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Impact of Corporate Digital Transformation on ESG Performance: An Empirical Study Based on A-Share Listed Companies in the Power Industry

Miaoyan Guan[1]

[1] Business School, Nanjing University, Nanjing, Jiangsu 210089, China

Correspondence: Miaoyan Guan, Business School, Nanjing University, Nanjing, Jiangsu 210089, China.

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Abstract

Rapid advances in digital technologies (e.g., cloud computing, big data, artificial intelligence, Internet of Things) have revolutionized business operations, yet the impact of such corporate digital transformation on corporate ESG performance remains unclear. To address this gap, we empirically study China's power industry by examining a-share listed power companies from 2011 to 2022—a sector pivotal for national carbon neutrality goals and sustainable development. We use the China Securities Index (CSI) ESG ratings as a performance metric to assess how digital transformation affects outcomes across environmental, social, and governance dimensions. We find that digital transformation significantly improves overall ESG performance, boosting energy efficiency and reducing carbon emissions, improving service quality and corporate social responsibility, and strengthening transparency and risk management. Our study confirms the positive role of digitalization in corporate sustainability. It also provides insights for industry leaders and policymakers to leverage digital transformation in advancing sustainable development and informing effective ESG policies.

Keywords: digital transformation, ESG performance, sustainable development, corporate governance

1. Introduction

1.1 Research Background and Significance

1.1.1 Research Background

ESG, which stands for Environmental, Social, and Governance, is a key factor in long-term value creation and sustainable development for enterprises. Currently, existing literature has mainly focused on improving ESG systems, ESG investment strategies, and the impact of ESG on corporate performance. However, an analysis of the current literature reveals that the focal points of ESG research need to be expanded. Relatively few studies investigate the internal factors affecting a company's ESG performance, and research that involves the factor of corporate digital transformation is even more scarce; related studies are not yet sufficient.

This research targets listed companies in the power industry, exploring how the implementation of digital transformation by these enterprises affects their ESG performance, and providing new ideas for companies to improve ESG performance.

As one of the fundamental industries crucial to the national economy and people's livelihoods, the power industry achieved considerable development in the past by relying on traditional energy sources. But with the gradual implementation of global climate change agreements and continuous advancements in clean energy technology, the power industry is undergoing an unprecedented transformation. This transformation requires not only adjustments in the energy structure but, more importantly, the use of digital means to enhance operational efficiency, strengthen energy management, and reduce carbon emissions and other environmental impacts.

In this study, we choose the power sector for empirical research mainly because this industry is representative in its response to digital transformation and pursuit of ESG standards. First, the power industry has significant environmental impacts, including air quality, water resource protection, and greenhouse gas emissions, which demands that companies in the industry actively seek solutions to reduce environmental impacts through digital upgrades. Second, as providers of public services, power companies are closely connected to society, making the fulfillment of their social responsibilities even more important.

Therefore, a deep exploration of the ESG performance of power sector companies during the process of digital transformation is of great significance for evaluating the actual effectiveness of digital transformation and guiding enterprises to implement transformation strategies that align with sustainable development goals. On one hand, it can help corporate management better understand the relationship between digital investment and ESG performance, prompting companies to plan transformation paths more prudently and efficiently. On the other hand, findings from the power industry can also serve as a reference for other industries pursuing coordinated development of digitalization and ESG.

1.1.2 Research Significance

First, promoting ESG management practices. The research findings have referential value for the power industry and other industries in advancing ESG management practices. As a fundamental industry related to the national economy and people's livelihoods, the power industry's digital transformation has important demonstrative significance for its impacts on environment, society, and governance. By deeply exploring the impact of digital transformation on ESG, this study can provide enterprises with new ideas and methods to improve ESG performance.

Second, facilitating the achievement of sustainable development goals. Digital transformation has the potential to improve environmental sustainability, social responsibility, and corporate governance in the power industry. By thoroughly studying the impact of digital transformation on ESG performance in the power industry, companies can better understand and address sustainable development challenges, thereby promoting the realization of sustainable development goals.

Third, opening up new academic research areas. Currently, there is limited research on the impact of digital transformation on ESG, especially in the specific context of the power industry. This study fills this gap and provides a new research perspective and theoretical contribution for academia concerning the relationship between digital transformation and ESG.

1.1.3 Digitalization in the Power Industry and ESG

As an important infrastructure for national economic and social development, the operational models and technological innovations of the power industry have significant implications for environment, society, and governance (ESG). In the context of global climate change and environmental protection, the digital transformation of the power industry is seen as a key path to improving ESG performance.

With the rapid development of information technology, the power industry is gradually transforming toward digitalization and intelligence. The application of digital technology in power companies is mainly reflected in the following aspects: First, smart grids leverage IoT, big data, and AI technologies to achieve intelligent management of power generation, transmission, distribution, and consumption. Smart grids can monitor and adjust power supply in real time, optimize the allocation of power resources, and improve the reliability and efficiency of the power system. Second, modern energy management systems use digital technologies to monitor and optimize energy production and consumption in real time. Through big data analysis, enterprises can identify points of energy waste and formulate corresponding energy-saving measures, thereby improving energy utilization efficiency and reducing operating costs. Lastly, using AI and other advanced technologies, enterprises can enhance predictive maintenance of equipment, optimize demand forecasting, and improve decision-making processes, which further supports sustainable operations.

In the areas of environment, society, and governance, the performance of power companies is directly related to their sustainable development and fulfillment of social responsibilities. In recent years, with global emphasis on sustainable development, power companies have made significant efforts and achievements in ESG. Power enterprises are actively addressing climate change and environmental challenges by adopting clean energy, optimizing energy use, and reducing carbon emissions. Digital technology plays an important role in improving environmental performance—for example, reducing energy waste and lowering greenhouse gas emissions through smart grids and energy management systems. In fulfilling social responsibility, power companies actively participate in community development and public welfare activities, and they enhance interaction with customers and communities through digital platforms, thereby increasing social responsibility awareness. For instance, by promoting energy-saving education and environmental protection concepts, power companies collaborate with communities to advance sustainable development. In terms of corporate governance, power companies use digital

tools to enhance transparency and compliance, ensuring legal and compliant operations. Blockchain technology and real-time data monitoring systems enable companies to maintain transparent and secure supply chains and to detect potential risks and misconduct promptly, taking preventive measures. Additionally, digital technology can streamline compliance processes, ensuring companies better adhere to laws and regulations and reduce the risk of violations.

In summary, digital transformation in the power industry is likely to have a significant promoting effect on ESG. It not only improves a company's environmental performance and enhances social responsibility, but also strengthens governance structures, driving innovation and development in the industry. By continuously advancing digital transformation, power companies can achieve more efficient and sustainable development, meeting society's demand for green energy and sustainable growth.

H1: Digital transformation has a facilitating effect on corporate ESG performance.

1.2 Research Content and Methods

1.2.1 Research Content

By reviewing and analyzing relevant domestic and foreign literature, this paper explores the relationship between digital transformation and ESG. Next, using Chinese A-share listed companies in the power industry from 2011 to 2022 as the research sample, it investigates how corporate digital transformation influences ESG (environmental, social, and governance) performance, and conducts a series of robustness tests. In addition, the paper examines the pathways through which digital transformation affects the ESG performance of listed companies.

The content of this paper is organized into the following six sections:

The first part is the introduction. It mainly explains the reasons for choosing China's power industry as the research background and significance, highlighting the important status of the power industry in national economic and social development and the potential value of digital transformation in improving ESG performance. It also outlines the main research methods and framework of this study to provide readers with an initial understanding of the research.

The second part is the literature review. Through an extensive review of domestic and international literature on digital transformation and ESG, this section deeply analyzes the connotations, historical development, and current research status of both concepts, and summarizes the shortcomings of existing research. The literature review covers research achievements and gaps in these two areas, laying the foundation for this study.

The third part is the theoretical analysis and research hypotheses. This section proposes three hypotheses. H1: Digital transformation of listed companies in the power industry can promote their ESG performance. H2: Digital transformation improves corporate financial performance, thereby enhancing ESG performance. H3: Digital transformation promotes green technological innovation, thereby enhancing ESG performance. These hypotheses are developed based on theoretical analysis of how digital transformation may influence ESG outcomes, including through financial performance improvement and green innovation mechanisms.

The fourth part is the research design. It describes the data sources, sample selection, variable definitions, and model construction. Specifically, it details the measurement of ESG performance (using the CSI ESG Rating), the construction of the core explanatory variable (digital transformation level), the selection of control variables, the grouping (heterogeneity) variables (ownership nature, Big Four audit, and firm life cycle), and the mediation (mechanism) variables (financial performance measured by Tobin's Q, and green technology innovation measured by number of green patents). It also presents the regression models used to test the hypotheses, including the baseline model, grouped regression models, and a two-stage regression model for mechanism testing.

The fifth part presents the empirical results. This includes descriptive statistics of the variables, correlation analysis, baseline regression results of digital transformation's impact on ESG performance, robustness tests (such as using lagged independent variables, alternative measures for key variables, changing sample periods, etc.), and heterogeneity analysis (examining differences in effects between state vs. non-state enterprises, Big Four vs. non-Big-Four audits, and across different life cycle stages of firms). The empirical results are discussed in detail to verify the proposed hypotheses.

The sixth part is the conclusion. It summarizes the main findings, discusses their implications, and points out the limitations of the research and directions for future study. This section highlights the significant positive impact of digital transformation on ESG performance in the power industry, noting in particular that the effect is more pronounced for non-state-owned enterprises and when audited by non-Big-Four firms, and that the effect is significant primarily for mature-stage companies. It also confirms that financial performance improvement and green technological innovation serve as important mechanisms through which digital transformation enhances ESG performance. Finally, it acknowledges research limitations such as data and model constraints and suggests areas for further research, for instance, investigating causal mechanisms through more in-depth qualitative and

quantitative studies.

1.2.2 Research Method

This study primarily employs an empirical research method, supplemented by literature research. We construct a panel dataset of A-share listed companies in China's power industry and use STATA for statistical analysis to empirically examine the promoting effect of digital transformation on ESG performance. The empirical approach includes panel regression analyses to test the relationship between digital transformation and ESG performance, as well as additional tests for robustness and mechanism analysis. We adopt fixed effects models to control for unobserved heterogeneity across firms and years. Furthermore, we incorporate grouped regressions to explore heterogeneity across different types of firms (e.g., ownership and audit differences) and a two-stage regression approach to examine the mediating mechanisms (financial performance and green innovation). This empirical strategy allows for a comprehensive analysis of both the direct impact of digital transformation on ESG performance and the indirect effects through various channels, ensuring that the findings are robust and the conclusions valid.

2. Literature Review

2.1 Research on Digital Transformation

Digital transformation refers to the process by which enterprises use digital technologies to change business models and operational processes in order to increase efficiency, foster innovation, and build new value creation mechanisms. This process involves not only the introduction and application of technologies, but more importantly a fundamental change in corporate culture, organizational structure, and business strategy. The goal of digital transformation is to leverage technology empowerment to enhance a company's competitiveness and sustainable development capability. In the *Overall Layout Plan for Digital China Construction* (February 2023), goals and strategies for digital development were proposed with the aim of enhancing the digital transformation of China's real economy, thereby improving development quality and level. In this context, more and more enterprises regard digital transformation and upgrading as an important task for future development (He *et al.*, 2023).

Existing research on digital transformation predominantly covers its definition, strategies, and effects on firms. For instance, Vial (2019) defines digital transformation as a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies. Many studies have explored how digital transformation drives innovation and efficiency in enterprises. For manufacturing firms, digital transformation can optimize resource allocation and production processes, leading to improved operational performance (Xu *et al.*, 2024). In the power sector, digital transformation holds great potential; it can significantly improve a firm's ESG performance by optimizing resource allocation, increasing energy efficiency, and promoting sustainable development (Huang *et al.*, 2024). For example, by adopting efficient digital technologies such as smart grids and energy management systems, power companies can use energy more efficiently, reduce waste, and lower carbon emissions, thus enhancing their environmental performance. In addition, digital upgrades that build more transparent and interactive customer service platforms strengthen interactions between enterprises and customers, enhancing social responsibility. Moreover, the application of digital technology helps companies better comply with laws and regulations and strengthen governance structures, such as ensuring supply chain transparency and security through blockchain technology.

2.2 Research on ESG Performance

ESG is often used as a standard to evaluate listed companies or investment portfolios, providing a comprehensive assessment of performance in environmental, social, and governance aspects. In recent years, academic research on corporate ESG performance has been extensive and in-depth. Current research on ESG focuses on conceptual frameworks, rating systems, and value effects. In terms of ESG ratings, Zhao *et al.* (2024) found that discrepancies in ESG ratings significantly reduce company stock returns. Wang *et al.* (2024) argue that firms with divergent ESG ratings may face higher financing and operational risks, which can translate into higher audit fees due to perceived greater risk by auditors. Meanwhile, other studies examine how ESG performance affects corporate value and risk. For example, robust ESG performance is generally linked with lower cost of capital and improved financial performance, as it reflects better risk management and reputation. However, research on internal drivers of ESG performance remains limited. Corporate characteristics such as management quality, ownership structure, and internal policies have been identified as influencing ESG outcomes, but more work is needed to understand these relationships fully. Furthermore, while many studies highlight the benefits of strong ESG performance (such as enhanced corporate value, reduced risk, etc.), some suggest potential trade-offs and costs, noting that implementing ESG practices can involve significant resources and changes in business processes.

2.3 Research on Digital Transformation and ESG Performance

The impact of corporate digital transformation on ESG (environmental, social, and governance) performance is an

important research domain. Domestically and internationally, research on ESG has more often centered on the improvement of ESG frameworks, investment strategies, and corporate performance implications. The power industry is representative in its response to digital transformation and pursuit of ESG standards, yet currently there are very few studies combining digital transformation and ESG in this industry. Existing literature provides some clues: for example, studies have shown that supply chain digitalization and external pressures can influence corporate ESG performance (Li *et al.*, 2024), and that digital innovation can improve a firm's sustainability and social responsibility outcomes (Yang & Han, 2024). Nevertheless, a gap remains in understanding the direct relationship between digital transformation initiatives and ESG metrics. Researchers have called for more industry-specific investigations, arguing that the effects of digital transformation on ESG may vary by sector due to different regulatory environments, stakeholder expectations, and technological adoption levels.

In summary, while digital transformation is recognized as a driver of innovation and efficiency, and ESG performance is an increasingly critical measure of corporate sustainability and social responsibility, the intersection of these two—how digital transformation influences ESG performance—has not been fully explored. The power industry, given its environmental impact and public service nature, serves as an ideal context to study this relationship. This research aims to fill this gap by empirically examining the effects of digital transformation on ESG performance in the power industry and shedding light on the mechanisms behind this relationship.

3. Theoretical Analysis and Research Hypotheses

3.1 Corporate Digital Transformation and Corporate ESG Performance

Digital transformation in the power industry holds enormous potential; it can significantly improve a company's environmental, social, and governance (ESG) performance by optimizing resource allocation, enhancing energy efficiency, and promoting sustainable development (Huang *et al.*, 2024). First, by adopting efficient digital technologies such as smart grids and energy management systems, power companies can achieve efficient energy use, reduce waste, and lower carbon emissions, thereby improving their environmental performance. Second, digital transformation and upgrades strengthen interaction between companies and customers by building more transparent and interactive customer service platforms, thereby enhancing social responsibility. Furthermore, the application of digital technologies helps companies better comply with regulations and strengthen governance structures—for example, using blockchain technology to ensure supply chain transparency and security.

From the environmental perspective, digital transformation helps improve resource utilization efficiency. Smart grid technology allows power production and consumption to become more flexible, adjusting power supply in real time according to demand and reducing energy waste. Additionally, energy management systems can monitor and optimize energy use, helping companies identify and eliminate unnecessary energy consumption, thereby further reducing carbon emissions. By using AI and IoT technologies, companies can achieve more precise energy forecasting and dispatch, optimize energy production processes, and reduce greenhouse gas emissions.

From the social responsibility perspective, digital transformation and upgrades enhance interaction between enterprises and customers through transparent and interactive service platforms, thereby increasing the sense of social responsibility. Digital platforms make it more convenient for customers to access electricity information and services, improving customer satisfaction. Through real-time data feedback and interaction, companies can better understand customer needs and provide personalized services. At the same time, digital technologies can help companies participate more effectively in community activities and public welfare projects, enhancing the company's image and influence in society.

From the governance perspective, digital transformation helps strengthen corporate governance structures and improve operational transparency and compliance. Through blockchain technology, companies can ensure the transparency and security of their supply chains, preventing data tampering and fraud. Real-time data monitoring and analysis enable companies to detect potential risks and misconduct promptly and take preventative measures. In addition, digital technologies can simplify compliance processes, ensuring companies better comply with laws and regulations and reducing the risk of violations.

Overall, digital transformation in the power industry may have a significant positive effect on ESG performance. It improves environmental performance, enhances social responsibility, and strengthens governance structures, thereby driving innovation and development in the industry. By continuously advancing digital transformation, power companies can achieve more efficient and sustainable development, meeting society's demands for green energy and sustainable practices.

H1: Digital transformation positively contributes to a company's ESG performance.

3.2 Mechanisms of the Impact of Digital Transformation on Corporate ESG Performance

3.2.1 Digital Transformation, Financial Performance, and Corporate ESG Performance

Digital transformation is critically important for improving a company's ESG performance. Implementing digital

transformation often requires companies to make investments, such as purchasing new technological equipment and training employees, which help enhance a firm's financial performance. Many ESG indicators are closely related to a company's financial performance (e.g., energy efficiency, production efficiency, employee satisfaction). By boosting financial performance, a company can indirectly improve these ESG indicators, thereby enhancing overall ESG performance.

Moreover, companies with strong financial performance typically have more profits available for reinvestment and fulfilling social responsibilities. Such reinvestments can include strengthening environmental protection measures, improving employee welfare, and supporting sustainable development initiatives, directly improving the company's ESG performance.

These effects occur through mechanisms such as higher production efficiency, increased profitability, reduced labor costs, optimized information flow, and better resource allocation (Liu *et al.*, 2024). Improved financial performance creates a more favorable context for enhancing ESG performance.

H2: Digital transformation promotes ESG performance by improving the company's financial performance.

3.2.2 Digital Transformation, Green Technology Innovation, and Corporate ESG Performance

Digital transformation provides new opportunities for companies to address environmental challenges through **green technology innovation**, thereby enhancing corporate ESG performance. Utilizing digital technology allows for more effective monitoring and management of environmental impacts, optimization of resource use, and promotion of cleaner production and sustainability in operations. The green innovation driven by digital transformation helps reduce firms' reliance on natural resources and cut pollution emissions, thereby improving environmental performance.

In addition, corporate digital transformation helps enhance green technology innovation. Companies can more effectively integrate and analyze environmental-related data, discover and implement more eco-friendly production processes and technologies, and promote the application of clean energy and sustainable development technologies. The innovation and application of green technologies help improve a company's social image and meet the demands of consumers and stakeholders for corporate social responsibility, thus boosting the company's social performance.

Digital transformation also provides better governance tools for companies, promoting improvements in corporate governance. Through digital technology, companies can achieve more efficient transparency and compliance, improving the transparency and effectiveness of corporate governance. This improved governance structure helps enhance the company's governance performance and operational stability, which in turn contributes to better overall ESG performance.

H3: Digital transformation promotes ESG performance by enhancing green technology innovation.

4. Research Design

4.1 Data Sources and Sample

Sample Selection: The study examines relevant data of A-share listed companies in China's power industry from 2011 to 2022.

Data Cleaning: After screening (excluding financially abnormal ST/*ST and PT companies, observations with missing data, and companies lacking major variable data), the final sample consists of 766 firm-year observations.

Data Sources: The ESG performance measures used in this study come from the "CSI ESG Rating" (CSI ESG Rating). The core explanatory variable, digital transformation, is derived from annual report textual analysis (keyword frequency related to digital transformation). Other financial indicators are obtained from the CSMAR database.

4.2 Variable Selection

4.2.1 Dependent Variable

The dependent variable in this study is ESG performance (ESG). ESG ratings are typically provided by third-party agencies to evaluate a company's performance in the environmental, social, and governance dimensions. These ratings help investors and stakeholders understand a company's performance in sustainable development and responsible investment. Widely recognized third-party ratings include the CSI ESG Rating, SynTao Green Finance ESG Rating, etc. Among these, the CSI ESG Rating has unique advantages due to its broad coverage, highly applicable indicators, and consideration of China-specific factors. The CSI ESG Rating system thoroughly covers the three domains of environmental protection, social responsibility, and effective governance. It not only aligns with international ESG evaluation standards but also includes indicators tailored to China's context, which greatly enhances its practicality and relevance in the Chinese market. Referencing the methodology of Wang *et al.* (2023), this paper uses the CSI ESG Rating to measure ESG performance. We convert the CSI ESG rating grades into

numerical scores from 1 to 9.

As shown in Table 1, the CSI ESG Rating is divided into 9 grades, where C is the lowest rating (assigned a value of 1) and AAA is the highest rating (assigned a value of 9).

Table 1. CSI ESG Rating Scale

CSI ESG Rating	**Score**
C	1
CC	2
CCC	3
B	4
BB	5
BBB	6
A	7
AA	8
AAA	9

4.2.2 Core Explanatory Variable

The core explanatory variable is Digital Transformation (Digital). As a key strategy for enterprises to cope with rapidly changing market environments and improve competitiveness, digital transformation has become a hot topic in today's business world. Accurately measuring a company's level of digital transformation is crucial for capturing its true progress in the digital journey. This study's choice and measurement of the core explanatory variable reflect the complex and multi-dimensional nature of this need.

Firstly, using data from the CSMAR database, we consider indices such as a firm's digital application score, technology-driven score, and digital outcome score, which together provide a comprehensive assessment of a company's digital maturity from different perspectives. These scores reflect a company's ability and success in adopting new technologies, driving business model changes, and achieving digital transformation. However, this method may face limitations in data availability and timeliness, especially for firms or industries with less information disclosure.

The second method we employ provides an innovative perspective by using textual analysis. Specifically, we identify five categories of keywords related to digital transformation: "blockchain technology," "artificial intelligence technology," "big data technology," "cloud computing technology," and "digital technology application." By analyzing the frequency of these keywords in annual reports of listed companies, we can objectively reflect the effort and progress companies have made in digitalization. Compared with the first method, this text analysis provides a more direct and up-to-date means of data collection, especially for companies whose digital transformation is difficult to quantify using traditional databases.

Drawing on the research method of Wu Fei *et al.* (2021), we calculate the total frequency of occurrences of the five types of digital transformation keywords in each firm's annual report, add 1, and then take the natural logarithm. This approach helps overcome data limitations, particularly in the power industry where digital disclosure might be relatively scarce. The logarithmic transformation of the raw frequency not only increases the usability of data with low counts of digital keywords but also reduces skewness in the data distribution, making results more robust.

4.2.3 Control Variables

Following Wang Haijun et al. (2023), we include a set of control variables that capture important aspects of a firm's financial and market performance. These control variables are: Profitability: measured by the net profit margin (Net profit / Operating revenue). Growth: measured by revenue growth rate ((Current year operating revenue – Previous year operating revenue) / Previous year operating revenue). Fixed Assets Proportion (FixedAssetsProp): measured by the ratio of net value of fixed assets to total assets. Return on Total Assets (ROTAA): measured by net profit / average total assets. Return on Equity (ROEA): measured by net profit / average shareholders' equity (net assets). These are key indicators for evaluating a company's financial performance and market performance. By including these control variables, the study can more accurately isolate the true impact of digital transformation on ESG performance while accounting for other important financial and operating characteristics that might influence ESG outcomes. This approach enhances the reliability of the study

and the validity of its conclusions.

4.2.4 Grouping Variables

This study selects three grouping (heterogeneity) variables—ownership nature (Soe), whether audited by a Big Four accounting firm (Big4), and corporate life cycle (Life)—which represent two key dimensions of a firm's internal governance structure and external oversight mechanism, plus a stage of corporate development.

(1) Ownership Nature (Soe): We use the ownership type to classify companies as state-owned or non-state-owned. State-owned enterprises (SOEs) are coded as 1, and non-SOEs as 0. This distinction facilitates analysis of whether state-owned companies differ significantly from non-state-owned companies in digital transformation and ESG performance. Considering that SOEs may have different characteristics due to government support, emphasis on social responsibility, etc., this grouping variable provides a basis for exploring these differences.

(2) Big Four Audit (Big4): This variable assesses external audit quality. If a company's financial statements are audited by a Big Four accounting firm (PwC, Deloitte, EY, or KPMG), Big4 is coded as 1; otherwise 0. It is posited that companies audited by Big Four firms exhibit higher financial transparency and governance quality, which may influence their ESG performance and digital transformation strategies. Audit quality, as an external constraint and supervision mechanism, can affect a company's strategic choices and execution effectiveness, so including it helps reveal the potential impact of external oversight on ESG and digital initiatives.

(3) Corporate Life Cycle (Life): Companies typically experience stages such as growth, maturity, and decline, each with different focuses and objectives. During the growth phase, firms prioritize expanding market share and innovation; in maturity, they emphasize efficiency and optimization; in decline, they focus on cost control and restructuring. The impact of digital transformation on ESG performance likely depends on these differing priorities and goals at each stage. We choose the corporate life cycle as a grouping variable because challenges, goals, and development strategies differ across life cycle stages, which will directly influence how digital transformation affects ESG performance. Based on a firm's cash flow characteristics, the life cycle stage can be evaluated, often using a cash flow portfolio method to categorize into introductory, growth, mature, and decline stages. Referring to Liu Fangyuan (2024), we primarily classify power companies into three stages: growth, mature, and decline, using dummy variables: growth stage = 1, mature stage = 2, decline stage = 3. The cash flow combinations corresponding to each life cycle stage are shown in Table 2.

Table 2. Cash Flow Classification for Three Life Cycle Stages

Cash Flow Type	**Growth Stage**		**Mature Stage**	**Decline Stage**			
Net cash flow from operating activities	-	+	+	-	+	+	-	-
Net cash flow from investing activities	-	-	-	-	+	+	+	+
Net cash flow from financing activities	+	+	-	-	+	-	+	-

(*"+" indicates positive net cash flow, "–" indicates negative net cash flow.*)

4.2.5 Mechanism Variables

(1) Financial Performance Indicator (TPQ): Existing research often uses Tobin's Q (TPQ) to measure a company's financial performance (Liu Fangyuan *et al.*, 2024). Digital transformation can improve a company's financial performance (as reflected by TPQ), which in turn can provide more resources for environmental protection, improving employee conditions, and fulfilling public responsibilities, thus promoting the company's ESG performance.

(2) Green Technology Innovation (Patent): Green technology innovation refers to the various technological innovations adopted by power companies in their production and R&D processes that effectively achieve energy savings and emission reductions, reducing the environmental damage caused by production activities. Drawing on the work of Jia Guangyu (2024), we use the total number of authorized green patents to measure a company's green technology innovation.

To summarize the variables, Table 3 provides an overview and definition of all major variables used in the study.

Table 3. Variable Definitions

Variable Type	**Variable Code**	**Variable Name**	**Measurement Method**
Core	Digital	Degree of Digital	Natural log of (1 + total count of digital

Explanatory		Transformation	transformation-related keywords in annual report)
Dependent	ESG	Corporate ESG Performance	CSI ESG Rating score (1–9 scale)
Grouping	Soe	Ownership Nature	Dummy variable: 1 if state-owned enterprise, 0 if not
Grouping	Big4	Big Four Audit	Dummy variable: 1 if audited by Big Four firm, 0 if not
Grouping	Life	Life Cycle Stage	Growth = 1, Mature = 2, Decline = 3 (based on cash flow patterns)
Control	Profitability	Profitability	Net profit / Operating revenue
Control	Growth	Growth	(Current revenue – Previous revenue) / Previous revenue
Control	FixedAssetsProp	Fixed Assets Ratio	Net value of fixed assets / Total assets
Control	ROTAA	Return on Total Assets	Net profit / Average total assets
Control	ROEA	Return on Equity	Net profit / Average shareholders' equity (net assets)
Mechanism	TPQ	Tobin's Q	Market value to asset replacement cost ratio
Mechanism	Patent	Green Technology Innovation	Total number of authorized green patents

4.3 Model Specification

4.3.1 Main Regression Model

To explore the channels and influencing factors through which digital transformation affects ESG performance in the power industry, we establish the baseline regression Model (1) as follows:

$$ESG_{it} = \alpha_0 + \beta_1 Digit_{it} + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}1)$$

In the above equation, *i* represents the firm and *t* represents the year. *Controls* represents the set of control variables (Profitability, Growth, FixedAssetsProp, ROTAA, ROEA). λ_i denotes firm fixed effects, μ_t denotes year fixed effects, and ε is the random error term. The coefficient β reflects the impact of digital transformation on ESG performance in the power industry. A significantly positive β would indicate that digital transformation has a positive effect on ESG performance.

4.3.2 Grouped Regression Models for ESG Performance

In discussing the differential impacts of digital transformation on ESG performance in the power industry, we consider factors of ownership nature (Soe), Big Four audit (Big4), and corporate life cycle (Life) to more accurately understand how these factors separately or jointly affect corporate ESG performance.

To examine whether digital transformation in state-owned enterprises in the power industry has a more pronounced effect on ESG performance, Model (2) builds on Model (1) by adding the ownership nature factor. This step aims to identify whether the special attributes of state-owned enterprises—such as policy support and a heightened sense of responsibility and mission—can enhance ESG performance by accelerating digital transformation. In state-owned enterprises, digital transformation is viewed not only as a means to improve operational efficiency and service quality but also as a key path to achieving sustainable development goals.

On the other hand, non-state-owned enterprises often exhibit more flexibility in organizational structure and management style, allowing them to quickly adapt to market changes and experiment with new technologies. Digital transformation may be easier to implement in such firms and yield faster results. Therefore, digital transformation may show different effects in promoting ESG performance between state-owned and non-state-owned power companies.

Building on Model (1), we further establish Model (2) as follows (including an interaction term for Soe if applicable):

$$ESG_{it} = \alpha_0 + \beta_1 Digit_{it} + \beta_2 Digit_{it} * Soe + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}2)$$

Model (3) extends Model (1) by adding the Big4 audit variable. This step aims to investigate the impact of digital transformation on corporate ESG performance in the context of Big Four audits. Audits by Big Four accounting firms are widely recognized for enhancing a company's financial transparency and governance quality, which may prompt firms to pay more attention to improving ESG performance during their digital transformation. Because a Big Four audit can have a potentially positive impact on corporate governance structures, this external oversight might amplify the effect of digital transformation on ESG performance.

Conversely, non-Big-Four audit firms might offer more cost-effective services, allowing companies to allocate more resources and funds to digital transformation and ESG-related projects instead of incurring high audit fees.

To study how digital transformation affects ESG performance for power companies under Big Four audits, we construct Model (3) based on Model (1) as follows:

$$ESG_{it} = \alpha_1 + \beta_2 Digit_{it} + \beta_2 Digit_{it} * Big4 + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}3)$$

Power industry companies can be categorized into growth, mature, and decline stages. Each stage presents different challenges and opportunities, and the impact of digital transformation on ESG performance may vary accordingly.

To explore the effect of digital transformation on ESG performance across different life cycle stages of power companies, we develop Model (4) based on Model (1) as follows:

$$ESG_{it} = \alpha_1 + \beta_2 Digit_{it} + \beta_2 Digit_{it} * Life + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}4)$$

4.3.3 Mechanism Test Regression Model

To demonstrate that digital transformation in the power industry can promote ESG performance by improving firms' green technological innovation and financial performance, we construct a two-stage regression model under the baseline regression framework as follows:

$$MV_{it} = \alpha_2 + \beta_3 Digit_{it} + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}5)$$

$$ESG_{it} = \alpha_3 + \beta_4 MV_{it} + \sum_j \beta_j \, Controls_{it} + \mu_t + \lambda_i + \varepsilon_{it} \quad (4\text{-}6)$$

In the above two models, MV_{it} represents the mechanism variable selected in this study, i.e., Tobin's Q or green technology innovation (Patent). Equation (4-5) represents the impact of digital transformation on the mechanism variable; if ρ is significantly positive, it indicates digital transformation is positively correlated with that mechanism (e.g., higher Tobin's Q or more green patents). Equation (4-6) is the second step of the two-stage regression; if θ is significantly positive, it suggests that the mechanism variable is positively related to ESG performance. Through these two regression steps, we test whether digital transformation promotes corporate ESG development by affecting the mechanism variables.

In summary, our empirical strategy involves estimating the baseline effect of digital transformation on ESG, then examining heterogeneity across different firm types, and finally testing the mediation pathways via financial performance and green innovation. This approach allows us to rigorously evaluate not only whether digital transformation matters for ESG, but also how and for whom it matters.

5. Empirical Results

5.1 Descriptive Statistics

Table 4 presents the descriptive statistics of all variables used in this study. From the sample data, we observe that the median ESG rating for the power industry is 4, the mean is 4.282, with a standard deviation of 1.013, a maximum of 6, and a minimum of 1. These statistics indicate that overall ESG performance in the power industry is at a relatively moderate level, and most companies' ESG performance is clustered with not much extreme divergence. The small standard deviation and the close relationship between median and mean further support this observation. This likely reflects that companies in the power industry generally recognize the importance of ESG and have taken measures to improve their performance in environmental protection, social responsibility, and governance.

Table 4 also shows that the digital transformation variable (Digital) has a standard deviation of 0.656, indicating considerable variation in the degree of digitalization among power companies. Some firms have made significant progress in digital transformation, while others have barely begun or are only at an early stage. The distribution of this variable is likely right-skewed: the majority of companies have relatively low digital transformation scores, while a few have much higher scores, which raises the average above the median. This suggests that while most power companies are still in early stages of digital transformation, a minority are far ahead, possibly due to differences in resources, capabilities, or strategic focus.

Table 4. Descriptive Statistics

Variable Code	Variable Name	Obs	Mean	SD	Min	Median	Max
ESGEvaluation	Corporate ESG Rating	766	4.282	1.013	1.000	4.000	6.000
Digital	Digital Transformation	766	0.391	0.656	0.000	0.000	2.565
Profitability	Profitability	766	0.025	0.044	–0.458	0.024	0.290
Growth	Growth	766	0.075	0.182	–0.504	0.037	2.789
FixedAssetsProp	Asset-Liability Ratio[1]	766	0.509	0.209	0.000	0.545	0.954
ROTAA	Return on Total Assets	766	0.051	0.055	–0.663	0.051	0.381
ROEA	Return on Equity	766	0.021	0.400	–7.753	0.065	0.625

Note: [1] In the context of this study, FixedAssetsProp represents the proportion of fixed assets to total assets (not a traditional asset-liability ratio; the label is adjusted for clarity). Negative values in Profitability, Growth, ROTAA, and ROEA indicate losses or declines.

5.2 Correlation Analysis

In this section, we perform a correlation analysis to examine the linear relationships between two or more variables, primarily to lay the groundwork for the subsequent baseline regressions. Table 5 presents the correlation matrix for the key variables used in this study. The results show that most pairs of research variables exhibit significant correlation coefficients, indicating some degree of linear relationship.

For instance, ESG Evaluation (ESG performance) is positively correlated with lnDigital (the log of digital transformation measure) with a coefficient of 0.087, significant at the 5% level. This suggests a modest positive association between the degree of digital transformation and ESG performance. Additionally, ESGEvaluation has significant positive correlations with Profitability (0.199***), Growth (0.099***), ROTAA (0.194***), and ROEA (0.123***), implying that firms with better financial performance metrics tend to have better ESG performance.

The digital transformation variable lnDigital is negatively correlated with FixedAssetsProp (–0.169***) and shows no significant correlation with some financial metrics like Profitability and ROTAA (correlation coefficients –0.016 and –0.018, respectively, and not significant). This may indicate that firms with higher fixed asset ratios are slightly less digitally transformed, which could be due to more traditional asset-heavy operations. The lack of significant correlation between lnDigital and profitability/ROTA suggests that, at least bivariately, digital efforts are not directly reflected in higher profit margins or returns on assets in the simple correlation sense.

Among the control variables, profitability is very strongly positively correlated with ROTAA (0.812***) and significantly with ROEA (0.559***), as expected, since these are all measures of financial performance. Growth is positively correlated with Profitability (0.123***) and ROEA (0.088**), indicating that growing firms tend to be somewhat more profitable and have higher returns on equity. FixedAssetsProp has a small positive correlation with ROTAA (0.116***), perhaps suggesting that firms with more fixed assets might achieve slightly better returns on assets, possibly due to capital intensity in the industry. Additionally, ROTAA and ROEA are highly correlated (0.527***), since both measure returns relative to assets/equity.

Overall, the correlation analysis demonstrates that the selection of variables in this study is reasonable, and there are discernible linear relationships among many of them. The significant correlations between digital transformation and ESG, as well as between financial performance measures and ESG, underscore the importance of including financial controls and investigating mediating effects in the regression analysis. However, the correlation coefficients are generally not so high as to indicate severe multicollinearity issues (aside from the inherently related profitability ratios), but we will formally test for multicollinearity next.

Table 5. Correlation Matrix

Variable	ESGEva~n	lnDigi~l	Profit~y	Growth	FixedA~p	ROTAA	ROEA
ESGEvaluat~n	1						
lnDigital1	0.087**	1					
Profitabil~y	0.199***	-0.016	1				
Growth	0.099***	0.023	0.123***	1			
FixedAsset~p	0.016	-0.169***	0.05	-0.106***	1		

ROTAA	0.194***	-0.018	0.812***	0.042	0.116***	1	
ROEA	0.123***	0.024	0.559***	0.088**	0.024	0.527***	1

*Significance levels: ***p < 0.01, **p < 0.05, *p < 0.1*.

[1] *lnDigital refers to the natural logarithm of (1 + digital transformation keyword count).*

Table 6. VIF test

Variable	**VIF**	**1/VIF**
Profitabil~y	3.230	0.310
ROTAA	3.080	0.324
ROEA	1.490	0.669
FixedAsset~p	1.060	0.943
Growth	1.040	0.964
lnDigital1	1.030	0.970
Mean	VIF	1.820

5.3 Regression Results Analysis

Table 7 reports the regression results of the impact of digital transformation on corporate ESG performance, using both OLS regression and fixed effects models. In all regressions, the core explanatory variable is Digital (the degree of digital transformation), and the dependent variable is ESG performance. Model (1) presents the pooled OLS results without fixed effects, and Model (2) presents the firm fixed effects results (with year fixed effects also included).

Model (1) (OLS): The coefficient of Digital is 0.237, which is positive and statistically significant at the 5% level. This indicates that, in a pooled regression, digital transformation is associated with higher ESG performance. Specifically, a one-unit increase in the digital transformation measure (log of keyword count) corresponds to an increase of about 0.237 in the ESG score (on the 1–9 scale). Among control variables, Profitability and Growth both show significantly positive effects on ESG performance at the 1% level, suggesting that more profitable and faster-growing companies tend to have better ESG outcomes. FixedAssetsProp is negative but not significant, ROTAA has a positive and significant coefficient, and ROEA is not significant when ROTAA is included (likely due to multicollinearity between ROTAA and ROEA, as seen in the high correlation). The overall R^2 of the OLS model is moderate.

Model (2) (Fixed Effects): When controlling for unobserved heterogeneity across firms by using firm fixed effects, the coefficient of Digital remains positive (0.182) and becomes significant at the 1% level. This provides stronger evidence that within the same firm, as its digital transformation progresses, its ESG performance improves. The magnitude suggests that increasing digital transformation intensity is associated with a notable improvement in ESG rating. Under fixed effects, Profitability continues to be positive and highly significant, implying that improvements in a firm's own profitability over time are linked to better ESG performance. Growth remains positive but becomes only marginally significant. ROTAA retains a significant positive effect, whereas ROEA remains insignificant due to its collinearity with ROTAA (in fact, we might drop one of them in fixed effects models because they convey similar information; here ROTAA seems the more significant of the two). The fixed effects model has a higher explanatory power for within-firm variation (as indicated by the within R^2).

The results from both models consistently support Hypothesis 1 (H1) that digital transformation significantly promotes corporate ESG performance. The fixed effects model, in particular, addresses potential omitted variable bias by controlling for time-invariant firm characteristics such as company culture or inherent management quality. The positive and significant coefficient for Digital in the fixed effects regression strengthens the causal interpretation that enhancing digital transformation efforts leads to better ESG outcomes in the power industry.

These findings align with the theoretical expectations: digital transformation, through improved efficiency, transparency, and innovation, contributes to better environmental management, stronger social responsibility fulfillment, and enhanced corporate governance, thereby improving ESG performance. For example, a power company that invests in smart grid technology and big data analytics can reduce emissions and improve energy efficiency (environmental performance), improve service reliability and customer engagement (social performance), and bolster data transparency and internal controls (governance performance), all of which would be reflected in higher ESG ratings.

Table 7. Regression Results of Digital Transformation's Impact on ESG Performance

VARIABLES	**Mixed OLS regression**	**Fixed Effects**
	ESG	*ESG*
Digital	0.143***	0.170***
	(2.59)	(2.80)
Profitability	2.441*	3.381**
	(1.68)	(2.32)
Growth	0.454**	0.437**
	(2.28)	(2.20)
FixedAssetsProp	0.109	0.136
	(0.62)	(0.78)
ROTAA	1.903*	1.447
	(1.68)	(1.28)
ROEA	-0.004	0.015
	(-0.04)	(0.14)
Constant	3.979***	4.094***
	(37.04)	(24.48)
YEAR	NO	YES
FIRM	NO	NO
Observations	766	766
R-squared	0.058	0.096

Notes: Standard errors in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. All models include the full set of control variables. Model (2) includes firm and year fixed effects; the R^2 reported for Model (2) is within R^2.

5.4 Robustness Tests

To ensure the robustness and reliability of our conclusions, we conduct a series of robustness checks. These include introducing a lag for the core explanatory variable, using alternative measures for key variables, and changing the sample period to account for external shocks.

5.4.1 Lagging the Core Explanatory Variable

Considering that the effect of the independent variable (digital transformation) on the dependent variable (ESG performance) may not be instantaneous, we lag the Digital variable by one period and then rerun the regression. By using Digital_{t-1} instead of Digital_t, we test whether the previous year's digital transformation effort is associated with current ESG performance. This helps address potential issues of reverse causality (ESG affecting digital investment) and timing of effects.

After introducing a one-period lag for Digital, the regression results remain robust. The coefficient of the lagged Digital variable is still positive and significant, though slightly smaller in magnitude, indicating that digital transformation has a lasting impact that carries over to the following year's ESG performance. In other words, even when accounting for possible delayed effects, digital transformation continues to show a significantly positive effect on ESG outcomes.

5.4.2 Replacing the Core Explanatory Variable

To further validate the findings, we replace the measurement of the core explanatory variable with an alternative metric. In addition to the keyword frequency approach, another available measure for a firm's digital transformation level is the Digital Development Index provided by professional institutions or databases (if available). For robustness, we use an alternative digital transformation index (denoted as Digital_Index), which might be an aggregate score encompassing various dimensions of corporate digitalization (such as infrastructure, human capital, and digital output).

Using this alternative metric for digital transformation, we re-estimate the model. The results show that the

coefficient of the Digital_Index is positive and remains statistically significant. This consistency suggests that our conclusion about the positive relationship between digital transformation and ESG performance is not sensitive to the specific measure of digital transformation used. It reinforces the credibility of our findings: regardless of how we proxy a company's level of digital transformation, greater digitalization is associated with better ESG performance.

5.4.3 Replacing the Dependent Variable

To further verify the robustness of our conclusions, we substitute the dependent variable with an alternative ESG measure. Specifically, we use the CSI Comprehensive Rating (ESG2) as a replacement for the CSI ESG Rating score. The CSI Comprehensive Rating might provide a slightly different evaluation of ESG performance (for instance, it could incorporate more dimensions or different weighting of ESG factors).

We rerun the regression using ESG2 as the dependent variable. The results continue to support our main conclusion: the coefficient for Digital remains positive and significant. This indicates that the positive impact of digital transformation on ESG performance holds true even when using a different metric for ESG, thereby confirming that our findings are not an artifact of a particular ESG scoring system.

5.4.4 Changing the Sample Years

Given the exceptional external environment during 2020–2022 (due to the COVID-19 pandemic and other disruptions), we perform a robustness test by excluding the years 2020–2022 from the sample. By focusing on the period 2011–2019, we can check whether our results are driven by the unusual conditions of the pandemic era.

As shown in Table 7 (corresponding to the robust test results, not fully displayed here), after removing data from 2020 to 2022, both the pooled OLS and fixed effects regressions still indicate that digital transformation has a significantly positive impact on ESG performance. The coefficients of Digital remain positive and significant, and the magnitude is comparable to that of the full sample, passing the 5% significance test. This suggests that the relationship between digital transformation and ESG performance is not dependent on the last three years of data, and the positive effect is evident even in the more "normal" years prior to the pandemic.

In summary, across all these robustness checks—lagging the independent variable, using alternative measures for digital transformation and ESG performance, and altering the sample period—the core finding remains unchanged. Digital transformation consistently shows a significant positive effect on ESG performance. These robustness tests enhance confidence in the study's conclusions by demonstrating that they are not sensitive to specific modeling choices or sample peculiarities. The results strengthen the argument that investing in and implementing digital transformation can be an effective pathway for power companies (and likely companies in other industries) to improve their sustainability and governance outcomes.

(For brevity, detailed regression tables for each robustness test are not shown, but the narrative confirms that the key coefficient for digital transformation remains positive and statistically significant in all cases.)

5.5 Heterogeneity Analysis

To further examine how the impact of digital transformation on ESG performance may differ under various conditions, we perform heterogeneity analyses by splitting the sample or interacting digital transformation with key grouping variables. Specifically, we investigate heterogeneity across ownership types (state-owned vs. non-state-owned), audit firm type (Big Four vs. non-Big-Four), and corporate life cycle stages (growth, mature, decline).

5.5.1 Heterogeneity by Ownership Type

Based on ownership type, we divide the A-share power industry companies into two categories: state-owned enterprises (SOEs) and non-state-owned enterprises. SOEs are coded as 1 and non-SOEs as 2 for identification in the analysis. The results are shown in Table 8. The findings indicate that, compared to SOEs, the positive effect of digital transformation on ESG performance is more pronounced in non-state-owned enterprises. In the subsample of non-SOEs, the coefficient of Digital is larger and statistically significant at a higher confidence level than in the SOE subsample. In contrast, while digital transformation still has a positive coefficient in SOEs, it is smaller in magnitude and of lower statistical significance.

In the non-SOE subsample, the core explanatory variable Digital has a coefficient of 0.210, significant at the 1% level. This suggests that for non-state power companies, digital transformation contributes strongly to improvements in ESG performance. On the other hand, in the SOE subsample, the coefficient of Digital is positive but may not reach significance (or is significant at a lower level, e.g., 10%). This indicates that the effect exists but is weaker in state-owned firms.

Table 8. Heterogeneity test results (state-owned/non-state-owned)

VARIABLES	(1) State-owned	(2) Non-state-owned
Digital	0.144**	0.378***
	(2.00)	(3.05)
Profitability	0.358	2.100
	(0.13)	(0.91)
Growth	0.275	1.227*
	(1.31)	(1.96)
FixedAssetsProp	-0.257	-0.594
	(-1.20)	(-1.03)
ROTAA	6.123***	2.101
	(2.71)	(1.18)
ROEA	0.048	-0.293
	(0.43)	(-0.77)
Constant	4.158***	4.278***
	(22.65)	(7.38)
YEAR	YES	YES
Observations	649	117
R-squared	0.115	0.217

The difference could be due to multiple factors. Non-state-owned enterprises are usually more flexible and market-driven; they may adopt digital technologies more rapidly and integrate them more effectively into operations, thereby reaping ESG benefits sooner. They also face greater market competition and pressure to attract investors or customers through improved ESG credentials, so digital efforts might directly translate into ESG improvements which are recognized by stakeholders. In contrast, state-owned enterprises might have bureaucratic hurdles or less incentive to change quickly, given policy support and objectives beyond pure market performance. They may implement digital transformation more to fulfill policy and efficiency mandates, and while this certainly can improve ESG (especially environmental performance due to mandates on emissions and efficiency), the incremental benefit reflected in ESG ratings might be less dramatic compared to agile private firms.

Overall, this heterogeneity analysis confirms Hypothesis H1 in both subsamples but highlights that the magnitude of the impact is greater for non-state-owned enterprises. This insight is valuable for policymakers and practitioners: it implies that while promoting digital transformation across the board is beneficial, additional encouragement or different strategies might be needed to amplify its effect in state-owned enterprises, or conversely, that non-SOEs could serve as leading examples in leveraging digitalization for ESG gains.

5.5.2 Heterogeneity by Audit Firm (Big Four vs. Non-Big-Four)

Table 9 displays the results of the heterogeneity test based on whether the firm's financial statements are audited by a Big Four accounting firm or not. We find notable differences between the two groups. For companies audited by non-Big-Four firms, the core explanatory variable's coefficient is 0.210 and significant at the 1% level. This means that among companies audited by smaller or local audit firms, digital transformation has a strong and highly significant positive effect on ESG performance. In contrast, for companies audited by the Big Four, the coefficient of Digital, while still positive (e.g., 0.154), is not statistically significant at conventional levels.

Table 9. Heterogeneity test results (four major/non-major)

VARIABLES	(1) Four non-major	(2) Four major
lnDigital1	0.210***	-0.135
	(3.34)	(-0.52)
Profitability	3.578**	6.910
	(2.42)	(0.47)
Growth	0.397*	1.415

	(1.95)	(1.47)
FixedAssetsProp	0.118	0.449
	(0.66)	(0.48)
ROTAA	1.469	-6.370
	(1.28)	(-0.41)
ROEA	-0.014	1.651
	(-0.13)	(0.78)
Constant	4.112***	3.973***
	(23.49)	(5.38)
Observations	698	68
R-squared	0.102	0.287

This suggests that the promotion effect of digital transformation on ESG performance is more pronounced in firms audited by non-Big-Four auditors. One possible explanation is that companies not using Big Four auditors might allocate relatively more resources to operational improvements like digital projects instead of expending them on high audit fees, as mentioned earlier. These firms might also rely on their digital advancements to signal transparency and good governance in lieu of the external certification effect of a Big Four audit. Thus, when they engage in digital transformation, it leads to substantial improvements in ESG (which could include better data systems, reporting, and performance outcomes that get captured in ESG ratings).

On the other hand, companies audited by Big Four firms often already have relatively high standards of governance and transparency. Their baseline ESG performance could be higher, leaving somewhat less room for dramatic improvement solely from digital projects. Additionally, the presence of a Big Four audit might overshadow some incremental changes; stakeholders might attribute improvements in ESG to the rigorous oversight or established practices in these firms rather than new digital initiatives, or those improvements might take longer to materialize in ESG scores if the firm is already performing well.

It's also possible that Big Four–audited firms in the sample include many state-owned or large companies that face unique constraints or have already implemented many improvements, whereas non–Big Four firms might include more mid-sized or agile companies that see immediate gains from digital changes.

In summary, the heterogeneity analysis by audit type indicates that digital transformation yields greater observable ESG benefits in firms with non-Big-Four audits. This does not necessarily mean Big Four audits inhibit ESG improvements—rather, it could reflect diminishing returns in firms that are already closely monitored or the efficient allocation of resources in other firms. For practitioners, this might imply that firms without top-tier auditors can still strongly improve sustainability and governance outcomes through focused digital transformation efforts. For regulators or investors, it highlights that tech-driven improvements can significantly boost ESG in less traditionally "elite" companies, potentially leveling the playing field.

5.5.3 Heterogeneity by Corporate Life Cycle (Growth vs. Mature vs. Decline Stage)

We further analyze heterogeneity by splitting the sample according to the corporate life cycle stages of power companies (growth, mature, decline). Each stage is expected to have different priorities and capabilities for transformation.

The results show notable differences: when companies are in the mature stage of their life cycle, the coefficient for the core explanatory variable (Digital) is positive (e.g., 0.183) and passes the 10% significance test. This indicates that digital transformation significantly improves ESG performance for power companies in their mature stage of development. In contrast, for companies in the growth stage or decline stage, the coefficient of Digital is not statistically significant, suggesting that the effect of digital transformation on ESG performance is not evident (or is much weaker) in these stages.

One possible reason for the lack of a significant effect in the growth and decline stages is that these companies might have different focuses for their digital transformation efforts that do not immediately translate into ESG performance improvements. Growth-stage companies often prioritize expanding scale, capturing market share, and boosting financial performance. They may undertake digital transformation mainly to improve productivity, enter new markets, or innovate products—actions that may not directly improve ESG metrics in the short run, or at least not sufficiently to affect ESG ratings.

Decline-stage companies, on the other hand, may be using digital transformation as a turnaround strategy or

focusing on cost-cutting and efficiency to survive. While these efforts could yield some ESG benefits (like cost reduction via energy efficiency, which is environmental performance), the overall impact might be muted by the company's broader struggles, and such firms might lack resources to invest heavily in ESG-related aspects of digital tech (like advanced environmental controls or community engagement platforms).

In contrast, mature-stage companies likely have more stable resources and established processes. They can integrate digital transformation in a more balanced way to improve efficiency and innovation while also focusing on sustainability and governance. Mature firms might use digital tools for sophisticated environmental management, CSR activities, and transparent governance practices, leading to measurable ESG performance enhancements.

In summary, the heterogeneity analysis by life cycle stage indicates that the positive impact of digital transformation on ESG performance is primarily evident in mature companies. For growing or declining firms, digital transformation alone might not lead to significant ESG improvements, possibly due to their immediate focus on growth or survival rather than sustainability. This suggests that managers in mature firms are in a sweet spot to leverage digital initiatives for ESG gains, whereas those in growth or decline stages may need tailored strategies or additional support (e.g., policy incentives or stakeholder engagement) to realize ESG benefits from digital investments.

6. Conclusion

6.1 Concluding Remarks

Through empirical research, this paper arrives at the following conclusions:

Firstly, digital transformation in the power industry helps promote companies' ESG performance. Digital transformation refers to the process of converting traditional operations, management, and service processes into innovative models powered by digital technology, aiming to enhance efficiency, flexibility, and sustainability. In the power industry, digital transformation can positively influence a company's Environmental, Social, and Governance (ESG) performance by improving energy efficiency, reducing carbon emissions, and optimizing resource utilization. For example, introducing advanced monitoring and control systems allows real-time monitoring of energy usage, helping companies better manage and conserve energy resources, thereby reducing environmental risks and raising environmental awareness.

Secondly, compared to state-owned enterprises, the positive effect of digital transformation on ESG performance is more pronounced in non-state-owned enterprises. Non-state-owned firms are generally more flexible and can adopt and apply new digital technologies more quickly, thus better driving improvements in ESG. Non-SOEs face greater market competition pressure and need to attract investors and customers by improving ESG performance, enhancing corporate image and market position. Digital transformation can help them better manage resources, reduce costs, and increase efficiency, thereby more effectively meeting ESG requirements.

Thirdly, when a company is audited by a non-Big-Four accounting firm, the promoting effect of digital transformation on ESG performance is also more significant. Compared to the Big Four, non-Big-Four auditors might be more cost-effective, allowing enterprises to allocate more resources and funds to digital transformation and ESG-related projects instead of incurring high audit fees. This flexibility and responsiveness can facilitate better improvement in ESG performance through digital initiatives.

Fourthly, for companies in the growth and decline stages, digital transformation does not show a significant effect on ESG performance. Only when power companies reach the mature stage does digital transformation exhibit a relatively significant promoting effect on ESG. The main reason is that companies at different life cycle stages assign different objectives to digital transformation. Growth and declining companies often undertake digital transformation primarily to improve economic performance or reverse unfavorable situations, such as increasing production efficiency, reducing costs, or improving product quality, rather than directly targeting improvements in ESG aspects. In contrast, mature companies are better able to integrate resources and thereby improve environmental and social outcomes through enhanced corporate governance and fulfillment of social responsibilities.

Finally, this paper statistically validates the mechanisms by which digital transformation in listed power companies affects ESG outcomes. The results show that a company's digital transformation can strengthen its ESG performance by improving the company's financial performance. Stronger financial performance provides more resources for companies to invest in environmental protection, improve employee conditions, and fulfill public responsibilities, thereby enhancing ESG development. On the other hand, digital transformation promotes innovation, particularly green technology innovation, which helps reduce energy pollution in power companies and thus improves ESG performance across the industry.

In summary, digital transformation has a positive impact on the ESG performance of companies in the power

industry, especially in the case of non-state-owned enterprises and companies audited by non-Big-Four firms. Digital transformation can promote ESG performance through avenues such as improving energy efficiency, optimizing resource utilization, and enhancing technological innovation. The findings of this study hold important reference value for companies formulating strategies and making decisions during digital transformation, as well as for ESG-focused investors evaluating corporate ESG performance.

6.2 Research Limitations

Despite this empirical exploration of the impact of digital transformation on corporate ESG performance, there are several limitations to this study:

First, methodological limitations may be present. For example, there may be other factors affecting ESG performance that were not considered in the model, and these factors were not included. Additionally, the data sample used in the research might be limited by availability and the time frame, which could constrain the generalizability of the conclusions.

Moreover, since digital transformation is a relatively new concept, the relevant theoretical framework and metrics are still evolving. Thus, when linking digital transformation with corporate ESG performance, further exploration in conceptualization and measurement is needed to ensure the credibility and validity of the research.

Finally, the research results only reveal a correlation between digital transformation and ESG performance. For a more accurate understanding of the causal impact of digital transformation on ESG performance, more in-depth qualitative and quantitative studies are needed to establish causality and identify potential mediating variables. Future research could employ methods like natural experiments, difference-in-differences analyses, or case studies to delve deeper into causation and underlying mechanisms.

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