An Empirical Analysis of the Construction of ESG Performance Evaluation System and the Improvement of Green Operation Efficiency in Health Industry Enterprises

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ABSTRACT Under China's dual-carbon goals, this study constructs an industry-specific Environmental, Social, and Governance evaluation system for health industry enterprises and examines how ESG performance affects green operation efficiency. The framework integrates the technical requirements of healthcare services with environmental governance, product responsibility, and corporate compliance, forming a hierarchical indicator system covering environment, society, and governance dimensions. Based on expert consultation, analytic hierarchy process weighting, and empirical analysis of listed health industry enterprises, the study evaluates ESG performance and green operation efficiency from resource utilization and process efficiency perspectives. The results show that overall ESG performance has a significant positive effect on green operation efficiency. Environmental performance provides the most direct path for improving resource efficiency, while technological innovation and digital investment serve as important mechanisms for operational optimization. The findings provide empirical evidence and practical guidance for improving operational efficiency, reducing environmental impact, and promoting sustainable development in the health industry under green transformation requirements.

INDEX TERMS health industry, ESG performance, green operation efficiency, evaluation system, sustainable development

I. INTRODUCTION

AGAINST the backdrop of global climate efforts and the national dual-carbon strategy, Environmental, Social and Governance (ESG) concepts have evolved into a crucial competitive advantage and a key valuation dimension for listed companies within the health sectors. For enterprises, integrating environmental stewardship and social responsibility into core operations has become essential for securing capital market recognition and maintaining a sustainable industrial position under the ecological civilization framework. In 2022, the State-owned Assets Supervision and Administration Commission of the State Council established the Bureau of Social Responsibility and the Central Enterprises ESG Alliance, signifying a new, top-down, and vigorous development of ESG in China. The health industry, including pharmaceuticals, medical equipment, and medical services, plays a critical role in safeguarding public health and safety and therefore possesses strong social responsibility attributes. However, the health industry faces unique environmental challenges, including relatively high energy and water consumption in R&D, production, and operation, and higher emissions of toxic substances and medical waste compared to the manufacturing sector. Furthermore, it faces social constraints related to the availability of traditional medicines, data security, and commercialization. Consequently, health industry enterprises face several challenges in implementing ESG practices, including information silos, ambiguous evaluations criteria, and unclear operational outcomes of ESG initiatives. Therefore, establishing an ESG performance evaluation system with Chinese contextual characteristics and conducting empirical research on the mechanisms through which ESG performance improves green operation efficiency can provide both theoretical support and practical guidance for Chinese enterprises. In addition, it can offer policy insights for regulators to promote industrial green transformation and support the formulation of relevant sustainability policies. This issue therefore has both significant theoretical value and important practical implications. The main purpose of this paper is to answer the following three progressively deeper questions: First, how to build a scientific ESG performance evaluation system for Chinese health industry enterprises that also takes

into account the characteristics of the industry? Second, how to measure the green operation efficiency of Chinese health industry enterprises? Third, what role does the ESG performance of Chinese enterprises play and how does it affect their green operation efficiency? Answering the above questions is the third relatively specific task of this paper: (1) Based on the latest materials at home and abroad, internationally accepted frameworks and domestic guiding documents such as the "Guidelines for Enterprise ESG Performance Evaluation", design a complete set of ESG evaluation indicators from top to bottom for key issues in the Chinese health industry (involving drug safety, green pharmaceutical manufacturing, business ethics, etc.). The second task is to analyze the connotation of green operation efficiency and carry out measurable indicator measurement from the two levels of utilization efficiency and process efficiency. The final task involves using empirical measurement methods to estimate the impact of ESG performance on the green operation efficiency of health , specifically calculating the leakage of factors related to the establishment of new production methods, such as technological innovation and medical digital investment. These verification analyses facilitate the construction of technical bottlenecks for practical operations, ensuring that sustainable governance directly optimizes the modernization of both medical services and manufacturing processes.

II. RELATED WORK

Focusing on corporate ESG performance, multiple dimensions and levels of research perspectives have been presented. Bin-Feng et al. [1] studied the impact of external environmental uncertainty on corporate investment decisions regarding corporate ESG activities. Arvidsson and Dumay [2] analyzed the improvement in the quantity and quality of ESG reports disclosed by Swedish multinational corporations and the changes in corporate ESG performance over the past 10 years. Shu and Tan [3] used data from Chinese listed industrial enterprises from 2010 to 2019 to define and measure a model to examine the impact of regulatory policy risks of carbon management on the company's ESG performance and the two transmission paths of financing constraints and loan costs, and conducted empirical tests. Fan et al. [4] examined how specific ESG indicators influence corporate ESG ratings. Zhang and Yang [5] reviewed how artificial intelligence enhances corporate operational efficiency, strengthens risk management, and supports technological innovation that contributes to improved ESG performance. The green finance reform pilot zone and other policies are important measures for China to promote the green transformation of the economy. Gao et al. [6] compared the changes in ESG performance of enterprises in the pilot zone and similar enterprises outside the zone before and after the implementation of the policy. Chen et al. [7] found that global economic uncertainty generally inhibits the ESG investment and performance of enterprises. Wang et al. [8] examined whether strong ESG performance can act as an effective signal that reduces information asymmetry, attracts investors, and improves stock liquidity. Yi et al. [9] compared the adjustment of ESG strategies of the enterprises under review before and after enforcement. Feng and Yuan [10] analyzed the relationship between changes in shareholding ratio and subsequent improvement in enterprise ESG performance, and used Granger causality test or instrumental variable method to infer the causal relationship. This paper takes the health industry as the research object, and is committed to building an ESG performance evaluation system that fits its industry characteristics, and empirically tests the impact mechanism of this performance on the green operation efficiency of enterprises, in order to provide theoretical basis and decision-making reference for the sustainable transformation of the health industry.

III. METHODS

A. CONSTRUCTION OF ESG PERFORMANCE EVALUATION SYSTEM FOR THE HEALTH INDUSTRY

The ESG evaluation system in this study is based on the "1+N" model proposed in the Guidelines for Enterprise ESG Evaluation issued by the China National Standardization Administration and also draws on industry reference frameworks such as the Huaxia Wind Power ESG Dandelion Index. However, this design incorporates more industry-specific content, prompting a clearer definition of the scope and objectives of any ESG evaluation. This study first employed the Delphi method, with 15 experts from corporate executives, academia, and industry associations screening and revising the initial indicators after two rounds of expert consultation until a consensus was reached. Based on this, the Analytic Hierarchy Process (AHP) was used to determine the indicator weights. Experts conducted pairwise comparisons of indicators at each level, ensuring that the consensus ratio (CR) of all judgment matrices was below 0.1 to guarantee the logical consistency of weight allocation. Corporate leaders, academics, and industry experts independently scored and evaluated the indicators according to the scoring criteria, reaching a consensus to ensure the scientific validity and robustness of each evaluation indicator. The tiered indicators follow a hierarchical structure of objective layer–criterion layer–solution layer. The objective layer represents overall ESG performance; the criterion layer comprises the three core dimensions of Environment (E), Society (S), and Governance (G); and the solution layer is further subdivided into specific evaluation indicators highly relevant to the healthcare industry. The environmental dimension of the three main indicators not only considers energy use and greenhouse gas emission reduction, but also includes green pharmaceuticals and control of chemical pollutants, such as the production of volatile organic compounds in drug manufacturing, the proportion of highly toxic wastewater, or the impact on biodiversity; the social dimension focuses on products and public health, such as the incidence of adverse drug reactions, the proportion of new product R&D and innovation expenditures, or specific practices in promoting

product adoption in economically disadvantaged regions; the governance aspect tends to focus on ESG integration strategies, examining whether companies have effective accountability mechanisms to maintain compliance with ESG principles, and how companies establish supply chain plans that consider ESG-related risks; the common feature of the three is that the goal is to seek a balance between standards and healthcare services in their respective regions [11,12]. Table 1 reflects the consensus of the expert panel on the relative importance of indicators at each level, highlighting the priority of core industry issues in the evaluation system:

The weighting of ESG in the healthcare industry is determined by expert subjective judgment. The environmental indicator high-risk wastewater treatment rate carries a weight of 9%, reflecting the stringent water pollution regulations faced by pharmaceutical and medical device companies. Resource utilization and restrictions on the production of certain restricted pollutants also contribute to high raw material consumption per unit of product and high VOCs utilization. The indicator adverse event rate of drugs and medical devices has the highest weight among social factors, with a weight of 10%, the highest among all tertiary indicators. This demonstrates that one of the most important social attributes of the healthcare industry is caring for life and health and ensuring the safety of products and drugs. The highest weight in the governance factor is assigned to the clear definition of the board's responsibilities and authority regarding ESG oversight (12%), indicating that a sound governance structure and strong commitment from senior management are prerequisites for effective ESG activities implementation. Third-party assurance (from third-party auditors) receives a significant weight, further demonstrating the importance of third-party assurance to ESG indicators and the significant implications of publicly disclosing ESG indicator levels. In other words, these weights successfully integrate the general ESG framework with the healthcare industry's specific environmental risks (such as special waste), social responsibility, and healthcare industry-specific governance characteristics (such as supply chain ethics), providing a context for healthcare industry-specific performance after assessing ESG performance.

B. MEASUREMENT OF GREEN OPERATION EFFICIENCY

Measuring green operations efficiency requires considering both environmental outcomes and the operational processes used to achieve them. This study explores how to construct a framework for measuring the efficiency of green operations from two dimensions. Dimension one examines the efficiency of resource utilization and the effectiveness of organizations in managing their environmental impact. This is measured through quantitative indicators, such as using absolute values and intensity indicators to measure the environmental impact per unit of economic output. Dimension two improves the efficiency of the operational processes themselves through green management and technology applications. This is reflected in the following indicators: 1) CNC machining rate of production equipment; 2) Total labor productivity; 3) First-pass yield (reducing rework and scrap); 4) Operating costs per 10,000 CNY of revenue. To achieve a comprehensive assessment, this study draws on integrated indicators such as Business Overall Performance and Sustainability Effectiveness (BOPSE) and constructs a composite index combining Overall Equipment Effectiveness (OEE) with environmental compliance performance for case study analysis. Data mainly comes from publicly disclosed ESG reports, social responsibility reports, annual financial reports, and environmental information disclosure reports of the sample companies [13,14].

C. EMPIRICAL ANALYSIS MODEL AND DATA COLLECTION

To examine the impact of ESG performance on green operational efficiency, this study proposes the following core hypotheses: H1: Corporate overall ESG performance has a significant positive impact on green operational efficiency; H2: The environmental (E) performance sub-dimension has the most direct and strong driving effect on resource and environmental efficiency; H3: Corporate R&D and digitalization investment play a partial mediating role in the process of ESG improving operational efficiency. The empirical model will employ a panel data multiple regression model. This paper uses the overall score or individual indicators of green operational efficiency (e.g., carbon emissions per unit of revenue) as the dependent variable, and the overall ESG score and the scores of each sub-dimension of E, S, and G as the core independent variables, while controlling for variables such as company size, debt-to-equity ratio, net profit margin, years since listing, R&D intensity, and digital capital expenditure. To test the mediating effect, the study introduces R&D intensity and digital capital expenditure as mediating variables after controlling for the aforementioned variables and applies stepwise regression and bootstrap methods for path analysis. In terms of sample selection, this study focuses on A-share and Hong Kong-listed healthcare companies, covering the period from 2020 to 2024, and constructs balanced panel data. At the same time, it selects 1–2 typical companies with excellent ESG performance (e.g., subsidiaries of Sinopharm Group) for longitudinal case studies, and reveals the dynamic management process behind the quantitative model through interviews and internal data analysis.

IV. RESULTS AND DISCUSSION

A. DESCRIPTION OF THE CURRENT STATUS OF ESG PERFORMANCE AND GREEN OPERATION EFFICIENCY IN THE HEALTH INDUSTRY

The evaluation of sample companies shows that the ESG performance of China's healthcare industry varies considerably across firms, although the overall trend indicates gradual improvement. Most large listed companies are considered to have normal corporate governance. However,

TABLE 1. Examples of Key Indicators and Weights in the ESG Performance Evaluation System for the Health Industry

Primary indicators	Secondary indicators	Example of a Level 3 Indicator	Weight (%)
Environment (E)	Green pharmaceuticals and pollution control	Raw material consumption per unit product	8.5
	Green pharmaceuticals and pollution control	VOCs emission intensity of process	7.0
	Green pharmaceuticals and pollution control	High-hazard wastewater treatment rate	9.0
	Energy and Climate Change Management	Comprehensive energy consumption per unit of revenue	6.5
	Energy and Climate Change Management	Greenhouse gas emission intensity	6.0
Society (S)	Product Liability and Public Health	Adverse event rate of drugs/medical devices	10.0
	Product Liability and Public Health	Proportion of investment in innovative drug research and development	8.0
	Employee Development and Supply Chain Ethics	Employee safety training coverage	5.0
	Employee Development and Supply Chain Ethics	Supply Chain ESG Risk Review Rate	4.5
Governance (G)	ESG Strategy and Governance Structure	Clarity of ESG regulatory responsibilities of the board of directors	12.0
	Risk Management and Compliance	Anti-corruption training coverage	7.5
	Information disclosure and transparency	ESG Report Third-Party Verification	9.0

there are large disparities in ESG environmental and social performance. Leading companies in environmental performance have established clear greenhouse gas reduction plans and are constructing corresponding green factories; however, pharmaceutical raw-material production remains widely distributed across multiple sub-sectors, and the average energy consumption and emission intensity across these sectors, as well as the average levels across individual industries, are far higher than industry standards. In terms of social performance, product quality and safety management are generally well maintained within the healthcare industry; however, improvements are still needed in the transparency of clinical and product development information, the availability of rare disease drugs, and supply chain processing standards—specifically, in terms of long-term transparent disclosure and practice. The results on green operational efficiency indicate a strong association with firm size, technological capability, and the age structure of corporate assets. To more specifically characterize the above features, this paper uses data from 50 sample companies from 2020 to 2024 to conduct descriptive statistics on the core indicators, and the results are shown in Table 2.

The descriptive statistics in Table 2 strongly support the conclusions regarding the overall situation, internal differentiation, and significant deficiencies. The average ESG performance score (65.2) is higher than the median (62.4), and P75 (72.8) indicates that some companies within the industry perform exceptionally well in ESG performance, resulting in an average ESG performance score higher than 65.2 (overall improvement). The ESG performance scores exhibit a clear pattern of differentiation: the social (S) average score is the highest (70.1), followed by governance (G) at 66.9, while the environmental (E) average score is only 58.7, indicating significant deficiencies in green production and pollution control (significant deficiencies). Furthermore, the indicators further support the characteristic of internal differentiation. The standard deviations of the indicators and the large gap between P25 and P75 (e.g., the P25 value (1.60) for comprehensive energy consumption per unit of revenue is significantly higher than the P75 value (0.90)) reveal a significant divergence in practice levels among companies, with some companies exhibiting excellent resource efficiency while others still have considerable room for improvement.

B. EMPIRICAL RESULTS ON THE IMPACT OF ESG PERFORMANCE ON GREEN OPERATION EFFICIENCY

The panel data regression analysis results strongly support the main hypotheses of this study. Table 3 shows the standardized regression coefficient estimates of ESG integration and performance of each dimension on the two types of green operation efficiency.

As shown in Table 3, overall ESG performance has a significant positive impact on both types of green operational efficiency—resource efficiency and environmental efficiency ($p < 0.01$) (coefficients are 0.421 and 0.387, respectively). This supports Hypothesis 1 (H1). The environmental (E) dimension of ESG has the most significant and direct impact on resource efficiency and environmental efficiency (coefficient = 0.502, $p<0.01$), which supports Hypothesis 2 (H2). Although social (S) and governance (G) performance dimensions also have a significant positive impact on operational efficiency, governance performance also shows a strong impact on operational efficiency (coefficient = 0.401, $p < 0.01$), indicating that a sound governance system is key to optimizing processes and improving overall organizational efficiency. Among the control variables examined, there is a small negative correlation between company size and its resource and environmental efficiency, which may be because large companies are currently in the process of transforming existing operations/facilities.

C. MEDIATING EFFECT ANALYSIS OF TECHNOLOGICAL INNOVATION AND DIGITAL INVESTMENT

To test hypothesis H3, namely that R&D investment and digitalization investment play a mediating role in improving ESG performance and green operational efficiency, this study used the Bootstrap method (5000 repeated samplings) to test the mediation effect. The results are shown in Table 4.

Table 4 shows that: (1) R&D intensity plays a significant

TABLE 2. Descriptive Statistics of Key Indicators of ESG Performance and Green Operation Efficiency of Sample Enterprises in the Health Industry

Indicator Categories	Indicator Name	Average value	Median	P25 (quantile)	P75 (quantile)	Standard deviation
ESG Overall and Dimensional Performance (Score)	ESG Overall Performance Score	65.2	62.4	55.1	72.8	12.3
	Environmental (E) dimension performance score	58.7	56.3	48.9	65.0	11.8
	Social (S) Dimension Performance Score	70.1	68.5	62.0	76.3	9.5
	Governance (G) Dimension Performance Score	66.9	66.0	59.2	73.1	10.2
Representative indicators of green operation efficiency	Energy consumption intensity (tce / 10,000 CNY revenue)	1.15	1.08	1.60	0.90	0.38
	Greenhouse gas emission intensity (t CO2e / 10,000 CNY revenue)	2.83	2.65	3.70	2.10	0.91

TABLE 3. Regression Results of the Impact of ESG Performance on Green Operation Efficiency in the Health Industry

Variable	Dependent variable: Resource and environmental efficiency (overall score)	Dependent variable: Operational process efficiency (overall score)	Significance
ESG Overall Performance Score	0.421	0.387	***
Environmental (E) Performance Score	0.502	0.256	***
Social (S) Performance Score	0.185	0.298	**
Governance (G) Performance Score	0.234	0.401	***
Control variable: Firm size	-0.089	0.112	*

Note: * $p < 0.10$: significant at the 10% level; ** $p < 0.05$: significant at the 5% level; *** $p < 0.01$: significant at the 1% level.

TABLE 4. Results of the mediating effect test between R&D investment and digitalization investment

Path	Effect Type	Effect Value	SE	95% CI	Conclusion
Total ESG Score → R&D Investment → Green Operational Efficiency	Indirect Effect	0.086*	0.045	[0.012, 0.188]	Partial Mediation
	Direct Effect	0.335***	0.092	[0.155, 0.516]	
	Total Effect	0.421***	0.101	[0.223, 0.619]	
Total ESG Score → Digital Investment → Green Operational Efficiency	Indirect Effect	0.072*	0.039	[0.008, 0.165]	Partial Mediation
	Direct Effect	0.349***	0.089	[0.174, 0.523]	
	Total Effect	0.421***	0.101	[0.223, 0.619]	
Environmental (E) Performance → R&D Investment → Green Operational Efficiency	Indirect Effect	0.102**	0.048	[0.021, 0.210]	Partial Mediation
	Direct Effect	0.400***	0.095	[0.214, 0.586]	
	Total Effect	0.502***	0.104	[0.298, 0.706]	

partial mediating role in the impact of overall ESG performance, especially environmental (E) performance, on green operating efficiency (indirect effects of 0.086 and 0.102, respectively, with confidence intervals excluding 0). This indicates that companies with excellent ESG performance, especially those focused on environmental management, tend to increase R&D investment, thereby improving resource efficiency and operational efficiency through technological innovation (such as green processes and energy-saving equipment). (2) Digital capital expenditure also plays a significant partial mediating role in the impact of overall ESG performance on green operating efficiency (indirect effect of 0.072). This means that leading ESG companies are more likely to invest in digital and intelligent solutions (such as energy management systems and production process monitoring), which directly optimize process control and management, thereby improving operational efficiency. In summary, hypothesis H3 is supported by empirical data. This finding reveals an important mechanism through which ESG performance influences operational efficiency: excellent ESG performance drives companies to make special investments in technological innovation and digitalization, and these investments are the key path to improving green operating efficiency.

D. DISCUSSION

This study has multiple theoretical implications. First, it empirically supports and expands the "Lean-Green" synergy theory, demonstrating that in the healthcare industry, a systematic ESG management framework can provide strategic guidance and institutional guarantees for the integration of Lean and Green practices, elevating their synergy from a tool-level practice to a strategic-level integration. Second, the findings deepen the application of stakeholder theory in

the healthcare industry, indicating that actively responding to the demands of a wide range of stakeholders, including the environment, patients, and the community (i.e., improving S and G performance), is not merely a cost or constraint, but can instead drive management innovation and technological upgrades, transforming into a driving force for improving internal operational efficiency and building long-term competitive advantages. In relation to existing literature, this study finds that environmental performance directly drives resource efficiency, consistent with classical environmental economics perspectives. It also identifies the fundamental role of governance performance and the mediating role of digitalization and R&D, providing new evidence from the Chinese healthcare industry for understanding the mechanism of ESG value creation. Notably, preliminary heterogeneity analysis shows that this driving effect is more significant in the capital-intensive and strictly regulated pharmaceutical sub-sector than in the healthcare services sub-sector.

V. CONCLUSION

This study constructs and empirically tests an ESG evaluation system with characteristics specific to the healthcare industry, drawing the following core conclusions: First, this study successfully constructs an ESG performance evaluation system for healthcare enterprises that integrates general principles and key industry issues. Second, empirical analysis confirms that improving ESG performance is an effective way for healthcare enterprises to improve green operational efficiency. Third, the study reveals the key mediating role of technological innovation (R&D investment) and digital investment in the process of ESG-driven efficiency improvement. Fourth, case evidence indicates that the positive relationship between ESG performance and operational efficiency does not occur automatically; it depends on enterprises deeply integrating ESG into their strategic planning and achieving this through systematic management activities and resource allocation. Based on the above conclusions, this study proposes the following suggestions:

Implications for enterprises:

Healthcare enterprises should elevate ESG management from the reporting and compliance level to the core strategic level. (1) In particular, it is necessary to address shortcomings in environmental management and formulate clear emission reduction and consumption reduction targets and implementation paths. (2) Strengthen the board of directors' ESG oversight responsibilities and establish a sound internal governance and risk management mechanism. (3) Consciously integrate ESG-related risk and opportunity assessments with investment decisions on R&D innovation and digital transformation upgrades, thereby making ESG an internal driving force for operational innovation and value creation.

Recommendations for policymakers:

(1) Refer to the industry indicator system in this study to further refine and promote ESG disclosure and evaluation standards in key industries such as healthcare, enhancing the comparability and decision-making usefulness of information. (2) Encourage enterprises to increase investment in green technologies and digital solutions through incentive policies such as green credit and R&D tax deductions, thus facilitating the transformation of ESG performance into operational benefits.

AUTHOR CONTRIBUTIONS

Hui Dai designed, collected and analyzed the data, and drafted the manuscript. Hui Dai conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Hui Dai participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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