Dynamic Assessment and Goal Optimization of Corporate ESG Performance Based on DEA-CCR-GML and Inverse DEA Integration Framework

Hui Liu[1], Tsung-Xian Lin[2]*, Yaqing Hu[3], Yingxi Xiao[4], Chengze Ou[5], Yayi Lao[6], Wenchao Pan[7]
School of Management, Guangzhou Huashang College, Guangzhou 511300, China[1, 2, 7]
Institute of Overseas Chinese-Chinese and Chinese Business Culture, Guangzhou Huashang College, Guangzhou 511300, China[2]
School of International, Guangzhou Huashang College, Guangzhou 511300, China[3, 5, 6]
School of Accounting, Guangzhou Huashang College, Guangzhou 511300, China[4]

***Abstract*—Since the Ministry of Ecology and Environment issued the "Reform Plan for the System of Environmental Information Disclosure in Accordance with the Law" in 2021, the nation has set forth new requirements for sustainable development. Against this backdrop, how enterprises enhance their value across all dimensions through ESG in compliance with national mandates holds significant implications for refining ESG management systems. This study employs DEA-CCR-GML and inverse DEA models to empirically examine how investments in specific dimensions of ESG's three pillars influence corporate value realization, using data from Shanghai to Shenzhen A-share listed companies from 2019 to 2024. Findings reveal that higher levels of scale efficiency and technical efficiency correlate with greater improvements in ESG scores, while mandatory enforcement of national policies exerts a highly effective driving force on enterprises. Mechanism analysis indicates that firms can enhance ESG score improvement efficiency by elevating scale and technical efficiency, thereby more effectively realizing their intrinsic value.**

***Keywords*—Corporate ESG performance; DEA; financing constraints; green innovation**

I. Introduction

Against the backdrop of the establishment of the National Social Responsibility Bureau (April 2022), policy initiatives by the China Securities Regulatory Commission, and the growing prevalence of ESG principles in China's capital markets, how companies can enhance their ESG ratings to improve governance standards has become a focal point [1]. While existing research predominantly examines the impact of ESG score changes on corporate performance volatility [2], firm value [3], and investor perspectives [4], it rarely explores how companies can more effectively improve their ESG scores by increasing investments in specific areas such as scale efficiency and technical efficiency. To address this gap, this study empirically examines the impact of corporate investments on key indicators and their underlying mechanisms using data from Chinese A-share listed companies from 2019 to 2024.

Zhang et al. demonstrate that corporate ESG measures enhance innovation performance through dual pathways: direct promotion and governance mediation (where strengthened environmental/social governance amplifies innovation). This process is moderated by institutional development levels, providing theoretical foundations and practical insights for sustainable innovation strategies in dynamic institutional environments [1].

Nguyen DT et al. based their study on data from 2,350 U.S. companies between 2018 and 2023, focusing on the heterogeneity of ESG risks (unmanaged risks versus management gaps). They revealed a significant negative correlation between total ESG risk and corporate performance, with the negative impact primarily driven by unmanaged risks (whose effect was approximately eight times that of management gaps). The negative impact of unmanaged ESG risks on performance is most pronounced in the first year and diminishes progressively thereafter. This conclusion holds even after controlling for endogeneity and undergoing multiple robustness tests [2].

Danny Zhao-Xiang Huang's theoretical analysis reveals a three-dimensional dilemma in shareholder ESG investment decisions: valuation conflict (ESG factors are difficult to quantify and integrate into earnings forecasts), the information paradox (ESG can reduce agency information asymmetry, but the validity of signals remains questionable), and the interest conflict (ESG embeds a multi-stakeholder interest game field). He proposes that future research should focus on the conditions under which ESG information triggers effective signals to bridge the cognitive gap in shareholders' long-term value assessment [3].

Avramov, D. et al. empirically demonstrated through the asset pricing equilibrium model and ESG rating discrepancies that ESG uncertainty elevates market premiums and reduces stock demand, driving simultaneous increases in CAPM alpha and effective beta while weakening the negative correlation between ESG and alpha. Supported by standard deviation data from six major rating providers, this study resolves the ESG-return relationship debate, demonstrating that ESG uncertainty distorts the risk-return tradeoff, thereby influencing sustainable investment decisions and social welfare [4].

A. Charnes et al. employed a nonlinear (nonconvex) programming model to address the challenge of efficiency evaluation in public programs for nonprofit entities. They developed a new definition of efficiency, an objective weighting method based on multiple observed output and input

*Corresponding author.

data, an equivalent computational relationship with standard linear programming models, and novel approaches for estimating extremes in dual models. Furthermore, they elucidated the connection between engineering and economics in efficiency assessment, offering fresh interpretations and applications for public project management [5].

Oh and Heshmati proposed a continuous Malmquist-Luenberger index combining a directional distance function with a continuous sequential production possibility set to address the challenge of measuring environmentally sensitive productivity growth, while excluding spurious technical regression from a macroeconomic perspective. They propose that this index exhibits trends similar to the traditional Malmquist-Luenberger index but with distinct decomposition components, and that efficiency changes dominate in the early stages while technological changes dominate in the later stages (based on empirical evidence from 26 OECD countries from 1970 to 2003) [6].

Chen et al. combined a novel counter-envelope analysis (DEA) model with undesirable outputs and a new inverse DEA model. By analyzing the relationships and differences among various objectives and their implementation pathways based on decision-makers' actual needs, they summarized valuable insights for advancing the achievement of China's road traffic safety goals [7, 8].

Lin explores the development prospects, economic benefits, and enabling environment of ESG investing within the context of carbon neutrality policy implementation and China's new development philosophy (green development). The study proposes that ESG has become a key factor in driving low-carbon transformation, assessing corporate performance, and influencing the economy. It aims to explore scientifically efficient methods for developing ESG to promote the transformation and upgrading of the carbon economy [9].

Wang et al. empirically examined the impact of performance-based budgeting (PBB) reforms on corporate ESG performance using quasi-natural experiments and multi-period DID models based on data from Chinese A-share listed companies from 2001 to 2020. Findings reveal that PBB reforms significantly enhance firms' economic and social contributions, with this effect being more pronounced in regions with high fiscal pressure and strong government audits. The impact is particularly significant for government-affiliated enterprises, firms with strong green innovation capabilities, or those facing high financing constraints. The mechanism operates by enhancing environmental governance through increased environmental subsidies and improved fiscal transparency, ultimately improving ESG performance and driving increases in return on assets, price-to-book ratios, and patent grants. This provides empirical evidence for deepening fiscal and tax system reforms and supporting the "dual carbon" strategy [10].

Weston and Nnadi et al. conducted research on the relationship between corporate social responsibility (CSR) and financial performance (CFP), establishing a framework for integrating CSR and environmental, social, and governance (ESG) principles into decision-making. By analyzing samples from the iShares MSCI KLD 400 Social ETF, the iShares Core S&P 500 ETF, and companies adhering to the Principles for Responsible Investment (PRI), the study found that ethical ETFs did not outperform traditional ETFs, but companies following PRI outperformed those not adhering to the principles [11].

Ye and Xu et al. examined the impact and mechanisms of ESG on carbon reduction (green innovation, efficiency, and managerial myopia) using data from China's listed manufacturing firms between 2010 and 2020. They found that ESG significantly reduces carbon emissions, with stronger effects observed in companies facing stricter environmental regulations, intense competition, and high capital intensity. Digital transformation plays a positive moderating role. This research provides new evidence for understanding ESG's emission reduction effects and offers insights for practical and policy approaches to achieving the" dual carbon" goals [12].

II. MODELING

This study employs the DEA-CCR model, the Globe-Malmquist-Luenberger index, and inverse DEA to conduct a scientific analysis of the profitability development efficiency of listed companies in China's A-share market.

A. DEA - CCR Model

There are n decision-making units (DMUs), each with m distinct input indicators and n output indicators. Let Xi denote the input vector for the i-th DMU, and Yi denote the output vector for the i-th DMU. When evaluating the efficiency of each DMU, the CCR model [5] is employed:

$$\begin{aligned} &\max\phi \\ &\text{s.t.} \quad \sum_{j=1}^{n}\lambda_j X_j \le X_0 \\ &\sum_{j=1}^{n}\lambda_j Y_j \ge \phi Y_0 \\ &\lambda_j \ge 0, \quad j=1,2,\ldots,n \end{aligned} \tag{1}$$

B. GML (Globe Malmquist-Luenberger Index) Model Construction

The GML index is constructed by integrating the Directional Distance Function (DDF) with the Global Production Technology Set (GPTS). It inherits the dynamic decomposition framework and relaxed measurement concept of the Malmquist index. By introducing a non-expected output constraint, it quantifies changes in Green Total Factor Productivity (Green TFP) within decision units, which balance expected output growth with reductions in non-expected output across intertemporal dynamics. Using the total production technology set across all study periods as the reference framework, it resolves shortcomings of the ML index such as lack of cyclical transitivity and unsolvability of linear programming [3], enabling more objective and accurate reflection of changes in the financial systems of listed companies. Let $\vec{D}_V^G(xt,yt,bt;g)$ denote the global directional distance function. Then the GML index from period t to period t+1 is defined as [6]:

$$GML^{t,t+1}=\frac{1+\vec{D}_V^G(x^t,y^t,b^t;g)}{1+\vec{D}_V^G(x^{t+1},y^{t+1},b^{t+1};g)} \tag{2}$$

The GML index can be decomposed into four interpretable components: Technical Efficiency Change (*EC*), Scale Efficiency Change (*SEC*), Pure Technical Change (*PTC*), and Scale-Technical Change (*STC*). The specific decomposition is as follows:

$$\begin{aligned}\mathrm{GML}^{t\to t+1} &= EC\times SEC\times PTC\times STC \\ &= \left(\frac{1+\vec{D}_V^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})}{1+\vec{D}_V^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})}\right)\times\left(\frac{\mathrm{SE}^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1})}{\mathrm{SE}^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t})}\right) \\ &\times\left(\frac{1+\vec{D}_V^{G}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})}{1+\vec{D}_V^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})}\cdot\frac{1+\vec{D}_V^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})}{1+\vec{D}_V^{G}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})}\right) \\ &\times\left(\frac{\left[\frac{1+\vec{D}_V^{G}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})}{1+\vec{D}_V^{CRS,G}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})}\right]/\left[\frac{1+\vec{D}_V^{G}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})}{1+\vec{D}_V^{CRS,G}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})}\right]}{\frac{\mathrm{SE}^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1})}{\mathrm{SE}^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t})}}\right)\end{aligned} \tag{3}$$

C. Inverse DEA Model Construction

Reverse DEA theory extends the boundaries of traditional Data Envelopment Analysis (DEA) through a reverse optimization framework. This approach translates abstract efficiency assessments into concrete action plans, making it suitable for resolving resource allocation disputes in public policy formulation [7]. The core value of Reverse DEA theory lies in addressing two critical issues: goal-oriented resource planning and short-term forecasting under constraints. This study focuses on short-term forecasting under constraints.

The inverse DEA of the output-oriented CRS super-efficiency DEA model is expressed as [8]:

$$\begin{aligned} &\max\varphi \\ &\textstyle\sum_{(j=1,\ j\neq k)}^{n}\lambda_j x_{ji}\le x_{ki}+\Delta x_{ki} \\ \text{s.t.}\quad &\textstyle\sum_{(j=1,\ j\neq k)}^{n}\lambda_j y_{jr}/\varphi_k^{*}\ge\gamma y_{kr} \\ &\lambda\ge 0 \\ &i=1,2,\ldots,p;r=1,2,\ldots,q;k=1,2,\ldots,n \end{aligned} \tag{4}$$

where, ϕ^{*}_{k} represents a known value, i.e., the optimal solution from the original DEA model or a manually set efficiency value; γ^{*}_{k} denotes the optimal solution from the inverse DEA model; $\gamma^{*}_{k}y_{kr}$ signifies the predicted output value; Δx indicates the increase in input quantity; and let Δy denote the increase in output quantity, then $\Delta y=\gamma^{*}_{k}y_{kr}-y_{kr}$.

III. Selection of the Indicator System

To evaluate the effectiveness of the efficiency assessment system, eight corresponding evaluation indicators were established based on the principles of scientific rigor, objectivity, and quantitative analysis, incorporating existing literature [9]. The data sources and their respective origins are detailed in Table I.

TABLE I. Variable Definitions and Data Sources

Indicator type	Indicators	Variant	Unit	Source
Input indicators	Market capitalization	X_1	Ten billion yuan	[8]
	Main revenue	X_2	Ten billion yuan	
	Operating cash flow	X_3	Ten billion yuan	/
	R&D expenditures	X_4	Hundred million yuan	
Output indicators	ESG score	Y_1	/	[8]
	Asset-liability ratio	Y_2	%	
	Total asset turnover ratio	Y_3	Times	/
	Return on total assets	Y_4	%	[8]

IV. Empirical Research

A. DEA Static Analysis

This study covers the period from 2019 to 2024, selecting 10 listed companies from five industries on the Shanghai and Shenzhen stock exchanges as research subjects, with data sourced from the Wind Database. By comparing and analyzing the scale efficiency, pure technical efficiency of technological innovation, and comprehensive efficiency of these 10 listed companies, the study dissects the internal factors influencing changes in corporate ESG scores and provides corresponding recommendations. Comprehensive efficiency values were calculated using the DEArun software, revealing the ESG improvement comprehensive efficiency for the 10 listed companies, as shown in Table II.

TABLE II. Comprehensive Efficiency of ESG Score Improvement for 10 A-Share Listed Companies

	2019	2020	2021	2022	2023	2024
Zijin Mining	0.464	0.266	0.623	0.362	0.228	0.316
China Northern Rare Earth	1.000	1.000	1.000	1.000	1.000	1.000
Beijing Capital Eco-environment	1.000	1.000	1.000	1.000	1.000	1.000
Originwater	1.000	1.000	1.000	1.000	1.000	1.000
Offshore Engineering	1.000	1.000	1.000	1.000	1.000	1.000
Hengli Petrochemical	0.317	0.367	0.602	0.668	0.620	0.579
Fuyao Glass	0.683	0.688	0.645	0.692	0.945	0.900
Conch Cement	1.000	0.737	0.500	0.284	0.329	0.288
999 Pharmaceutical	1.000	1.000	1.000	1.000	1.000	1.000
WuXi AppTec	1.000	0.811	0.737	0.723	1.000	0.936
Average value	0.846	0.787	0.811	0.773	0.812	0.802

Table II shows that the average comprehensive efficiency of ESG score improvement for the 10 A-share listed companies fluctuated between 2019 and 2024, peaking in 2019 before exhibiting an overall downward trend. Over the past six years, the mean comprehensive technical efficiency of the sample companies ranged between 0.773 and 0.846. Although

generally at a high level, it has been decreasing annually, reflecting that, under given resource input conditions, companies still have room for improvement in their comprehensive development in ESG-related areas. Specifically, five companies achieved a comprehensive efficiency score of 1 in each of 2020, 2021, 2022, and 2024, rising to six in 2023. In contrast, seven companies attained optimal comprehensive efficiency in 2019, further confirming the overall downward trend in the average efficiency score. This phenomenon is primarily linked to companies' relatively high debt-to-asset ratios during the period, insufficient R&D investment, and strong volatility in ESG scores. In particular, inadequate R&D expenditure significantly impacted companies' scores in the "ESG Technology R&D" category, thereby lowering their overall ESG scores and slowing the pace of improvement in their comprehensive ESG efficiency.

At the individual enterprise level, Zijin Mining, Hengli Petrochemical, and Fuyao Glass remained in a non-DEA efficient state throughout the review period. This indicates significant room for improvement in their overall efficiency across ESG resource allocation, environmental management (E), social responsibility (S), and corporate governance (G) dimensions. Their input factors have not achieved optimal allocation, necessitating urgent improvements through measures such as optimizing ESG strategic structures, increasing green R&D investments, and enhancing environmental information disclosure. Conch Cement achieved DEA efficiency only in 2019, remaining inefficient in other years. Fluctuations in environmental indicators like carbon emissions intensity and water resource utilization efficiency may have undermined its sustained high performance. WuXi AppTec failed to meet DEA efficiency in all years except 2019 and 2023, reflecting unstable input-output structures in S and G dimensions-including green R&D, employee rights, and business ethics. In contrast, China Northern Rare Earth, Beijing Capital Eco-environment, OriginWater, Offshore Engineering, and 999 Pharmaceutical maintained DEA validity throughout the six-year period. This demonstrates strong synergies across all three ESG dimensions-such as China Northern Rare Earth resource recycling, OriginWater's water environmental protection technologies, Offshore Engineering's low-carbon project investments, and 999 Pharmaceutical's health product responsibility management-along with rational resource allocation with both technical and scale efficiencies optimized simultaneously, demonstrating robust comprehensive ESG management capabilities. Notably, in observations of companies within the Greater Bay Area, years with a comprehensive efficiency value of 1 corresponded to significant improvements in the ESG technology R&D segment, indicating rational innovation resource structures and leading green technology output efficiency.

In summary, the overall efficiency of improving corporate ESG scores is not only constrained by financial structure and R&D investment levels but also closely tied to specific performance indicators in environmental outcomes, social responsibility fulfillment, and governance transparency. Moving forward, companies should address their ESG weaknesses by intensifying technological R&D efforts, optimizing capital structures, and enhancing the quality of ESG disclosures. This approach will enable simultaneous improvements in resource allocation efficiency and overall ESG ratings.

B. Dynamic Analysis of Global Malmquist-Luenberger Index

The Global Malmquist-Luenberger index dynamically and comprehensively reflects changes in the technological innovation efficiency of A-share listed companies. Applying this index to decompose the ESG score improvement rates of 10 A-share listed companies from 2019 to 2024 yields the following results:

TABLE III. AVERAGE GLOBAL MALMQUIST-LUENBERGER INDEX AND DECOMPOSITION FOR ESG SCORE IMPROVEMENT OF 10A-SHARE LISTED COMPANIES FROM 2019 TO 2024

	Effch	Rech	Pech	Sech	tfp
2019-2020	0.968	0.971	0.994	0.973	0.942
2020-2021	1.025	0.982	1.006	1.020	0.999
2021-2022	0.976	1.003	1.000	0.976	0.976
2022-2023	1.022	0.944	0.992	1.031	0.960
2023-2024	0.996	0.991	0.997	0.999	0.986
Average value	0.997	0.978	0.998	1.000	0.973

As shown in Table III, from the perspective of overall efficiency changes, the average ESG score improvement rate index for the 10 A-share listed companies from 2019 to 2024 was 0.978, while the Global Malmquist-Luenberger productivity decreased by 2.2%. Throughout the study period, the tfpch for 2019–2024 remained below 1, indicating that the ESG score improvement rate of these 10 listed companies showed a declining trend year by year. This suggests that inputs and outputs related to ESG score improvement have not been optimized. Further analysis of each company's ESG indicator performance reveals that the following factors directly impact ESG score improvement: within the Environmental (E) dimension-carbon emission intensity, energy efficiency, and waste management rate; within the Social (S) dimension-employee training investment, community welfare expenditure, and labor rights protection; and within the Governance (G) dimension-board independence, information disclosure transparency, and anti-corruption mechanism development. For instance, some companies fall short of industry benchmarks in environmental metrics, limiting overall efficiency. In social metrics, insufficient investment in employee training may weaken innovation momentum, thereby impacting total factor productivity.

Breaking down total factor productivity (TFP) further into scale effect and technological progress indices reveals: 1)TFP reached its lowest point between 2019 and 2020, primarily due to scale effect and technological progress indices falling below other indicators. This indicates that the synergistic interaction between technological progress and scale effects was the main factor driving the decline in TFP. Specifically regarding ESG indicators, insufficient R&D investment in the environmental dimension and reduced scale of public welfare projects in the social dimension jointly constrained efficiency gains. Enhancing corporate technological innovation efficiency can be achieved by encouraging enterprises to increase their investment and scale in ESG and R&D. 2) The TFP value

reached its peak in 2020-2021, at 0.999. Further analysis reveals that the primary drivers of this increase were higher values for the scale effect index and the pure technical efficiency index. This demonstrates that scale effects and technical efficiency are crucial factors in enhancing corporate innovation efficiency. During this period, companies' improved information disclosure in governance and expanded community investments in social dimensions effectively supported higher ESG scores. However, the lack of technological advancement hindered the efficiency gains in ESG scoring, particularly the lag in environmental indicators like carbon reduction technology adoption, which may further depress overall performance.

Overall, specific ESG metric performance-including environmental compliance, social responsibility fulfillment, and governance structure optimization-constitutes the key driver of total factor productivity (TFP) fluctuations. Enterprises must implement targeted adjustments across these dimensions to optimize resource allocation and enhance efficiency.

TABLE IV. GLOBAL MALMQUIST-LUENBERGER INDEX AND DECOMPOSITION FOR ESG SCORE IMPROVEMENT AMONG 10 A-SHARE LISTED COMPANIES

	Effch	Rech	Pech	Sech	tfp
Zijin Mining	0.992	0.979	1.000	0.992	0.955
China Northern Rare Earth	1.000	0.965	1.000	1.000	0.965
Beijing Capital Eco-environment	1.000	1.000	1.000	1.000	1.000
Originwater	1.000	1.001	1.000	1.000	1.001
Offshore Engineering	1.000	1.018	1.000	1.000	1.018
Hengli Petrochemical	1.039	0.974	1.000	1.039	1.009
Fuyao Glass	1.027	0.950	1.000	1.027	0.971
Conch Cement	0.918	0.992	0.978	0.943	0.911
999 Pharmaceutical	1.000	0.953	1.000	1.000	0.953
WuXi AppTec	0.997	0.949	1.000	0.997	0.942
Average value	0.997	0.978	0.998	1.000	0.973

As shown in Table IV, during the period from 2019 to 2024, only four of the ten sample companies-OriginWater, Offshore Engineering, Hengli Petrochemical, and Beijing Capital Eco-environment, achieved a total factor productivity (TFP) index greater than or equal to 1. This indicates that these companies demonstrated relatively strong efficiency in improving their ESG scores. The remaining six companies all had TFP indices below 1, reflecting that while the overall efficiency of ESG score improvement showed an upward trend, there remains significant room for improvement. Comparisons across companies and industries reveal both limited gradient-based differences and technology-driven structural disparities, particularly in the uneven integration of Environmental (E), Social (S), and Governance (G) dimensions. Analysis based on the Global Malmquist-Luenberger index categorizes these ten companies into the following three groups:

1) Companies with a technical efficiency score of 1 or higher include China Northern Rare Earth, Beijing Capital Eco-environment, OriginWater, Offshore Engineering, Hengli Petrochemical, Fuyao Glass, and 999 Pharmaceutical-seven companies in total. These enterprises positively contributed to their ESG scores through enhanced technical efficiency. For instance, OriginWater made significant investments in water resource management and environmental technology applications, demonstrating strong environmental metrics such as wastewater treatment efficiency and carbon reduction performance. Offshore Engineering has strengthened practices in marine environmental protection and safety production measures, with improvements in employee training and community engagement on the social dimension; Hengli Petrochemical reduced environmental impacts through process optimization and resource recycling, though governance transparency requires further enhancement; Beijing Capital Eco-environment demonstrated efficient governance in environmental project operations and board diversity; China Northern Rare Earth made progress in resource utilization efficiency and mine ecological restoration; Fuyao Glass performed well in employee welfare, safety production and product sustainability; 999 Pharmaceutical has continuously optimized drug accessibility, patient safety and corporate ethical governance. However, these companies generally exhibit low technological advancement scores, which have constrained further growth in their ESG score improvement rates. Particularly, there is a lag in applying innovative technologies to environmental and social risk management.

2) Conch Cement experienced the largest decline in ESG score growth rate among all companies, decreasing by 8.91%. Its decline in total factor productivity primarily stemmed from a 6.23% reduction in scale efficiency, reflecting potential neglect of environmental compliance and social responsibility integration during rapid expansion, leading to deteriorating ESG performance. Specifically, in the social dimension, weaknesses were observed in community relations and labor rights protection; in the governance dimension, insufficient internal controls and execution efficiency of sustainability strategies exacerbated the negative impacts stemming from scale effects.

3) Both Zijin Mining and WuXi AppTec experienced varying degrees of decline in their ESG score improvement rates, at 4.5% and 5.8%, respectively. Both companies exhibited unchanged pure technical efficiency indices, while technical efficiency, technological progress, and scale efficiency indices all decreased. The reduction in scale efficiency directly led to the decline in technical efficiency. Zijin Mining faces challenges in environmental restoration, biodiversity conservation, and labor safety within its mining operations. Social dimension issues, including local community conflicts and governance transparency, constrain its ESG improvement. WuXi AppTec exhibits deficiencies in governance areas such as R&D ethics, supply chain management, and data privacy protection. Its social responsibility practices-particularly regarding patient rights and employee diversity-require strengthening, as its scale expansion has failed to effectively align with ESG management demands.

Overall, the disparity in ESG score improvement efficiency among the ten companies highlights uneven development across environmental, social, and governance dimensions. Future efforts should focus on optimizing technical efficiency and economies of scale, while strengthening the integration of ESG metrics tailored to each industry's characteristics to drive sustainable enhancement of overall ESG performance.

V. Case Study

A. Performance Target Setting

The budget values for 2025 [10] for each unit are set at 80% of the 2024 increase, as shown in Table V.

TABLE V. Budgeted Investment Targets for each Unit in 2025

Subjects of evaluation	Company market capitalization (Tens of billions of dollars)	Main revenue (Tens of billions of dollars)	Operating cash flow (Tens of billions of dollars)	R&D expenditures (Billions of dollars)
Zijin Mining	70.151	54.655	59.620	28.482
China Northern Rare Earth	13.809	5.9339	5.1862	5.3982
Beijing Capital Eco-environment	4.3339	3.6090	3.0401	3.1888
Originwater	3.3009	1.5389	1.3163	6.1700
Offshore Engineering	4.3533	5.3900	5.9200	22.290
Hengli Petrochemical	19.449	42.529	50.997	30.650
Fuyao Glass	28.156	7.0653	7.0520	30.200
Conch Cement	21.427	16.385	18.823	22.627
999 Pharmaceutical	10.250	4.9710	5.2525	17.154
WuXi AppTec	28.423	7.0630	7.8237	22.290

Substituting the budgeted input values into the inverse DEA model yields an output value of 10 units, which represents the 2025 output indicator performance target. The results are shown in Table VI.

TABLE VI. Performance Targets for Output Indicators of each Unit in 2025

Subjects of evaluation	ESG score	Gearing ratio (%)	Total asset turnover (times)	Return on assets (%)
Zijin Mining	236.39	1891.14	5.837	169.27
China Northern Rare Earth	11.929	76.7852	0.800	7.783
Beijing Capital Eco-environment	10.871	87.7268	0.263	7.358
Originwater	9.5707	85.1268	0.162	2.058
Offshore Engineering	10.892	71.8277	0.700	5.600
Hengli Petrochemical	73.175	645.200	1.286	18.90
Fuyao Glass	23.776	189.324	00.700	13.80
Conch Cement	1153.59	1279.89	3.347	81.30
999 Pharmaceutical	13.718	93.2226	0.700	11.40
WuXi AppTec	20.429	163.663	0.502	14.50

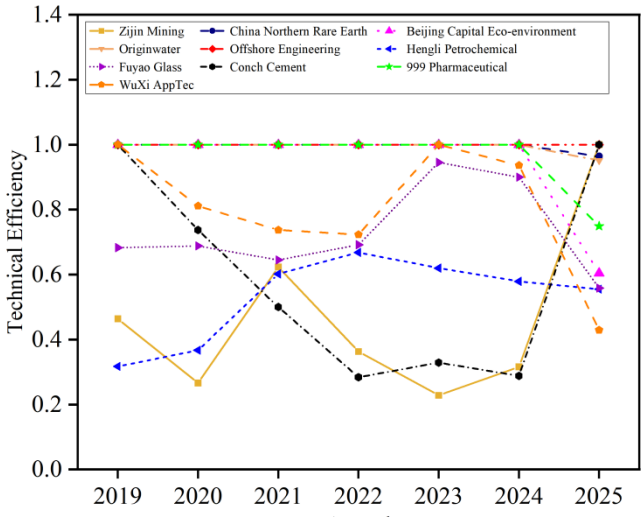

Fig. 1. Comprehensive technical efficiency of various units in 2019–2025.

Fig. 1 was created by plotting the comprehensive technical efficiency of each unit for the period 2019-2024 and their target comprehensive technical efficiency for 2025.

Conch Cement's comprehensive efficiency curve exhibits a V-shaped pattern with significant volatility. This trend of initial decline followed by recovery clearly demonstrates the effectiveness of resource allocation and technological application across different phases of Conch Cement's operations.

From the data characteristics, the decline phase from 2019 to 2022 indicates issues in certain input-output segments of enterprises, suggesting potential resource redundancy or misallocation. The recovery phase from 2023 to 2025 indicates improved efficiency following strategic adjustments. Notably, comprehensive technical efficiency saw a brief uptick in 2023 before declining again to the0.2-0.3range in 2024. A sharp upward trend is projected for 2025.

In summary, by 2025, Conch Cement should increase R&D investment to enhance automation levels and production efficiency, particularly by improving return on assets. This will help resolve the existing contradiction of high debt and low R&D investment, thereby boosting the ability to convert investments into profits. Additionally, in the realm of "circular economy", Conch Cement can increase the proportion of co-processing industrial solid wastes (such as steel slag and blast furnace slag) and construction waste, develop related products, reduce raw material costs, and simultaneously enhance resource recycling efficiency. Regarding suppliers, establish an ESG rating system for upstream suppliers (such as coal and sand/gravel enterprises), prioritizing collaboration with low-energy-consumption and compliant-emission suppliers. Promote the "green cement+low-carbon construction" integrated solution to downstream construction clients, driving overall ESG improvement across the supply chain while aligning with national policies and requirements. For governance structure, establish an ESG working group under the existing Board Strategy or Risk Control Committee, staffed by current executives to oversee ESG governance matters. Senior executives will leverage their management expertise

and resource advantages across respective domains to embed ESG requirements into core processes, including strategic planning, operational management, and risk control. This ensures ESG initiatives are integrated into the company's core business rather than treated as superficial formalities. The approach enhances brand reputation and credibility among investors, regulators, and the public, aligning with current ESG investment trends and policy directions. It simultaneously drives the company's green and low-carbon transformation and supply chain sustainability, laying the foundation for long-term high-quality development.

In analyzing corporate historical performance and forecasting future decisions, the core value of the reverse DEA model lies not only in its application as a tool but also in its methodological innovation for short-term ESG forecasting—an innovation that breaks through the limitations of traditional forecasting reliant on experiential judgment or linear extrapolation. By deeply integrating historical ESG efficiency characteristics, input budget constraints, and reverse optimization logic, it constructs a closed-loop forecasting framework that starts with efficiency attribution, proceeds through resource allocation optimization, and culminates in target quantification. This approach fills the gap where traditional methods struggle to precisely align efficiency assessments with specific ESG objectives. Specifically, enterprises can leverage this integrated model to precisely calculate ESG output targets based on input indicator budget values, enabling targeted forecasting and pathway planning for short-term ESG performance. For instance, Conch Cement leveraged this integrated approach to not only pinpoint redundant inputs underlying prior inefficiencies but also directly link optimization directions with short-term improvement targets across ESG dimensions through reverse DEA's backward-tracking capability. This provides quantitative grounds for setting stable and achievable ESG output goals, enabling enterprises to clearly define "which inputs to optimize, which ESG dimensions to enhance, and what targets to achieve". Compared to traditional performance goal-setting methods, reverse DEA emphasizes the dynamic alignment of performance evaluation outcomes with ESG objectives. It transforms static efficiency assessments into dynamic, actionable ESG improvement pathways, ensuring goal-setting aligns with both operational realities and core ESG development priorities. This significantly enhances the scientific rigor, precision, and operational feasibility of short-term ESG target setting.

VI. Conclusion and Recommendations

This study employs a methodological framework of "static evaluation—dynamic decomposition—reverse optimization," integrating the DEA-CCR model, Global Malmquist-Luenberger (GML) index, and reverse DEA methodology. It conducts a systematic analysis of ESG performance improvement efficiency across 10 representative listed companies from different sectors in China's A-share market during 2019–2024. Based on historical performance, it further establishes resource optimization pathways for 2025. DEA-CCR analysis reveals these companies exhibit overall decline with significant divergence. The core contradiction lies in the combined effects of insufficient R&D expenditure, high debt-to-asset ratios, and volatile ESG scores, which collectively suppress efficiency gains. Meanwhile, GML index decomposition indicates that overall efficiency is declining amid fluctuations, largely consistent with the preceding description. Despite heterogeneity among different enterprises, technology (tech) emerges as the primary driver of decline, revealing weak innovation momentum in the ESG domain. Finally, constrained short-term forecasts for input budgets and target efficiency values are generated using an inverse DEA model, providing quantitative guidance for budget allocation [10]. This reveals that under China's deliberate efforts to enhance corporate ESG integration and innovation, enterprises across different sectors can improve their ESG performance through management process optimization. However, it is noteworthy that scale efficiency and technological innovation may emerge as constraining factors in further elevating ESG performance.

At the corporate level, this study provides inefficient units with pathways for optimizing scale structures and identifies key areas for technological upgrading in declining units. At the policy level, it establishes an ESG budget performance management paradigm centered on "efficiency diagnosis-attribution analysis-target generation". The study proposes the following differentiated improvement strategies for enterprises: For non-DEA-efficient enterprises such as Zijin Mining and Hengli Petrochemical, the focus should be on optimizing scale structures and increasing R&D expenditures in line with reverse DEA budgets. Declining enterprises like Conch Cement should enhance scale efficiency through automation upgrades and capacity efficiency improvements. Overall, both domestic and international enterprises should focus on long-term capacity building, strengthen synergies between technological progress and economies of scale [11], particularly by enhancing ESG-related technological innovation capabilities and mitigating the negative impact of ESG score volatility on total factor productivity. Concurrently, the inverse DEA model can serve as a reference for budget allocation.

Funding

This work was funded by Guangzhou Huashang College Scientific Research Tutorial System Project (Project Number: 2024HSDS03), Guangzhou Huashang College Horizontal Scientific Research Project (grant number 2025HSHX03), and Scientific Fund of Guangzhou Huashang College (Grant HSRHKC2024136).

References

[1] Zhang Q, Loh L, Wu W. (2020). How do environmental, social and governance initiatives affect innovative performance for corporate sustainability? Sustainability, 12(8): 1-18.

[2] Nguyen DT, Tran VT, Phan DHB, et al. (2025). Unmanaged ESG risks and corporate performance - The impact of management gaps. Finance Research Letters, 83: 107707. DOI: 10.1016/J.FRL.2025.107707.

[3] Huang D. (2022). Environmental, social and governance factors and assessing firm value: valuation, signaling and stakeholder perspectives. Accounting and Finance, 62, 1983-2010.

[4] Avramov D, Cheng S, Lioui A, et al. (2022). Sustainable investing with ESG rating uncertainty. Journal of Financial Economics, 145 (2): 642-667.

[5] Charnes A, Cooper WW, Rhodes E. (1978). Measuring the efficiency of decision making units. European Journal of Operational Research, 2(6): 429-444.

[6] Oh D-h, Heshmati A. (2010). A sequential Malmquist-Luenberger productivity index: environmentally sensitive productivity growth considering the progressive nature of technology. technology. Energy Economics, 32(6): 1345-1355.

[7] Chen L, Gao Y, Li M, et al. A new inverse data envelopment analysis approach to achieve China's road transportation safety objectives transportation safety objectives. Safety Science, 2021, 142: 105362.

[8] Wei, Q.L., Zhang, J., Zhang, X., 2000. An inverse DEA model for input/output estimate. Eur. J. Operat. Res. 121 (1), 151–163.

[9] Lin Z. Does ESG performance indicate corporate economic sustainability? Evidence based on the sustainable growth rate. Borsa Istanbul Review, 2024, 24(3): 485-493.

[10] Wang X, Hu S. Can performance-based budgeting reform improve corporate environment in ESG? Evidence from Chinese-listed firms. Frontiers in Environmental Science, 2022, 10: 982160. DOI: 10.3389/FENVS.2022.982160.

[11] Weston P, Nnadi M. (2023). Evaluation of strategic and financial variables of corporate sustainability and ESG policies on corporate finance performance. Journal of Sustainable Finance & Investment, 13(2): 1058-1074.

[12] Ye J, Xu W. (2023). Carbon reduction effect of ESG: empirical evidence from listed manufacturing companies in China. Frontiers in Ecology and Evolution, 11: 1311777.