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ARTICLE

DIGITAL TRANSFORMATION AS A COMPETITIVE INTELLIGENCE MECHANISM IN ESG-DRIVEN CARBON PERFORMANCE: EVIDENCE FROM ENERGY FIRMS

TRANSFORMAÇÃO DIGITAL COMO UM MECANISMO DE INTELIGÊNCIA COMPETITIVA NO DESEMPENHO DE CARBONO ORIENTADO POR ESG: EVIDÊNCIAS DE EMPRESAS DO SETOR ENERGÉTICO

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ABSTRACT

Purpose: This study examines the effects of Environmental, Social, and Governance (ESG) performance on carbon emission performance in fuel and energy companies and investigates whether digital transformation moderates this relationship in high-carbon industries.

Methodology/approach: Using panel data from Chinese A-share, the study applies a two-way fixed-effects regression model to control for firm- and time-specific effects. Carbon emission performance is measured by the logarithm of operating revenue per unit of carbon emissions. ESG performance is proxied by standardized ESG ratings, while digital transformation is captured through a composite index. Robustness checks include sample exclusion during the COVID-19 period and regressions with lagged variables.

Originality/Relevance: The study integrates ESG governance and digital transformation within a unified analytical framework, contributing to a deeper understanding of how digital technologies enhance the effectiveness of ESG-based environmental management in high-carbon sectors.

Key findings: The results show that ESG performance has a significant positive impact on corporate carbon emission performance. Moreover, digital transformation strengthens this relationship by enhancing firms' ability to translate ESG practices into effective carbon reduction outcomes.

Theoretical/methodological contributions: This research advances the ESG and environmental performance literature by demonstrating the moderating role of digital transformation. It provides empirical evidence that digital technologies function as a key enabling mechanism for ESG effectiveness, offering a novel "ESG-digital transformation" perspective for future studies on green and low-carbon development in high-carbon industries.

Keywords: ESG performance. Carbon emission performance. Fuel and energy companies. Digital transformation. Fixed-effects model

RESUMO

Objetivo: Este estudo examina os efeitos do desempenho Ambiental, Social e de Governança (ESG) sobre o desempenho em emissões de carbono em empresas dos setores de combustíveis e energia, bem como investiga se a transformação digital modera essa relação em indústrias de alta intensidade de carbono.

Metodologia/abordagem: Utilizando dados em painel de empresas de combustíveis e energia listadas no mercado chinês A-share, o estudo aplica um modelo de regressão de efeitos fixos bidirecionais para controlar efeitos específicos de firma e de tempo. O desempenho em emissões de carbono é mensurado pelo logaritmo da receita operacional por unidade de emissão de carbono. O desempenho ESG é representado por ratings ESG padronizados, enquanto a transformação digital é capturada por meio de um índice composto. Testes de robustez incluem a exclusão do período da COVID-19 e regressões com variáveis defasadas.

Originalidade/Relevância: O estudo integra governança ESG e transformação digital em um framework analítico unificado, contribuindo para uma compreensão mais aprofundada de como as tecnologias digitais ampliam a efetividade da gestão ambiental baseada em ESG em setores de alta emissão de carbono.

Principais resultados: Os resultados indicam que o desempenho ESG exerce um efeito positivo e significativo sobre o desempenho em emissões de carbono das empresas. Além disso, a transformação digital fortalece essa relação ao ampliar a capacidade das empresas de converter práticas ESG em resultados efetivos de redução de carbono.

Contribuições teóricas/metodológicas: Esta pesquisa avança a literatura sobre ESG e desempenho ambiental ao demonstrar o papel moderador da transformação digital. Fornece evidências empíricas de que as tecnologias digitais atuam como um mecanismo habilitador fundamental para a efetividade do ESG, oferecendo uma nova perspectiva “ESG–transformação digital” para estudos futuros sobre desenvolvimento verde e de baixo carbono em indústrias intensivas em carbono.

Palavras-chave: Desempenho ESG. Desempenho em emissões de carbono. Empresas de combustíveis e energia. Transformação digital. Modelo de efeitos fixos.

1. INTRODUCTION

In high-carbon industries, carbon emission performance has increasingly become a strategic intelligence challenge rather than a purely regulatory concern. The fuel and energy sector plays a very critical role. The fuel and energy business is the keystone to the economic development, industrial output, and social well-being and contributes inestimable energy sources of the contemporary economies. Conversely, they contribute to the emission of greenhouse gases in the world the most because they consume fossil fuel, the production process is energy-intensive, and the technological direction is long-established (IEA, 2022; Stavins, 2019). These regulatory tools have so far performed quite well, but they also have limitations including the cost of enforcement, compliance cost as well as less business competitiveness.

ESG is not a one-dimensional concept (Friede et al., 2015). ESG performance is used to assess the integrity of the firm concerning the willingness to become sustainable, interests of the stakeholders, and the right management of the business. The ESG is taking on a vital role in capital markets as regards investment decisions, financing structure of companies, and firm value (Eccles et al., 2014). To a manager, ESG performance is no longer considered as a compliance measure or a reputational instrument, but as a strategic asset that can contribute to risk management, efficiency in operations and competitiveness in the long-term.

Under the ESG, the environmental aspect is relevant to the management of corporate carbon emission. Companies that perform well in their environmental activities have a higher tendency of adopting cleaner technology of production, enhance energy saving, and proactive emission-reduction policies (Porter and van der Linde, 1995). When firms experience more pressure on environmental issues by environmentally aware stakeholders, including regulators, investors, consumers, and communities, these firms will be motivated to do better on environmental issues in order to retain legitimacy and ensure long-term backing. Companies strive to ensure the alignment of their operations with the expectations of society and especially in the sectors where they are concerned with the environmental leadership as a way of maintaining social license to operate (Suchman, 1995).

Although the increasing number of studies demonstrate that ESG engagement can lead to a positive impact on the environment and reduce carbon emissions (F. He et al., 2023), other researchers believe that ESG activities can be symbolic, greenwashed, or lack operational efficiency, particularly in high-carbon industries with a strong technological lock-in (Delmas and Burbano, 2011). This leads to a very crucial question, in what circumstances can ESG performance be successfully used to enhance carbon emission performance among the fuel and energy businesses?

Here, the digital transformation has come out as a potentially decisive enabling factor. Digital transformation can be defined as the process of involving digital technologies, including big data, artificial intelligence, cloud computing, and the Internet of Things, in corporate strategies, organisational structures and operational processes and is one of the basic remodels of creating value and managing resources by firms (Vial, 2019). In the case of fuel and energy companies, digital technologies can be used to be able to

optimize energy consumption, track real-time emissions, improve efficiency, and make informed decisions in environmental management using data (Han et al., 2025).

Regarding environmental governance, the digital transformation may lead to a strong improvement in the ability of a firm to respond to ESG strategies. With developed data analytics and incoming surveillance tools, there is increased precision in the measurement of carbon emissions and minimized information asymmetry and enhanced internal control over the sources of carbon emissions (He & Chen, 2023). The research on ESG performance is mainly based on its immediate influence on carbon emissions, environment efficiency, or green innovation (Broadstock et al., 2021; Liuru et al., 2025). In the meantime, the digital transformation research is more likely to examine its independent effect on productivity, novelty, or emission-reduction output (Li and Li, 2023; Meng et al., 2024).

This literature gap is quite interesting in a number of ways. To start with, fuel and energy companies are better regulated and exposed to higher environmental risks than companies operating in most other business areas, which makes them a perfect venue in which to analyze the efficiency of ESG governance mechanisms. Second, digital transformation in energy-intensive sectors can be associated with significant investment and organisational shifts, which can affect the process of designing and executing ESG strategies. Third, the critique of the moderating nature of digital transformation may offer more detailed information on why ESG performance results in meaningful carbon reduction in certain companies but not in others.

To address this gap, this study examines the relationship between ESG performance and carbon emission performance in Chinese A-share listed fuel and energy companies, with a specific focus on the moderating role of digital transformation. China provides a uniquely relevant setting due to its dual emphasis on carbon neutrality and digital economy development. Using panel data from 2014 to 2023 and a two-way fixed-effects model, this study conceptualizes digital transformation as a **competitive intelligence enabler** that enhances the informational efficiency and strategic execution of ESG governance.

This research contributes to the competitive intelligence literature in three ways. First, it reframes carbon emission performance as a strategic outcome of information-based governance rather than a purely environmental metric. Second, it positions digital transformation as a mechanism that converts ESG governance into actionable intelligence and operational advantage. Third, by focusing on fuel and energy firms, it provides industry-specific insights into how high-carbon companies can achieve sustainable competitiveness through the integration of ESG and digital capabilities.

This study frames carbon emission performance as a competitive intelligence outcome driven by firms' ability to process ESG-related information and convert it into strategic action. Accordingly, this study addresses the following research question: under what conditions does ESG governance translate into superior carbon emission performance in high-carbon energy firms, and how does digital transformation shape this process?

2. THEORETICAL FRAMEWORK

From a competitive intelligence perspective, digital transformation enhances firms' information acquisition, analytical capacity, and decision speed, thereby shaping the effectiveness of ESG governance. In this study, ESG performance is conceptualized as a strategic governance signal, while digital transformation represents an internal competitive intelligence capability that enhances information accuracy, monitoring, and execution. Carbon emission performance is therefore treated as an outcome of firms' information efficiency rather than regulatory compliance alone.

At a firm level, the ESG performance is defined as the degree to which the firms internalize the environmental externalities, consider the expectations of all stakeholders and establish effective governance systems that provides the firms with long-run sustainable operations. Digital transformation, in its turn, enhances the capacity of the firms to operationalize ESG strategies by enhancing the quality of information processing, accuracy and efficiency of the information monitoring, as well as allocation of resources. The combination of these two dimensions is particularly acute to the fuel and energy companies, the process of the reduction of the emissions will demand not only a strategic investment, but also the high level of technological support.

2.1 ESG Performance and Corporate Carbon Emission Performance

Carbon emissions can be viewed as a canonical negative externality, as taken into consideration through the lens of environmental economics. Companies which do not internalize the entire social cost of emissions are likely to over-produce output that is carbon-intensive (Pigou, 1920). ESG performance is a mechanism of internal governance that the firms can voluntarily internalize the environmental externalities by employing more stringent environmental standards, enhancing transparency, and enhancing accountability. In this light, it is possible to consider ESG performance as a continuation of environmental regulation in the firm, which guides the managerial behavior in a more sustainable production decision.

Companies have to balance the interests of various parties such as regulators, investors, customers, employees and surrounding communities. Companies that are actively involved in ESG activities tend to build better environmental management framework, amplified risk-management apparatus, and heightened alignment within the organizational parts (Eccles et al., 2014). Such abilities give the firms the ability to find sources of emissions more precisely, streamline the production processes and reduce energy wastes and eventually enhance carbon emission performances.

All these theoretical arguments predict the positive nexus between ESG performance and corporate carbon emission performance in fuel and energy companies. Companies that have a better ESG performance will tend to bring environmental factors in strategic decision-making, invest resources in emissions-cutting efforts, and get more productive carbon results.

2.2 Digital Transformation and Environmental Governance

Digital transformation can be defined as the implementation and use of digital technologies, including big-data analytics, artificial intelligence, cloud computing, and the Internet of Things in the business model, organizational structure, and business processes of firms (Vial, 2019). The past few years have been characterized by digital transformation that has significantly changed the way companies handle information, organize resources as well as react to environmental issues.

Digital technologies significantly reduce the information asymmetry and transaction costs in the framework of environmental governance. The modernized monitoring systems would allow tracking the energy usage and carbon emissions in real-time so that firms could identify the areas of inefficiency and carbon emissions more specifically (Bai et al., 2022). Predictive analysis and optimization of the processes also occur with the help of big-data analytics and artificial intelligence, which help companies to reduce energy waste and maximize emission efficiency. These abilities are particularly useful to fuel and energy companies, the processes of which are complicated and carbon-consuming.

Online resources enhance transparency and enhance the quality of disclosure of ESG information, which will strengthen external control by investors, regulators, and the general population. Increased transparency puts reputational pressures on companies to improve real environmental performance but not take part in ESG window dressing.

Digital transformation is also a foundation of innovation based emission reduction. The digital tools would assist a business to pilot test new methods of production, streamline supply chains, and utilize renewable energy sources in a better manner. Empirical scholars demonstrate that more environmentally and more emission reduction successful digital transformed organizations are more likely to perform better (Li and Li, 2023; Zheng et al., 2023). The outcomes of such show that digital transformation is not only the technological improvement but also the strategic enabler of sustainable development.

2.3 The Moderating Role of Digital Transformation

Though ESG performance has strategic direction and governance motivation to reduction of emission, it is based on the ability of firms to operate. The ESG turnover of promises into actual carbon-reducing outcomes in energy and fuel firms might need elaborate technological assistance. The digital transformation is a moderating factor in the process which is essential because it intensifies the relationship between ESG performance and carbon emission performance.

First, the digital change enhances the performance of ESG strategies implementation. The higher the levels of digital transformation of companies, the higher are the chances to track environmental indicators, invest in emission-reduction processes, and quantify the results of the ESG initiative. As a result, the discrepancy between ESG intentions and reality environmental performance is reduced. On the other hand, companies that are less digitized might not easily operationalize ESG commitments, which means that

they have small emission cuts despite high ESG scores.

Second, digital transformation precludes the threat of symbolic ESG implementation and greenwashing. Digital technologies increase the credibility of the information about ESG disclosure and make superficial environmental practices more challenging to maintain by enhancing the accuracy and transparency of the information. In this regard, the digitally advanced firms are more apt to have an ESG performance that represents within the realms of environmental endeavor and leads to greater improvements in carbon emission performance.

Third, digital transformation increases the impacts of innovation of ESG governance. ESG oriented companies are predetermined to undertake green innovation though the success of the green innovation will rely on the sound technological infrastructure and data integration. Digital transformation provides the tools needed in experimentation, learning, and continuous improvement, which help firms to attain long-term emission reduction.

On the basis of the analysis above, this research hypothesizes the existence of a positive relationship between ESG performance and corporate carbon emission performance, as well as the positive moderating effect of digital transformation on the same. The theoretical propositions form the basis on which the empirical hypotheses discussed in the following sections are built.

Table 1 Theoretical mechanisms and competitive intelligence logic

Element	**Role**	**CI mechanism**
ESG performance	Strategic governance	Sets sustainability priorities
Digital transformation	Capability	Reduces information asymmetry
Carbon performance	Outcome	Reflects decision efficiency

3. METHOD

The research design is a quantitative empirical study that seeks to examine the impact of the environmental, social, and governance (ESG) performance on the carbon emission levels of fuel and energy businesses, and the moderating role of digital transformation. The adoption of panel data and econometric methods will aim at achieving causal relationships, which takes into consideration firm and time specific heterogeneity.

The sample and data sources will be described as follows:

3.1 Sample Selection and Data Sources

The sample of the empirical data includes fuel and energy companies that are listed in the Shanghai and Shenzhen A-share markets during the 2014-2023 years. The industry classification is based on the standard of China Securities Regulatory Commission. In ensuring data integrity, entities marked as ST or ST were eliminated and the observations

where key variables are missing were eliminated. Upon the screen and cleaning, a balanced sample of 82 firms offering 713 firm-years observations was determined. Standardized ESG ratings were used to derive ESG performance measures which were converted into ordinal numeric measures to be analyzed quantitatively. The information on the indicators of the digital transformation and financial metrics was obtained in the best corporate finance and digitalization databases. The entire data processing and analyses were made through Excel and Stata.

3.2 Variable Measurement

3.2.1 Dependent Variable

The dependent variable is the corporate carbon emission performance. Due to the low direct company-level reporting of carbon emissions, an indirect proxy was employed, which is operating revenue per unit of carbon emissions, which was in turn transformed to a natural-logarithmic form. The higher the values of this measure, the better the performance in terms of carbon emission meaning it produces high economic output at a given unit of carbon emitted.

3.2.2 Independent Variable

ESG performance is the main independent variable, which is operationalized as ordinal scores based on ESG ratings. A higher score indicates stronger all-round ESG performance which includes being a good steward of the environment, socially responsible, and good governance practices.

3.2.3 Moderating Variable

The digital transformation is realized using a composite index of strategic orientation, technological adoption, organizational empowerment, environmental support, digital achievements, and results. High index scores represent a higher degree of digital transformation.

3.2.4 Control Variables

The model includes some of the firm-level controls that are used to isolate the ESG-carbon performance relationship; these are financial leverage (total liabilities/total assets), profitability (return on equity), firm size (log of total assets), operating efficiency (asset turnover ratio) and, finally, ownership concentration (shareholding proportion of the top ten shareholders). These checks reduce confounding factors of the financial structure, the operating capacity, and governance disparities. Table 2 gives the Variable definition and operationalization

Table 2 Variable definition and operationalization

Variable type	Variable name	Definition	Measurement	Strategic / analytical justification
Dependent variable	Carbon emission performance (LNCEP)	Firm-level efficiency in generating economic output per unit of carbon emissions	Natural logarithm of operating revenue divided by total carbon emissions	Captures carbon efficiency rather than emission scale, reflecting firms' ability to convert environmental governance into operational performance
Independent variable	ESG performance (ESG)	Overall sustainability governance quality encompassing environmental, social, and governance dimensions	Standardized ESG rating score converted into ordinal numerical values	Represents firms' commitment to sustainability governance and strategic accountability
Moderating variable	Digital transformation (Digital)	Degree of firm-level digitalization and technological capability	Composite digital transformation index based on digital strategy, technology adoption, organizational empowerment, and digital outcomes	Reflects firms' information-processing capability and competitive intelligence infrastructure
Control variable	Financial leverage (Lev)	Firm's financial risk exposure	Total liabilities divided by total assets	Controls for capital structure effects on environmental investment capacity
Control variable	Profitability (ROE)	Firm's operating performance	Return on equity	More profitable firms may have greater resources for emission reduction
Control variable	Firm size (Size)	Scale of firm operations	Natural logarithm of total assets	Larger firms may benefit from economies of scale in emission management
Control variable	Operating efficiency (Turnover)	Efficiency of asset utilization	Asset turnover ratio	Controls for operational intensity effects on emissions

Control variable	Ownership concentration (Top10)	Governance structure	Shareholding proportion of top ten shareholders	Controls for governance influence on strategic decision-making

Source: Prepared by the authors

3.3 Model Specification

It is a fixed-effects, two-way, model that includes firm and year fixed effects, to explain unobservable heterogeneity and macroeconomic shocks, which could impact carbon emission performance. The moderating role of the digital transformation is discussed through an interaction term between ESG performance and the digital transformation index. The digital transformation in the ESG-carbon performance association is statistically significant and has a positive or negative value depending on the value of this interaction coefficient. Figure 1 illustrates the empirical framework of this study. ESG performance is specified as the primary explanatory variable influencing corporate carbon emission performance. Digital transformation functions as a moderating capability that enhances firms' information accuracy, monitoring efficiency, and execution of ESG-driven strategies. Firm-level and year-level fixed effects are incorporated to control for unobserved heterogeneity.

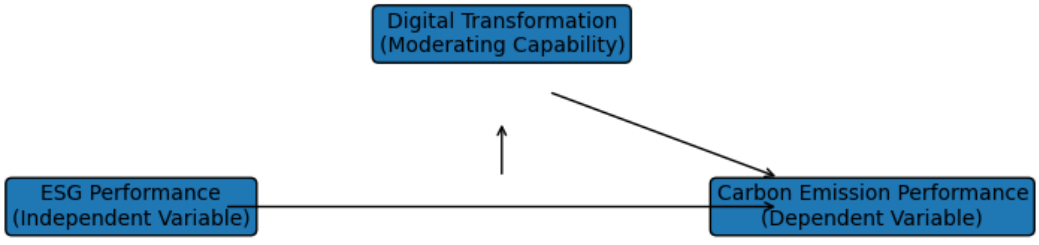


Figure 1. Empirical model of ESG performance, digital transformation, and carbon emission performance

3.4 Estimation Strategy

Fixed-effects estimation of the panel regression analysis is done to overcome the possibility of bias due to unobserved heterogeneity.

3.5 Robustness Test

The strength of the results is supported with various diagnostics. To eliminate

exogenous shocks that can confound firm operations and carbon emissions data, first, the observations during the COVID-19 period will be eliminated. Second, all the explanatory variables are one-period lagged to address the issue of endogeneity and reverse causality. Similar findings in these alternative specifications are evidence of the strength of the empirical findings.

4. RESULTS AND DISCUSSION

In this section, the study empirical findings are presented and discussed. Taking into consideration the mentioned research objectives, the analysis will be organized in the following order; first, the statistical nature of the sample will be described, then the initial relationship between environmentally sustainable governance (ESG) performance and carbon emission performance will be assessed, the moderating impact of digital transformation will be evaluated, and, ultimately, the strength of the findings will be evaluated. The argument incorporates the econometric evidence as well as the economic nature of the fuel and energy industry.

4.1 Descriptive statistics and industry characteristics

The fuel and energy sector is a carbon-intensive sector with strong regulatory control and growing pressure to follow the green transformation path. Companies in this industry are highly heterogeneous in terms of size, profitability, operations system and technology and this is represented in their environmental impact.

Table 3 gives the descriptive statistics of the key variables. The average carbon emission performance (LNCEP) is 9.611 with a standard deviation of 1.297 that shows that there is significant variation in the efficiency of emission across the fuel and energy companies. The gap between the maximum (11.910) and minimum (5.300) values is large, indicating that some corporations have attained rather high values of economic output, as a unit of carbon emission, whereas others are very carbon-intensive.

The average ESG score is 4.162 and the values are between 1 and 7 showing disequilibrium in ESG development among firms. This dispersion means that the ESG governance practices remain in their early and differentiated setting in the fuel and energy sector. Digital transformation index means 31.14 and standard deviation 6.036, which indicate that the majority of firms have already started to do digital transformation, but the extent and efficiency of digitalization is quite different.

Table 3 Descriptive statistics of main variables

Variable	Mean	Std. Dev.	Min	Max	N
LNCEP	9.611	1.297	5.300	11.910	713
ESG	4.162	1.116	1.000	7.000	713
Digital	31.140	6.036	23.060	50.140	713
Lev	0.560	0.151	0.137	0.868	713
Roe	0.071	0.082	-0.226	0.294	713
Size	23.920	1.570	20.540	28.500	713
Turnover	0.420	0.237	0.091	1.462	713
Top10	44.760	17.280	11.790	82.550	713

Source: Prepared by authors (The descriptive statistics are based on the final balanced panel used in the regression analysis, consisting of 82 firms and 713 firm-year observations)

On the whole, the descriptive statistics are variable enough to be subjected to the econometric analysis and reflect the structural features of the fuel and energy industry over the course of the considered sample.

4.2 Baseline Regression Results

An Environmental, Social and Governance (ESG) performance on carbon emission performance was also examined using a two-way fixed-effects model. The resulting findings of the baseline regression are as summarized in Table 4.

Column (1) provides regression estimates which control firm-level and year-level fixed effects only. Column (2) adds control variables of firms to the specification. ESG coefficient has maintained the positive signs and statistically significant at the 5% level though with reduced magnitude. This finding shows that the positive association between the ESG performance and the carbon emission performance is strong to the addition of controls of financial structure, profitability, firm size, operating efficiency, and ownership concentration.

Table 4 Baseline regression and moderating effect results

Variables	(1) LNCEP	(2) LNCEP	(3) LNCEP	(4) LNCEP
ESG	0.012***	0.006**	0.006**	-0.075**
Digital			0.000	-0.013***
ESG × Digital				0.002**
Lev		-0.114***	-0.124***	-0.124***
Roe		1.677***	1.671***	1.453***
Size		0.098***	0.090***	0.012
Turnover		-0.052**	-0.068***	-0.230***
Top10		-0.001	-0.000	-0.000
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	713	713	713	713
R^2	0.995	0.998	0.998	0.997

Source: Prepared by authors

Economically, the results at the baseline would indicate that ESG governance functions to increase the efficiency of emissions, and it does not have a purely symbolic or reputation role. In the energy sector and oil industry in particular, companies that regard the ESG seriously tend to streamline their energy mixes, invest in more environmentally-friendly technologies, and strengthen their internal environmental management frameworks, thus achieving a high level of carbon emissions performance.

Economically substantive effects are seen in control variables. The relationship between profitability and size of firm is positive in relation to both carbon emission performance and should this be considered as a positive relationship since larger firms and profitable firms are more able to fund emission-reduction projects. On the other hand, financial leverage and asset turnover have a negative impact, meaning that an increased financial strain and large scale expansion to operations can hinder environmental performance.

4.3 Moderating Effect of Digital Transformation

In order to find the extent to which the digital transformation mediates the correlation between ESG performance and carbon emission performance, the terms of interaction were included in regression. The results of regression analysis in column (3) provide ESG performance and digital transformation simultaneously. The interaction term between ESG performance and digital transformation is contained in column (4). The coefficient of interaction is positive and significant at the 5% level, which means that the digital transformation can strengthen the positive impact of ESG performance on the carbon emission performance. This finding supports the existence of substantive moderating effect.

These findings indicate that ESG governance produces environmental value only when supported by adequate digital intelligence. Digital transformation acts as a force multiplier, enabling firms to transform ESG commitments into measurable carbon efficiency. This explains why ESG performance alone may remain symbolic in low-digital firms. The conceptual model in Figure 2 explains how ESG performance can have a marginal impact on carbon emission performance in different levels of digital transformation. The ESG performance gradient is steeper with the higher the level of digital transformation, which implies that companies that are more digitally endowed can better translate ESG promises into actual emission-reduction performances.

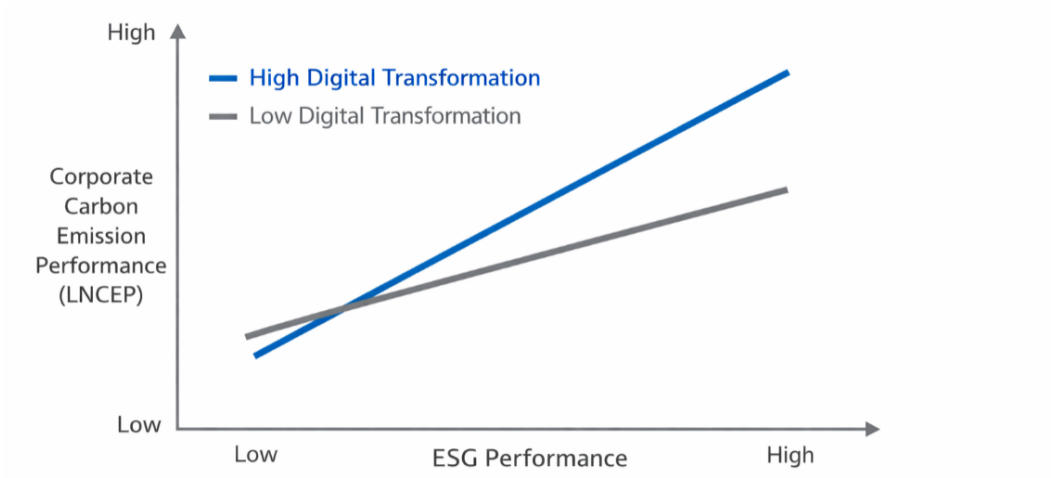


Figure 2. Moderating effect of digital transformation on the ESG–carbon emission performance relationship

As a managerial suggestion, the implications of the findings are that ESG governance and digital transformation cannot be substituted, but complement each other. Digital technologies enhance the accuracy of monitoring, transparency of data, optimization of processes, which reduces the implementation gap between ESG strategies and performance outcomes. In much digitalized companies ESG performance is more likely to be a substantive environmental enhancement and not a symbolic one.

This finding extends prior ESG–environmental performance studies by demonstrating that digital capability is a necessary condition for ESG effectiveness in high-carbon industries, rather than a parallel influence.

4.4 Robustness Analysis

In order to make the empirical findings reliable, several robustness tests had been performed. Table 5 reports the results.

To begin with, the observations during the COVID-19 period were not included to avoid the effects of exogenous shocks on the operation of firms. The ESG coefficient is statistically significant and positive at the 1% level, which means that the conclusion of the baseline is not based on the pandemic-related anomalies.

Second, all the explanatory variables were lagged by one period so as to address the possibility of endogeneity and reverse causality. The lagged ESG coefficient at the 5% level is still positive and significant, which indicates that the ESG performance is a continuing influence on the future carbon emission performance.

Table 5 Robustness test results

Variables	Excluding COVID	Lagged model
ESG	0.020***	0.007**
Lev	-0.318***	0.110***
Roe	2.019***	1.030***
Size	0.067***	0.032***
Turnover	-0.064***	-0.007
Top10	0.001***	0.003***
Firm FE	Yes	Yes
Year FE	Yes	Yes
R^2	0.999	0.997

Source: Prepared by authors

The robustness tests support a positive nexus between ESG performance and carbon emission outcomes, further showing that digital transformation is a moderator of this relationship, a trend that is also consistent in a diverse model specification.

5. FINAL CONSIDERATIONS

This paper discusses the effect of the Environmental, Social, and Governance (ESG) performance on the carbon emission performance of the fuel and energy companies with the digital transformation moderating its impact. The study based on panel data of the A-share listed fuel and energy companies in China and a two-way fixed-effects model can give the empirical data on the joint effect of sustainability governance and digital capability on the corporate environmental performance of high-carbon sectors.

The result also coincides with the view that the ability of the firms to internalize the environmental externality and maximize operational efficiency is increased due to their effective sustainability governance (Hart and Dowell, 2011; Khan et al., 2016).

The second significant finding is that digital change grows intensely the strong relationship between ESG performance and carbon emission performance. The high degree of interaction means that ESG governance alone may not be an appropriate step to achieve a significant output as far as emission reduction is concerned unless that companies possess enough digital capacities. The digital technologies are able to improve the precision of data, track performance, and the optimization of processes that enables firms to turn the ESG promises into actual environmental outcomes (Verhoef et al., 2021). Such an observation is in line with the stand that sustainability governance and digital transformation are not independent strategic aspects but complementary.

Third, the findings suggest that ESG governance in reality vary in effectiveness of firms. Companies with better digital structure, granting them more capital and allowing them to be more flexible in terms of organization can more easily accomplish environmental returns on ESG participation. This observation is consistent with the past

findings that show that sustainability strategy performance outcomes are a matter of firm-level abilities (Aguilera et al., 2007). On the other hand, possibly, the firms, which have technological or financial constraints, may experience lower environmental payoffs of ESG investment.

5.1 Policy and Managerial Implications

The introduction of ESG-oriented regulatory frameworks along with the disclosure provisions can contribute to the emission reduction in the event that they are supplemented by the policies increasing the digitalization of industries. The governments can help make the ESG rule more environmentally efficient by encouraging digital solutions, such as smart energy and data-driven platforms of environmental monitoring (OECD, 2021).

To corporate administrators, the findings highlight the importance of including ESG management in digital transformation plans and not considering it as an independent compliance exercise. Companies are expected to incorporate ESG targets into digitalized management systems to help them monitor carbon emissions in real time, assess performance, and optimize it continuously. The combined strategy can be used to enable companies to attain environmental and long-term competitiveness (Bohnsack et al., 2014).

To the investors, the study recommends that ESG ratings be read in conjunction with the levels of digital transformation in the firms. The performance of ESG is more likely to be converted into actual environmental value in case the firms have adequate technological capacity. ESG performance measurement alongside digital maturity could thus be a better measure of long-term sustainability potentials in firms (Berg et al., 2022).

5.2 Limitations of the study

Although this study made contributions, it has a number of limitations. The first is that carbon emission performance is calculated on an indirect proxy as opposed to direct firm level-based emission data. This is a popular method though it might not represent the absolute levels of emissions. Second, the sample will include solely Chinese A-share of fuel and energy firms. The differences in institutional factors, regulatory frameworks, and the state of digital infrastructure across countries can be a limitation to the external validity of the findings.

Third, ESG performance is established in an index form that can conceal the different impacts of the environmental, social, and governance components. According to prior research, the effect of various ESG elements on environmental outcomes could be heterogeneous (Khan et al., 2016). Lastly, endogeneity issues may be addressed by the use of lagged variables, but unobservable variables and the dynamics on the feedback can still influence the estimated associations.

5.3 Future Research Directions

This study can be developed by future research in a number of ways. To begin with, researchers might utilize company level disclosure of carbon or satellite emission information to have more accurate indicators of environmental performance. Second, the comparative studies at the cross-country level might be implemented to explore the possibility of the moderating role of digital transformation being different in various institutional settings and regulatory frameworks.

Third, future research can break down ESG performance into individual dimensions in order to investigate its discriminating impacts on carbon emission performance. Fourth, the nonlinear or threshold models may be used to examine the hypothesis of diminishing or increasing marginal effect of digital transformation towards ESG effectiveness. Lastly, qualitative research approaches, e.g., case studies or interviews, may allow gaining a better understanding of internal firm coordination of ESG governance and digital transformation in practice.

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