large-scale implementation of the three-dimensional innovation path, a guarantee system needs to be constructed at three levels: standard alignment, technological breakthroughs, and talent cultivation. The relevant core contents are presented in the three-line table.

3.1. Promote the alignment of carbon accounting standards in the manufacturing industry

In response to the pain points of cross-border compliance for manufacturing enterprises, industry associations will take the lead in promoting the alignment of domestic standards with the EU CBAM rules, and the core alignment dimensions are presented in Table 7.

Alignment dimensions	Domestic standard optimization direction	Key points of alignment with the EU CBAM
Scope of accounting	Extend to the supply chain end	Define the accounting boundaries for each link in the entire life cycle
Data traceability	Establish an electronic data traceability system	Connect to the EU CBAM data upload port
Mutual recognition of certification	Promote mutual recognition of domestic green certifications with EU EPD certifications	Unify the certification indicators for the utilization rate of recycled materials
Accounting tools	Develop dual-standard compatible carbon accounting software	The software data format complies with EU requirements
Alignment dimensions	Domestic standard optimization direction	Key points of alignment with the EU CBAM
Alignment dimensions	Responsible entities for implementation	Responsible entities for implementation
Scope of accounting	China Machinery Industry Association	China Machinery Industry Association

Data traceability	Industry leaders, technology companies	Industry leaders, technology companies
Mutual recognition of certification	State Administration for Market Regulation (SAMR)	State Administration for Market Regulation (SAMR)
Accounting tools	University research teams	University research teams
Alignment dimensions	Responsible entities for implementation	Responsible entities for implementation

Table.7.Comparison Table of Core Dimensions for Alignment of Carbon Accounting Standards in the Manufacturing Industry

In 2023, the China Machinery Industry Association led the establishment of a carbon accounting standard connection working group for the manufacturing industry, in collaboration with 12 leading enterprises and 5 research institutions, to formulate the "Guidelines for Carbon Accounting in Machinery Industry with Dual Standards", clarifying the accounting boundaries between the production end and the supply chain end, and developed the first carbon accounting software compatible with dual standards, which was promoted in 30 pilot enterprises in 2024. The average cost of cross-border compliance for enterprises has decreased by 25 percent.

3.2. Focus on green technology breakthroughs in manufacturing

Manufacturing enterprises should collaborate with research institutions to focus on breakthroughs in sub-technologies of the circular economy. The core research directions and responsible entities are presented in Table 8.

Technical fields	Specific directions to tackle	Responsible parties
Metal scrap sorting	Multi-category intelligent sorting technology, impurity purification technology	Leading enterprise, Materials College of the university

Low-carbon smelting	High-frequency induction melting, hydrogen energy melting technology	Research institutes, smelting equipment enterprises
Performance enhancement of recycled materials	Recycled aluminium, a technology for enhancing the mechanical properties of steel	Enterprise research and development center, university laboratory
Digital control	Full-chain real-time monitoring technology for carbon footprint	Technology companies, manufacturing enterprises
Technical fields	Specific directions to tackle	Responsible parties
Metal scrap sorting	Multi-category intelligent sorting technology, impurity purification technology	Leading enterprise, Materials College of the university
Technical fields	Expected breakout time	Application value
Metal scrap sorting	2025	Sorting accuracy increases to 99.9%
Low-carbon smelting	2026	Reduce carbon emissions from the smelting process by 40 percent
Performance enhancement of recycled materials	2025	The performance of recycled materials meets the standards of virgin materials
Digital control	2024	Carbon accounting efficiency increased by 80%
Technical fields	Expected breakout time	Application value

Metal scrap sorting	2025	Sorting accuracy increases to 99.9%
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Table.8.Key Technological Research and Development Directions and Responsible Entities for Circular Economy in the Manufacturing Field

At the same time, a manufacturing industry circular economy technology sharing platform was established within the industry. Leading enterprises such as XCMG and Sany Heavy Industry opened up 18 mature technological achievements, helping small and medium-sized enterprises reduce technology research and development costs by more than 60% in 2023. A small machinery company completed its circular economy transformation with an investment of only 800,000 yuan through technology sharing, saving 2 million yuan compared to independent research and development.

3.3. Cultivate compound sustainable management talents for manufacturing enterprises

Universities and enterprises need to work together to build a system for cultivating compound talents. The specific courses and training modules are presented in Table 9.

Training subjects	Course Training module	Core content
Colleges	Fundamentals of Mechanical Manufacturing	Traditional manufacturing processes, circular production techniques
	Green management and carbon accounting	Dual carbon policy, carbon accounting standards, circular economy theory
	Industrial chain collaboration practices	Supply chain environmental management, stakeholder co-governance

Manufacturing enterprises	Carbon footprint training for production team leaders	Workshop carbon emissions accounting, low-carbon process operation
	Green supplier assessment training for procurement personnel	Supplier environmental rating, recycled raw material standard review
	Target Competence	
Training subjects	The ability to integrate manufacturing processes with circular technology	
Colleges	Carbon accounting and sustainable management capabilities	
	Industrial chain synergy capabilities	
	Low-carbon control capabilities for front-line production	
Manufacturing enterprises	Green supply chain management capabilities	
	Green product market conversion capabilities	
	Target Competence	

Table.9.Curriculum System for Cultivating Compound Sustainable Management Talents in the Manufacturing Industry

In 2023, Henan University of Science and Technology launched an interdisciplinary experimental class in mechanical manufacturing and green management, with an initial enrollment of 50 students. The curriculum incorporates practical content such as carbon accounting practice and recycled material technology, and builds internship bases with enterprises such as LY-BC. In 2024, the first batch of interns completed three carbon accounting optimization plans for enterprises, saving 150,000 yuan in costs.

Conclusion

This paper discards the macro-level generalization research and focuses on the micro-level pain points of manufacturing enterprises' circular economy transformation. It clarifies the specific problems that enterprises face in circular transformation, such as cost-benefit imbalance, cross-border standard disconnection, and industrial chain synergy disruption, and systematically presents the resource closed-loop production system and customized digital control platform by embedded in 9 sets of three-line data comparison tables. A three-dimensional innovative path for the precise co-governance mechanism of stakeholders, and the feasibility of the path was verified through in-depth cases of three typical enterprises.

The research shows that the sustainable management transformation of manufacturing enterprises requires a circular economy as the core approach, linking up the upstream and downstream of the industrial chain with multiple entities such as policies and markets, to achieve a balance between efficient resource utilization and carbon emission control at the micro operational level. Among them, the resource closed-loop production system can achieve 100% recycling and regeneration of waste materials and reduce raw material costs by more than 20%; Customized digital control platforms can solve the problem of multi-standard carbon accounting and increase the proportion of recycled materials in the supply chain by more than 20 percentage points; The precise co-governance mechanism of stakeholders can quickly recover transformational investment and achieve market premium for green products.

This study not only provides implementable transformation solutions for manufacturing enterprises, but also offers a micro-perspective reference for sustainable management research in sub-sectors. In the future, it can be further extended to different manufacturing sub-sectors such as electronic manufacturing and chemical manufacturing to explore differentiated circular economy management models.

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