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Firm-Level Digital and Sustainability Indicators and Sustainability Outcomes: Evidence from Chinese Listed Industrial Firms under Environmental Regulation

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Abstract

This study examined the associations between digital and organizational capabilities and sustainability outcomes among 200 industrial firms listed on the Shanghai Stock Exchange in China from 2013 to 2023. The study applied the theory of Dynamic Capabilities and Institutional Theory to explore the digital transformation, corporate sustainability culture, cultural capital and digital media literacy, and their relationship with environmental performance and sustainability innovation. Media coverage intensity and the financial support of sustainability initiatives were investigated as possible indirect pathways and environmental regulation as a moderating institutional condition. Firm and year fixed-effects models were supplemented with dynamic System GMM and bootstrapped indirect-effect analysis, moderation analysis, and robustness specifications. The findings indicate that digital transformation, corporate sustainability culture, and digital media literacy were positively associated with both environmental performance and sustainability innovation, whereas cultural capital was positively associated with sustainability innovation but not environmental performance. Media coverage intensity and financial support for sustainability initiatives showed statistically supported indirect associations for digital transformation, corporate sustainability culture, and digital media literacy, but not cultural capital. Environmental regulation generally strengthened the positive capability–sustainability associations, while its negative interaction with cultural capital for sustainability innovation provided only tentative evidence of a weakening association, as the interaction was significant only at the 10% level. These findings contribute to the Dynamic Capabilities Theory by bringing into focus capability-specific sustainability associations and the Institutional Theory by establishing differentiated regulatory conditions. The indirect effects and relationships estimated are therefore viewed as associative in nature for the purpose of the observational panel design.

Keywords: Digital transformation; environmental performance; sustainability innovation; dynamic capabilities; institutional theory; environmental regulation; Chinese industrial firms.

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Graphical abstract

1. Introduction

Digital transformation (DT) is an emerging feature of modern manufacturing, affecting how companies handle information, manage production, allocate resources, and adapt to technology and environmental challenges. Artificial intelligence (AI), the Internet of Things (IoT), cloud computing, big-data analytics, and intelligent automation constitute some of the technologies that can enhance process monitoring, resource scheduling, and production decision-making (Li *et al.*, 2023). On this basis, there have been recent firm-level studies reporting relations between digital transformation and results in terms of green innovation, environmental performance, or carbon efficiency (Liu *et al.*, 2025; Sun *et al.*, 2025). But the presence of digital technologies does not guarantee similar sustainability performance for companies. The environmental value of digital resources partly relies on firms' integration of information, knowledge, organizational routines, and sustainability objectives into decision-making and resource reconfiguration processes (Alsubai *et al.*, 2023; Li *et al.*, 2023). Thus, an important question is not simply whether digital transformation is associated with sustainability, but why firms with similar opportunities for digital transformation may exhibit different sustainability outcomes.

This question highlights some particular gaps in the current literature. First, existing studies have focused on understanding the digital transformation and sustainability at the macro level of capabilities, and less on the different roles of organizational capabilities and conditions. Studies have increasingly considered green dynamic capabilities, human capital, organizational knowledge, and information networks in explaining the relationship between digitalization and sustainability (Ologeanu-Taddei *et al.*, 2025; Suparman *et al.*, 2025). However, these dimensions of sustainability are generally investigated individually, and it is hard to establish that changes in different aspects of organizational resources are correlated with sustainability effects in different ways. Therefore, this study distinguishes between the concepts of corporate sustainability culture (CSC), cultural capital (CC), and digital media literacy (DML) instead of considering this organizational capability as a composite. CSC relates to the extent to which sustainability is integrated into organizational values and routines, CC encompasses human and knowledge resources that could support learning and knowledge integration, and DML concentrates on the ability to access, interpret, evaluate and utilize digital information to facilitate organizational communication and decision-making processes (Alemu, 2025; Rubio-Andrés & Abril, 2024). An analysis of these dimensions individually helps to determine if technological resources and various organizational capacities are related in similar or discrete patterns with respect to sustainability.

Second, the literature has overlooked the difference between multiple types of sustainability outcomes. Environmental performance and sustainability innovation are conceptually different and related outcomes. Environmental performance is the observed environmental impact of firms, while sustainability innovation represents novel products, processes and practices developed or implemented for sustainability (Awwad *et al.*, 2026; Lailatul Elvia *et al.*, 2025). A firm can then exhibit improvement in environmental performance without showing the same pattern of sustainability innovation and vice versa. Differentiation of outcomes gives extra clarity on the possibility that digital and organizational capabilities are

linked to achieve environmental outcomes, to action-oriented sustainability responses, or both.

Third, there has been less focus on the external pathways through which an organizational and digital resource could be linked to sustainability outcomes. Media Coverage Intensity (MCI) refers to an external information and visibility context that can amplify stakeholder demands, transparency, reputational gains, and corporate accountability of corporations (Menicacci & Simoni, 2024; Moalla & Dammak, 2025). In the same vein, Financial Support for Sustainability Initiatives (FSSI) is the access to financial resources relating to the field of green finance, government subsidies, and sustainability-oriented investments, which can support environmental technologies and sustainability-related innovation. Also, current evidence has shown that the government can influence the link between digital transformation and green innovation (García-García & Alonso-Magdaleno, 2023; Song *et al.*, 2025). However, these external factors have been less than studied in combination with differential organizational capability in a single entity-level perspective. Thus, the focus of the present study is on MCI and FSSI as potential indirect pathways linked to sustainability outcomes rather than in assuming that the estimated relations provide evidence of causal mediation.

Fourth, the role of institutional conditions as a boundary condition of digital sustainability relationships is not appropriately explained. Digital and Sustainability related strategies are not implemented in an institutional vacuum. Consequently, environmental regulation (ER) may modify environmental access conditions, investment opportunities and rules of engagement constrained by environmental activities. Earlier studies indicate that environmental regulation can be used alongside green transformation and technological development, and that environmental regulations can have compliance and adaptation value (Chen *et al.*, 2022). Thus the meaning of regulation can depend on the set of organizational resources of the firms around which the regulations address demands. This research does not presume that regulation effects organisations uniformly but rather that ER is a boundary condition that can affect the intensity of the relationships between organizational/digital capabilities and sustainability outcomes. In particular, the study empirically evaluates whether the DT–sustainability, CSC–sustainability, CC–sustainability, and DML–sustainability relationships vary across different levels of environmental regulation. The specific pattern of CC and sustainability innovation is constructed as an empirical finding to be understood based on the results and not as a theoretical expectation.

China seems an appropriate empirical setting to study these relationships. China is a major manufacturing economy, and it is both important and challenging to maintain its competitiveness while minimizing its environmental impact during manufacturing operations, which depend on energy-intensive production processes. By achieving peak carbon emissions before 2030 and becoming carbon neutral before 2060, it has pushed the low-carbon development agenda (Gonçalves *et al.*, 2023; Shen & Zhang, 2023). Other policies like intelligent manufacturing, industrial digitalization, green manufacturing and digital–green transformation have also been effective in driving technological improvement. This mix provides an environment in which the two processes of digital transformation and the sustainability of the environment are evolving simultaneously, and are experiencing significant institutional and technological pressures. China's continuing environmental pressures are also evident in the trajectory of national CO_2 emissions during 2010–2023 (**Figure 1**).

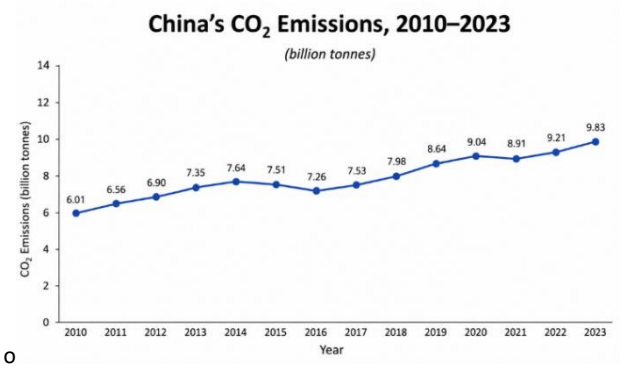

Figure 1. China's CO_2 Emissions, 2010–2023. Source: Author's compilation based on Global Carbon Budget data.

China is also relevant at the institutional level, where the policy environment affects companies' operations through corresponding aspects of the environment laws, green-finance programs, intelligent manufacturing policies and the dual-carbon agenda. Prior studies have shown that ownership structure, financial accessibility, institutional governance, and policy involvement affect digital enhancement and green innovation in Chinese companies (Al Mamun *et al.*, 2025; Wang *et al.*, 2022). Chinese manufacturing companies are appropriate platforms for investigating if the relationships between digital and organizational capabilities and sustainability outcomes differ based on the broader regulatory context.

The study draws on Dynamic Capabilities Theory (DCT) and Institutional Theory to develop this framework. DCT highlights a firm's ability to detect opportunities and threats, exploit opportunities, and restructure resources under varying circumstances (Chen, 2024; Han *et al.*, 2023). From this aspect, DT offers technological and information-based resources that may or may not be relevant to sustainability, depending on additional organizational skills and circumstances. This study further examines this view as it differentiates the potential between DT as a technological tool, CSC as an organizational condition oriented toward sustainability, CC as a human and knowledge-related tool, and DML as digital information ability. This distinction allows for the analysis to shift from general stating that digital transformation is a homogeneous organizational capability to exploring whether different dimensions of resources and capabilities have different associations with environmental performance and environmental sustainability innovations.

In essence, Institutional Theory complements DCT by highlighting the external pressure, regulatory needs, legitimacy issues, and institutional expectations on institutional response (Cheng *et al.*, 2024; Tan *et al.*, 2025). In this study, the main institutional boundary condition is ER. In contrast to looking at the impact of institutional pressure in a uniformly positive or negative way, the paper asks how the strength of the relationships between digital/organizational capabilities and sustainability outcomes are altered by regulatory intensity. This is an integration of DCT and Institutional Theory which serves as the theoretical framework to explore not only internal capability differentiation but also external institutional contingency.

The study therefore establishes a framework where DT, CSC, CC, and DML constitute different technological and organizational aspects related to the sustainability outcomes, while MCI and FSSI are analyzed as possible indirect pathways and ER is looked upon as a boundary condition which could influence the relationships. This framework fills a gap in the literature by incorporating technological resources, organizational capabilities, external information and financial factors, as well as institutional pressure, with a clear demarcation of the proposed interventions. Based on the background, the study examines associations between digital transformation and sustainability outcomes among manufacturing companies based in China, and the relationships between organizational capabilities, external pathways, and sustainability outcomes. Specifically, the study addresses four research questions:

RQ1: **To what extent is digital transformation associated with environmental performance and sustainability innovation among Chinese manufacturing firms?**

RQ2: How do corporate sustainability culture, cultural capital, and digital media literacy contribute to sustainability outcomes and the relationship between digital transformation and sustainability?

RQ3: Do media coverage intensity and financial support for sustainability initiatives provide explanatory mechanisms linking digital transformation with sustainability outcomes?

RQ4: Do environmental regulations reinforce or hinder the link between digital transformation and sustainability outcomes?

The study makes three main contributions. First, it applies DCT to digital sustainability by identifying three organizational dimensions – sustainability culture, cultural capital, and digital media literacy – that are differentiated from technological resources and focused on their respective connection to environmental performance and sustainability innovation. This offers a more nuanced capability-based view to organisational capacity rather than an organisational capability view.

Second, from the institutional perspective, environmental regulation becomes a boundary condition of digital and organizational capability–sustainability relationships in the study. This moves from the question of whether regulation is inherently positive or negative to whether its correlation to sustainability impacts is different across organizational resources.

Third, the study provides strong empirical evidence for the Chinese manufacturing firm in the concurrent digital upgrading, industrial transformation and environmental policy pressure environment. The study illuminates the technological, organizational, informational, financial, and regulatory dimensions extricated from a unified framework, giving a more comprehensive description of conditions of variation related to environmental performance and sustainability innovation.

2. Literature Review

2.1. *Theoretical Framework*

2.1.1. Dynamic Capabilities Theory

Dynamic Capabilities Theory (DCT) proposes mechanisms by which companies identify change, capture opportunities, and restructure capabilities to meet new technological, market and environmental requirements (Nagai, 2009). In the digital sustainability perspective, digital technologies provide potential sustainability benefits for the environment, but the extent of these benefits is dependent on firms' use of information, knowledge and organizational resources.

Digital transformation (DT) can be used as a technological and informational tool that can enable environmental monitoring, decision making via data, optimization of resources and production reconfiguration. However, firms may differ in their ability to convert these resources into sustainability outcomes because of differences in organizational capabilities. Evidence from manufacturing indicates that digitalization can be associated with green innovation through organizational mechanisms such as internal control and inter-organizational technological cooperation (Meyer & Rowan, 2021).

In this way, DT is conceptualized as a technological resource, and the empirical dimensions of renewable energy adoption, cultural/knowledge-oriented employment, and employment with a computer are understood as specific observable dimensions related to DT, namely, the concepts of corporate sustainability culture (CSC), of cultural capital (CC) and of digital media literacy (DML) respectively. This differentiation allows the study to look at the relationship between these distinct firm-level indicators and environmental performance and at sustainability innovation without making assumptions about the proxies equating to the full theoretical constructs.

2.1.2. Institutional Theory

The Institutional Theory captures organizational behavior influenced by formal rules, social norms, instances of face legitimacies and institutional demands (Meyer & Rowan, 2021). This view complements the DCT in suggesting that companies use technological and organizational resources operating in an external institutional context.

Environmental regulation (ER) is of specific interest since the regulatory requirements can promote environmental

monitoring, cleaner technologies, resource efficiency and sustainable innovation. Compliance, however, can also involve fiscal expenses and organizational burdens, which limit the firms' resources. There is evidence from Chinese manufacturing that digitalisation and environmental regulation could be related in driving green transformation, implying that institutional conditions may influence the link between firm capabilities and sustainability performance and outcomes (Javeed *et al.*, 2024).

Thus, ER is conceptualized as a boundary condition, rather than simply another determinant of sustainability. The study does not make any assumption about the overall effect of regulation on strengthening or weakening all capability–sustainability relationships. Instead, it investigates the interactions between the strength of the regulations and the associations of DT, CSC, CC, and DML with environmental performance and sustainability innovation. This perspective understands that institutional pressures may have varying impacts depending on organizational capacities.

2.1.3. Integrated Theoretical Framework

DCT and Institutional Theory provide complementary explanations of the digital sustainability relationship. DCT provides an internal set of capabilities framework that describes how companies integrate and reconfigure technological, human, knowledge, and organizational resources. Institutional Theory offers a more external angle, which gives an explanation of how the future resource deployment environment is formed by the regulatory pressures.

The integrated framework, therefore, sees DT as a technological and informational tool, whereas the extension of renewable energy use, cultural/knowledge-related employment, and the use of computers by employees are the empirical signifiers linked to CSC, CC, and DML, respectively. MCI and the ESG-based sustainability-resource indicator that operationalized FSSI were explored as possible indirect statistical pathways and ER was tested as an institutional boundary effect that could alter the associations with sustainability outcomes.

There are research gaps in this integration: existing studies often have focused on digital transformation, organizational capability, information environment and financial resources separately, and they have minimally contributed to understanding their interactions at the firm level. The framework thus relates the differences in internal capabilities to the external conditions of institutions, and avoids the notion that the estimated indirect or interaction effects are causal mechanisms.

2.2. *Digital transformation and Sustainability Outcomes*

Digital transformation can support sustainability by improving firms' ability to collect, process, and apply information to environmental and production decisions. The use of technologies such as artificial intelligence, IoT, big data analytics and cloud computing enables environmental monitoring, resource optimization, process control and technological experimentation (Wang *et al.*, 2025; Xu *et al.*, 2023). In a DCT context, these functions can enable companies to detect inefficiency, mitigate environmental opportunities, and reorganize production processes (Sarfraz *et al.*, 2022; Sun, 2024).

This is empirically supported, but there are also studies showing that the organizational context plays a significant role (Lei *et al.*, 2026). Previous research on Chinese manufacturing companies links digitalization with green innovation and better resource use through organizational arrangements and structures (Rahman *et al.*, 2025; Ribeiro-Navarrete *et al.*, 2025). There are other studies that associate data-driven transformation to resource efficiencies and less carbon-intensities pressure (Hu, 2025; Li & Lin, 2024). However, results for sustainability are not uniform. Environmental performance refers to environmental results of firms, while sustainability innovation refers to the development and introduction of new and improved products, processes, technologies and organizational practices that have a positive impact on the environment. Both results should be considered in this context to achieve a differentiated evaluation of the sustainability relevance of digital transformation.

H1: Digital transformation is positively associated with environmental performance.

H2: Digital transformation is positively associated with sustainability innovation.

2.3. *Corporate sustainability culture and Sustainability Outcomes*

Corporate sustainability culture (CSC) captures how environment is integrated within the organizational values, operating procedures, employees' attitudes and behaviors, and the way how leadership makes decisions (Asif *et al.*, 2024; Costa & Opare, 2025; Saini *et al.*, 2025). In DCT, such a direction may affect the allocation of resources and the use of technological capabilities into the sustainability dimension. Therefore, companies of similar technological means can achieve varying sustainability results as a result of the differential integration sustainability priorities in company practices.

The current available evidence typically relates sustainability-oriented organizational culture to environmental performance. Research shows that there exist relationships between environmental values and environmental management practices with the improvement in environmental outcomes in manufacturing organizations (Khan & Badulescu, 2025; Rivo-López *et al.*, 2025; Zhang *et al.*, 2025). However, sustainability-oriented cultures can also foster employees and managers to recognize environmental issues, value the importance of sustainability in innovation, and have a positive impact on cleaner technologies and processes (Asif *et al.*, 2024; Barker, 2025; Dhyanasaridewi *et al.*, 2024). The supporting literature has, however, been less consistent regarding the connection between sustainability-oriented organizational practices and sustaining environmental performance and innovation. The results of this study are thus considered in both outcome categories separately. The study is empirical, treating the adoption of renewable energy as a specific observable proxy construct related to

the overall construct of CSC but not representative of organizational values, beliefs, and norms. The scope and limitations of this operationalization are discussed in the measurement section.

H3: Adoption of renewable energy, as a proxy of the empirical sustainability culture among companies, is positively correlated with environmental performance.

H4: Renewable-energy adoption, as the empirical proxy for corporate sustainability culture, is positively associated with sustainability innovation.

2.4. *Cultural capital and Sustainability Outcomes*

Cultural capital (CC) is defined as human and knowledge-based resources that aid in organizational learning, experience and experience sharing, knowledge integration, or dealing with complex environmental challenges (Hack-Polay *et al.*, 2023; Keçi *et al.*, 2026). From the DCT point of view, these resources can assist in integrating current knowledge and new information about the environment, and reconfigure resources as a reaction to changing sustainability needs.

Research increasingly emphasizes the importance of human and organizational capabilities for sustainability. Human capital, employee competencies, and organizational knowledge can support environmental technology adoption and firms' responses to environmental challenges (Kumar *et al.*, 2025). Similarly, organizational learning and knowledge integration is linked to environmental practices and resource utilization. Likewise, these capabilities can be used for sustainability innovation since innovation is the capability that requires knowledge assimilation, learning, problem-solving and storing of new knowledge in solving problems in the environment (Astuti & Ahmar, 2025; Dwiputri *et al.*, 2023; Wirasedana *et al.*, 2024). However, little is known about whether workforce-based cultural and knowledge resources have similar associations with environmental performance and sustainability innovation. Hence, both outcomes are considered when analysing the differentiated sustainability relevance. The empirical study is based on proxies such as the proportion of employees at the selected cultural/knowledge-oriented employment category that involve workers' groups related to CC as a whole but not as encompassing measures of actual capital.

H5: Cultural/knowledge-oriented employment (the empirical proxy for cultural capital) is positively related to environmental performance.

H6: Cultural/knowledge-oriented employment, as the empirical proxy for cultural capital, is positively associated with sustainability innovation.

2.5. *Digital media literacy and Sustainability Outcomes*

Digital media literacy (DML) is defined as the skill to access, understand, analyze, produce, and utilize digital information appropriately (Ningsi *et al.*, 2025; Somboonvechakarn *et al.*, 2022). These capabilities can assist sustainability employees and corporate managers in understanding environmental issues, finding sustainability knowledge, sharing sustainability priorities, and guiding data-driven decision-making in sustainability contexts.

DCT argues that DML can augment digital technology to help organizations transform content into knowledge and action. In a digital transformation, there can be significant environmental and operational data created, but if it is going to help the employees, they have to be able to interpret and utilize it. Empirical studies also associate digital competences, technological skills, and human capital with implementing environmental technologies and sharing of information for sustainability (Iskandar *et al.*, 2024; Mandić *et al.*, 2024). Digital information processing can also facilitate knowledge acquisition, sustainability-oriented innovation (Ika Sari *et al.*, 2024; Jasin *et al.*, 2024; Rahmani *et al.*, 2025). But there are limited firm-level studies on the links between the use of digital technologies and the effect on environmental performance and sustainability innovation. This study examines both outcomes using the proportion of employees regularly using computers as an observable proxy related to the employee-use dimension of DML. This indicator is not intended to measure all aspects of digital media literacy skills, and the limitations of the indicators are described in the methodology.

H7: The use of employees' computers for the empirical proxy of digital media literacy is positively related to the environmental performance.

H8: Employee computer use, as the empirical proxy for digital media literacy, is positively associated with sustainability innovation.

2.6. *Media Coverage Intensity as a Potential Indirect Pathway*

Media Coverage Intensity (MCI) is defined as the visibility of firms seen in the information environment (Lei & Zhang, 2026). According to the institutional Theory, visibility can lead stakeholders to be more critical, expect higher levels of transparency, worry more about their reputation, and have more pressures toward legitimacy (Ren *et al.*, 2026; Rong & Kim, 2024; Song *et al.*, 2025). The pressures could be important for digital sustainability if firms with higher technology and organizational capabilities can generate, communicate, and disseminate information on sustainability.

DT can assist in generating and disseminating environmental data; CSC can promote sharing of sustainable practices. CC can contribute to the creation and dissemination of the knowledge bases related to sustainability and DML can support interactions with digital information environments and stakeholders. The presence of media visibility and the information environment has been linked to CSR responses in the existing literature (Gao *et al.*, 2025; Zou *et al.*, 2025). There are, however, only limited studies that look at the statistical relationship between various capabilities and various sustainability outcomes. This study thus examines MCI as an indirect pathway, but does not view a statistically significant indirect as an indication of a causal pathway.

H9: Media coverage intensity plays a statistically significant mediating role in the correlations between digital transformation, renewable-energy adoption, cultural/knowledge-oriented employment, employee computer use, environmental performance and sustainability innovation.

Financial Support for Sustainability Initiatives as a Potential Indirect Pathway

Financial support for sustainability initiatives (FSSI) can contribute to environmental technologies, cleaner production and sustainability-oriented innovation (Lei *et al.*, 2026). Green finance, government subsidies, and investments related to sustainability can mitigate financial barriers to environmental investments and facilitate businesses' sustainability initiatives (Dorkas Rambu Atahau *et al.*, 2023; Kurniasari *et al.*, 2025).

From a DCT perspective, organizational capabilities may influence firms' ability to identify and use available financial resources. DT can help to improve access to financial information and data-based resource allocation; CSC can help to boost the importance attached to sustainability investment; CC can help create knowledge on financing opportunities and CC can help identify and interpret information regarding green finance and subsidies. The current literature shows linkages between green finance and sustainability oriented investment, environmental technology adoption and green innovation (Cahyawati *et al.*, 2023; Ekayani *et al.*, 2024). While it is well documented that environmental orientation of organizational resources is correlated with organizational capabilities and sustainability outcomes, the level of statistical documentation is still inadequate. Accordingly, in the empirical analysis, FSSI is measured as the ESG-based sustainability-resource indicator and thus not as an indicator of financing, spending, or investment. The study analyses this ESG-based indicator in comparison with MCI as a possible indirect statistical route, but not as a potential evidence of a causal route.

H10: The ESG-based sustainability-resource indicator, which has been selected as the empirical proxy for FSSI, serves as a statistically significant indirect pathway in the relation between digital transformation, renewable-energy adoption, cultural/knowledge-oriented employment, and environmental performance and sustainability innovation.

2.7. *Environmental Regulation as a Boundary Condition*

Environmental regulation (ER) is defined as an institutional state that can change the relationship between the capabilities of firms and the sustainability outcomes. According to Institutional Theory, it is the regulatory sets that can ensure environmental monitoring, adoption of cleaner technologies, economy of resource, and innovation for environmental sustainability (Chen *et al.*, 2024; Shao *et al.*, 2024). Moreover, the compliance may also involve cost, resource and organizational requirements, which can have non-uniform effects on firms under either regulatory pressure.

This contingency view applies to DT, CC, CSC and DML. Regulation can deepen the uptake of digital monitoring for tech-savvy companies, bolster sustainability agendas in businesses and ultimately change how knowledge and digital information can be leveraged to meet environmental needs. From a Chinese manufacturing perspective, it is concluded that digitalization and environmental regulation can combine to exert an influence on green transformation, and the pressure on environmental regulation itself can reduce environmental investments (Dong *et al.*, 2025; Feng *et al.*, 2024; Liu *et al.*, 2023). Despite this evidence, limited research examines whether ER systematically changes the associations of multiple technological and organizational capabilities with both environmental performance and sustainability innovation. In this study, the direction and magnitude of these interactions are therefore considered as questions of fact, as opposed to identical interactions. Specifically, any negative interaction with CC and sustainability innovation is only understood after empirical results are analyzed.

H11: Environmental regulation moderates the associations of digital transformation, renewable-energy adoption, cultural/knowledge-oriented employment, and employee computer use with environmental performance and sustainability innovation.

3. Research Methodology

3.1. *Research Design and Approach*

This study adopted quantitative longitudinal design with firm-level panel data on industrial listed firms in China for the period between 2013 and 2023. It examined the associations of digital transformation (DT), corporate sustainability culture (CSC), cultural capital (CC), and digital media literacy (DML) with environmental performance (EP) and sustainability innovation (SI). Media coverage intensity (MCI) and financial support for sustainability initiative (FSSI) were considered as indirect pathways, and environmental regulation (ER) was defined as a boundary condition.

Empirical analysis methods used descriptive statistics, correlation and multicollinearity diagnostics, two way fixed-effects (FE) model, System Generalized Method of Moments (System GMM), indirect-effect analysis, moderation analysis, and robustness tests. While FE models adjusted for inputs of other firm-specific factors and common year-specific factors. The FE models explicitly acknowledged firm-specific heterogeneity and common year-specific shocks while System GMM served as a separate dynamic model in order to properly capture endogeneity and/or outcome persistence under maintained internal-instrument assumptions. This study used observational secondary data and these estimators do not provide causal identification by themselves. This may leave out some time-varying omitted variables and introduce reverse causality. The findings are therefore interpreted as being associations, and statistical relationships between variables that are conditional and/or indirect, and are not causal effects (Gamage, 2025; Pitman, 1998). The study employed observational secondary data, and the estimators were not able to provide any causal inferences. Reverse causality and time-

varying omitted variables could remain. Consequently, results were interpreted as associations, indirect, conditional, rather than causal.

3.2. *Sample Selection*

The subjects in this sample were firms listed on the Shanghai Stock Exchange (SSE) from 2013 to 2023. The companies included on this list were chosen because they filed annual reports, financial statements, sustainability information, and corporate information that shared reasonably similar firm-level data. Firms were retained only if enough information was on hand to create the main variables and estimate the appropriate models. Firms with large amounts of missing information were excluded, and missing firm-year observations were dropped from analyses only when the information is necessary. A total of 200 listed Chinese industrial firms were selected, and a maximum of 2,200 firm-year observations were obtained (200 × 11 years). The number of samples for each model was different due to the number of variables and observations needed for different specifications. The sample consists of manufacturing and potentially related industrial activity such as renewable energy, power generation, heavy industry, electronics, and automotive activities which are defined by the relevant classifications of SSE. While listed firms were generally more consistent in what they disclosed and reported, the results lacked broad applicability to unlisted firms, which may vary in terms of governance, funding, reporting, technology and exposures to regulation.

3.3. *Data Collection and Variable Measurement*

Annual reports, financial statements, sustainability/ESG reports, patent records, corporate disclosures, and firm-level media databases were used to compile firm-year data. Patent information related to green invention was acquired from the China National Intellectual Property Administration (CNIPA) and the relevant corporate records. A coding framework was employed to sample enterprises, select observations, convert measurement units and reconcile the information with original data. Ln(1+x) was used to transform right-skewed count variables such as numbers of patents and number of media, respectively. The operational measures selected were those that appeared as firm level proxies for the theoretical constructs measured in the study. In the case of several constructs, the measures are broader than its empirical indicators, thus, the measures should not be interpreted as exhaustive representations of underlying constructs. In particular, CSC, CC, DML, and FSSI are operational proxies capturing specific observable dimensions of sustainability-oriented practices, cultural/knowledge resources, employee digital technology use, and sustainability-oriented resource support, respectively. Interpretation of the empirical results is thus limited to the dimensions measured by these operational measures.

Table 1 below summarizes the variables, their measurement indicators, and data sources.

Table 1. Variables and their Measurements

Variable	Operational measure	Measurement	Main source
Environmental Performance (EP)	GHG-emission intensity	Direction-adjusted emissions-intensity measure	Annual reports and financial disclosures
Sustainability Innovation (SI)	Green invention patents	ln(1 + number of green invention patents)	CNIPA and annual reports
Digital Transformation (DT)	ICT-specialist employment	Percentage of employees classified as ICT specialists	Annual reports and corporate disclosures
Corporate Sustainability Culture (CSC)	Renewable-energy adoption	Renewable energy as a proportion of total energy use	Sustainability/ESG reports
Cultural Capital (CC)	Cultural/knowledge-oriented employment	Proportion of employees represented by the selected employment measure	Annual reports and corporate disclosures
Digital Media Literacy (DML)	Employees regularly using computers	Percentage of employees regularly using computers in their work	Annual reports and IT/HR disclosures
Media Coverage Intensity (MCI)	Firm-specific media mentions	ln(1 + number of firm-specific media mentions)	Firm-level media database
Financial Support for Sustainability Initiatives (FSSI)	ESG-based sustainability-resource indicator	ESG score used as a proxy for sustainability-oriented financial/resource support	ESG/sustainability database
Environmental Regulation (ER)	Environmental regulatory/sustainability rating	Six-point scale from lower to higher regulatory pressure	Environmental/corporate disclosures

Source: Developed by the Researcher

EP was measured using GHG-emission intensity rather than absolute emissions to reduce the influence of differences in firm scale. The measure was direction-adjusted such that higher levels consistently reflected better EP; since emissions intensity was indicative of worse environmental performance. This treatment allowed the expected positive relationships in the hypotheses to be consistent with the direction of the dependent variable achieving positive results.

SI was measured using the number of green invention patents, an established firm-level indicator of environmentally oriented technological innovation. To

prevent skewness and the impact of extreme values, the number of patents was rescaled to ln(1 + patents).

DT was measured by the proportion of employees classified as ICT specialists. This measure reflects the human capital aspect of firms' digital characteristics. It was a relevant part of digital transformation but was not an exhaustive measure of digitalization aspects, including digital infrastructures, software investment, or technology intensity.

CSC was proxied by renewable-energy adoption, calculated as the percentage of all energy use by the firm that came from renewables. This observable operational indicator reflects the degree to which firms' energy use decision-making is oriented towards sustainability. It does not directly assess the overall dimensions of organizational culture such as shared values, beliefs or informal norms among employees. Renewable-energy adoption therefore is considered only as an observable proxy measure of the operational expression of CSC, not as a total measure of culture for sustainability. Mechanical association with use of renewable energy may also relate to emissions–based environmental performance, which is specifically highlighted and accounted for when interpreting the CSC–EP association.

For CC, the proportion of employees in the selected cultural/knowledge-based employment category was used as an indicator and was expressed as a percentage of the total number of employees. This employment-share measure reflects a dimension of the firm's culture and knowledge resources that can be easily observed in the workforce. But it is not comprehensive in its scope as related to the multi-dimensional aspects of cultural capital such as education, professional networks, competencies, shared knowledge, and organizational learning. CC is therefore then read as a proxy indicator of cultural capital for the purposes of this study, rather than as an indicator of cultural capital in itself.

DML was operationalized as being the percentage of employees who use their computer daily for their job. The measure reflects an observable aspect of workers' engagement with digital technologies and so serves as an empirical indicator of the assessment of practical digital technology exposure and use at a firm level. It does not directly assess the broader aspects of digital media literacy such as information evaluation, critical digital skills, digital communication competence, or content assessment. Therefore, the variable is seen as a proxy measure of the employee-use aspect of DML, and is not a complete indicator of digital media literacy.

MCI was measured using the number of firm-specific media mentions and transformed as ln(1 + media mentions). The measure gained traction in the external media and the attention of stakeholders at the firm level.

The operationalisation of FSSI was done by adopting the firm-level ESG score as an indicator of sustainability-oriented financial and resource support. The ESG score is not a monetary amount, expenditure measure or a direct measure of sustainability financing and is reported in the units of the underlying ESG rating scale. Rather, it acts as an externally visible indicator of the organisations' resources and support for sustainable themed activities. ESG scores can include an environmental aspect, which is conceptually related to environmental performance, and the degrees of association that are uncovered in such areas are to be interpreted with care and can not be concluded as proof of a unique separate financing mechanism.

ER was measured using a six-point environmental regulatory/sustainability rating, with higher values representing stronger environmental regulatory pressure. ER was included as a moderator variable because institutional pressures can influence the manner in which the internal capabilities of companies are manifested in sustainability outcomes.

An extra sensitivity analysis was performed for both the CSC and the FSSI to prevent the risk of measuring overlap. For CSC, the analysis involved checking if the principal association survived when the component of the relevant specification that was set up primarily to link with the emissions-based EP measure is removed, or when it is separated from the EP measure. The analysis was carried out using FSSI's measure, excluding the environmental component, as there was an overlap with EP. These sensitivity analyses were performed to determine the possibility that the associations reported were mainly due to mechanical or definitional overlap between the proxy measures and the outcome.

3.4. *Data Analysis and Econometric Strategy*

All analyses were conducted in Stata. Prior to the main estimations, descriptive statistics, cross-sectional dependence, panel specification tests, VIFs, cross correlations, and slope heterogeneity were analyzed. The baseline estimates were the two-way firm and year FE models, and System GMM were used as a complementary dynamic estimator.

Firm FE controlled for unobserved firm specific factors which were fixed within the firm level and year FE accounted for common year-wide shocks. Nevertheless, these estimates did not address omitted time-varying characteristics and reverse causality. For example, firms with stronger sustainability performance could subsequently invest more in DT or attract greater media attention and sustainability-related resources. Some dynamic endogeneity concerns were dealt with using instruments constructed within System GMM, assuming maintained relationships, but no causal identification was achieved. Hence, the econometric approach was applied to evaluate the stability and conditionality of associations and not to assume that DT, organisational skills, MCI, FSSI or ER explain the change in sustainability results.

3.4.1. Baseline Fixed-Effects Models

Two-way firm and year fixed-effects models were estimated for EP and SI:

$$EP_it = \alpha + \beta_1 DT_it + \beta_2 CSC_it + \beta_3 CC_it + \beta_4 DML_it + \mu_i + \lambda_t + \varepsilon_it \quad (1)$$

$$SSI_it = \alpha + \beta_1 DT_it + \beta_2 CSC_it + \beta_3 CC_it + \beta_4 DML_it + \mu_i + \lambda_t + \varepsilon_it \quad (2)$$

Here, μ_i and λ_t denote firm and year fixed effects, respectively. Fuller specifications additionally included MCI, FSSI, and ER. Standard errors were clustered at the firm level.

No additional firm-level control variables were included in the reported specifications; μ_i and λ_t represent firm and year fixed effects, respectively

3.4.2. Dynamic System GMM

Because EP and SI were persistent over time, dynamic System GMM models included the lagged dependent variable (Blundell & Bond, 1998):

$$Y_{\{it\}} = \alpha + \backslash rho\, Y_{\{i,t-1\}} + \beta' X_{\{it\}} + \gamma' Z_{\{it\}} + \mu_i + \lambda_t + \varepsilon_{\{it\}}, Y \backslash in \{EP, SI\} \quad (3)$$

System GMM combined equations in first differences and levels and used lagged variables as internal instruments (Blundell & Bond, 1998). The approach relied on moment conditions requiring the selected lagged instruments to be sufficiently uncorrelated with the relevant error terms.

System GMM employed internal instruments generated as lags of the variables to overcome dynamic persistence and endogeneity, keeping the maintained moment conditions in place. The validity of the dynamic specifications was assessed using the Arellano–Bond tests for first- and second-order serial correlation and the Hansen test of overidentifying restrictions. The AR(1) tests were statistically significant for both EP and SI ($p = 0.003$ and $p = 0.004$, respectively), whereas the AR(2) tests were not statistically significant ($p = 0.284$ and $p = 0.317$), providing no evidence of second-order serial correlation. Under the maintained instrument assumptions, both the EP model test ($p = 0.362$) and the SI model test ($p = 0.417$) did not reject the overidentifying restrictions for these two models. The EP and SI specifications used 28 and 27 instruments, respectively, relative to 200 firms. The instrument counts were therefore kept reasonably low to reduce concerns on proliferation of instruments. These diagnostic tests are used to provide specification checks for the System GMM models, but are not used to establish instrument validity or to identify instruments as causal.

3.4.3. Panel Diagnostics

Using panel diagnostics, the study checked for cross-sectional dependence, slope heterogeneity and model specifications. Cross sectional dependence was studied using the Pesaran CD test, and the Pesaran–Yamagata Delta and adjusted Delta tests were used to test slope homogeneity.

$$CD = \sqrt{\left\{\frac{2T}{\left[N(N-1)\right]}\right\}} \sum_{\{i=1\}}^{\{N-1\}} \sum_{\{j=i+1\}}^{\{N\}} \{\rho\}_{\{ij\}}. \quad (4)$$

The Pesaran CD statistic tested cross-sectional independence. The Pesaran–Yamagata Delta and adjusted Delta tests assessed slope homogeneity. The Hausman statistic was:

$$H = (\hat{\beta}_FE - \hat{\beta}_RE)'[Var(\hat{\beta}_FE) - Var(\hat{\beta}_RE)]^{-1}(\hat{\beta}_FE - \hat{\beta}_RE) \quad (5)$$

A significant Hausman test supported fixed effects.

3.4.4. Mediation Analysis

MCI and FSSI were examined as potential mediators using separate path models:

$$M_it = \alpha_a + aX_it + \mu_i + \lambda_t + e_{ait} \quad (6)$$

$$Y_it = \alpha_b + c'X_it + bM_it + \mu_i + \lambda_t + e_{bit} \quad (7)$$

$$Indirect\ Effect = a \times b \quad (8)$$

Indirect effects were evaluated using 95% bootstrap confidence intervals and were considered statistically supported if they did not include zero. This procedure tested H9a–H10d for MCI and H11a–H12d for FSSI. Mediation was understood as a statistical phenomenon instead of a causal explanation as a result of the observational design.

Indirect effects were estimated using 95% bootstrapped confidence intervals and were deemed to be statistically supported if the interval did not include zero. Where relevant, proportion mediated was interpreted with caution, and total and direct effect was reported as well. Given the nature of the data collected in this study, which was observational with no attempt to elicit exogenous variation or definitive temporal ordering of the pathway variable, indirect effects were interpreted as indirect statistical association instead of as causal mediation. Therefore, the hypothesis structure in this regard suggested that MCI was H9 and FSSI was H10.

3.4.5. Moderation Analysis

Environmental regulation (ER) was tested as a moderator:

$$Y_it = \alpha + \beta_1 X_it + \beta_2 ER_it + \beta_3 (X_it \times ER_it) + \mu_i + \lambda_t + \varepsilon_{it} \quad (10)$$

$$\frac{\partial Y_{\{it\}}}{\partial X_{\{it\}}} = \beta_1 + \beta_3 ER_{\{it\}}$$

where X was the technological or organizational capability of interest. Positive interaction meant stronger association at higher levels of ER, while negative meant a decrease in association at higher levels of ER. Significant interactions were examined using marginal effects at meaningful levels of ER and presented graphically. The direction of the interaction effects was presumed to be empirical instead of a priori theoretical, especially for the CC-SI relationship.

3.4.6. Robustness and Alternative Specifications

Robustness analysis was conducted by lagged FE models, System GMM and other specifications of EP and SI as appropriate. For the observed associations, consistency across estimators and measures was interpreted as evidence that they were not very sensitive to a particular specification. These robustness checks were not designed to rule out omitted variable bias or reverse cause and effect, and so did not provide causation. They were taken as indication of the reliability of the observed relationships. The lagged FE model was:

$$Y_it=\alpha+\beta' X_i,t-1+\mu_i+\lambda_t+\varepsilon_{it} \quad (11)$$

Overall, the basic patterns of DT, CSC, DML, and CC were maintained. These checks enhanced the reliability of the stability of the associations but did not rule out omitted-variable bias and reversion problems.

3.5. *Conceptual Framework*

The conceptual framework in **Figure 2** integrated DCT and Institutional Theory. Technological and organizational aspects related to EP and SI was represented through DT, CSC, CC, and DML. MCI and FSSI were identified as statistical indirect pathways, and ER was chosen as an institutional boundary condition which may impact the magnitude of the capability–sustainability links. The framework thus made a distinction between direct associations and potential indirect associations through MCI and FSSI; and conditional associations through ER. Since observational information from firms has been used, these pathways were hypothesized but not necessarily causal mechanisms.

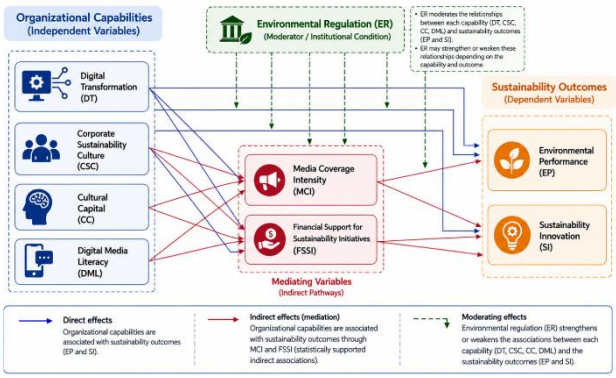

Figure 2. Conceptual Framework

3.6. *Methodology Flowchart*

Figure 3 summarized the empirical procedure. The analysis started with sample selection, data collection, construction of variables, and descriptive analysis. Multicollinearity, cross-sectional dependence, slope heterogeneity and model specifications were subsequently examined using panel diagnostics. Two-way FE models provided the baseline estimates, followed by System GMM. MCI and FSSI were analyzed indirectly, and ER was analyzed as a boundary condition by moderation models. Estimates of the robustness of findings were subsequently obtained using robustness specifications. The last stage was the interpretation of the results within the boundaries of the hypotheses and the theoretical framework.

4. Data Analysis

Table 2 reports the descriptive statistics for the study variables. The number of usable observations varies across measures, ranging from 1,670 for cultural capital (CC) to 2,095 for media coverage intensity (MCI) and environmental regulation (ER), compared with a maximum possible panel of 2,200 firm-year observations. This variation is not necessarily due to sampling frame differences, but as a result of failure to identify information needed to create specific variables. Importantly, these are observation-level counts, and the subsequent regression models should only include observations for which all the variables in the respective regression model specification apply. Therefore, the estimation-sample sizes presented in the regression tables have been verified to be consistent with the availability of the CC and the other variables included in the analysis. There was also considerable variation in sustainability outcomes, with EP having a mean of 4.872 (SD = 1.286) and SI a mean of 1.126 (SD = 0.914). DT and DML have means of 6.741 and 5.612, respectively. Since DT is operationalized through employment rates of ICT specialists while DML is operationalized through standard computer use, the units and construction of these two measures are detailed in the variable-definition section to be not interpreted as shares of employees from the same unit. There was meaningful dispersion both within and across firms on CSC (M = 4.082). Likewise, cross-firm variation was observed for CC, MCI, FSSI, and ER. Overall, the descriptive statistics indicate variation in the principal variables used in the subsequent panel estimations.

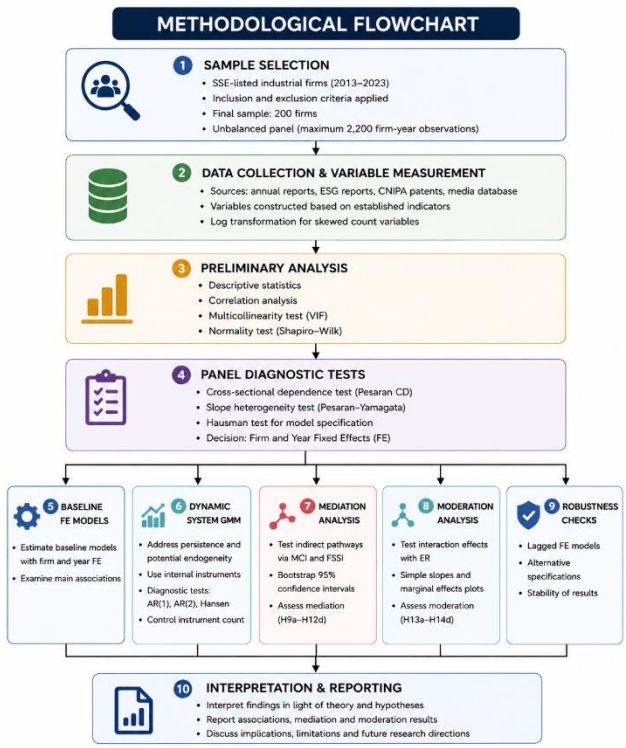

Figure 3. Methodology Flowchart

Table 3 reports the pairwise correlations among the study variables. EP and SI showed a positive correlation ($r = 0.184$, $p < 0.001$); both were sustainability outcomes, but it was determined that they were different aspects. However, there was positive and statistically significant relationship between DT and EP ($r = 0.241$) and SI ($r = 0.276$) with CSC and DML also sharing a positive association with both. These were more modest correlations for CC, especially with EP ($r = 0.052$), consistent with its differentiated role in the next analysis. MCI, FSSI, and ER were generally positively correlated with the sustainability outcomes and several explanatory variables. More importantly, the correlations among the explanatory variables were only moderate and none of the correlation coefficients showed an unusually close linear association.

These findings gave initial support to the hypothesized relationships, and it appears that multicollinearity did not significantly affect the subsequent regression estimates.

Table 2. Descriptive Statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Environmental Performance	1,910	4.872	1.286	1.215	8.114
Sustainability Innovation	1,845	1.126	0.914	0.000	4.672
Digital Transformation	2,020	6.741	1.821	2.214	9.015
Corporate Sustainability Culture	1,915	4.082	0.891	1.604	7.321
Cultural Capital	1,670	1.583	0.821	0.412	4.218
Digital Media Literacy	1,985	5.612	2.341	1.524	9.102
Media Coverage Intensity	2,095	2.318	1.746	0.000	8.426
Financial Support for Sustainability Initiatives	1,985	6.184	1.472	2.314	9.217
Environmental Regulation	2,095	3.487	1.214	1.000	6.000

Table 3. Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Environmental Performance	1.000								
(2) Sustainability Innovation	0.184***	1.000							
(3) Digital Transformation	0.241***	0.276***	1.000						
(4) Corporate Sustainability Culture	0.163***	0.194***	0.118***	1.000					
(5) Cultural Capital	0.052*	0.086***	0.041	0.137***	1.000				
(6) Digital Media Literacy	0.176***	0.213***	0.287***	0.154***	0.071**	1.000			
(7) Media Coverage Intensity	0.094***	0.121***	0.158***	0.089***	0.036	0.112***	1.000		
(8) Financial Support for Sustainability Initiatives	0.132***	0.168***	0.211***	0.226***	0.074**	0.193***	0.146***	1.000	
(9) Environmental Regulation	0.117***	0.102***	0.095***	0.181***	0.029	0.084***	0.063**	0.157***	1.000

Table 4. Shapiro–Wilk Distributional Diagnostics

Variable	Obs.	W	z	p-value
Environmental Performance	1,910	0.914	9.842	<0.001
Sustainability Innovation	1,845	0.876	12.116	<0.001
Digital Transformation	2,020	0.928	9.164	<0.001
Corporate Sustainability Culture	1,915	0.941	8.327	<0.001
Cultural Capital	1,670	0.901	10.481	<0.001
Digital Media Literacy	1,985	0.883	11.746	<0.001
Media Coverage Intensity	2,095	0.921	9.632	<0.001
Financial Support for Sustainability Initiatives	1,985	0.936	8.704	<0.001
Environmental Regulation	2,095	0.952	7.291	<0.001

Table 5. Variance Inflation Factor

Variable	VIF	1/VIF
Digital Transformation	1.42	0.704
Corporate Sustainability Culture	1.38	0.725
Cultural Capital	1.16	0.862
Digital Media Literacy	1.51	0.662
Media Coverage Intensity	1.21	0.826
Financial Support for Sustainability Initiatives	1.34	0.746
Environmental Regulation	1.17	0.855
Mean VIF	1.31	

Table 6. Cross-Sectional Dependence Test

Dependent Variable	Pesaran CD Statistic	p-value	Decision
Environmental Performance	4.286	<0.001	Reject H_0; cross-sectional dependence
Sustainability Innovation	3.917	<0.001	Reject H_0; cross-sectional dependence

Table 4 indicates that the Shapiro–Wilk tests rejected the null hypothesis of normality for all variables ($p < 0.001$). The results therefore suggested deviations from normal distribution in the data of the firms, not surprising as several measures were bounded, count-based and heterogeneous, such as sustainability innovation and media coverage. These distributional properties were taken into account in the specification and the inference of the model. In addition, the non-normality of the individual variables was not a problem for the panel-data estimators; on the contrary, robust inference was practiced and, in relevant cases, appropriate transformations of highly skewed measures were used.

Table 5 provides the variance inflation factor (VIF) diagnostics. The VIF values ranged from 1.16 to 1.51, with a mean VIF of 1.31. The values were significantly smaller than typical benchmarks for problematic multicollinearity among the variables, suggesting minimal linear dependency among the variables used to explain the dependent variable. The low values for VIF allow maintaining DT, CSC, CC, DML, MCI, FSSI, and ER in the empirical specifications and indicating that coefficient estimates are not likely to be seriously biased by the potential of highly raised standard errors due to multicollinearity.

Table 6 reports the Pesaran cross-sectional dependence test. The cross sectional independence null hypothesis was rejected in both EP (CD = 4.286, $p < 0.001$) and SI (CD = 3.917, $p < 0.001$), suggesting that there is statistically significant dependence across companies. Overall, this finding indicates that sustainability outcomes of firms were not entirely unrelated and may be related to macroeconomic conditions, regulation, technological progress or sectoral shocks. Additionally, the study accounted for cross-sectional dependence in the econometric analysis conducted thereafter, thereby keeping the emphasis on the need of the estimators and the inference procedures to be robust against cross-sectional dependence among firms.

Table 7 presents the Hausman specification tests comparing fixed- and random-effects models. The null hypothesis was rejected for both the EP model ($\chi^2 = 18.624$, $p = 0.005$) and the SI model ($\chi^2 = 21.387$, $p = 0.003$). The findings thus confirmed the use of firm fixed effects, which suggests that unobserved firm-specific effects were likely to be collinear with the explanatory variables. The fixed-effects specification was then the better baseline approach for the control of the time-invariant firm heterogeneity, and for the removal of possible omitted-variable bias caused by aggregated persistent firm characteristics.

H_0: Slope coefficients are homogeneous across firms. **Table 8** reports the Pesaran–Yamagata slope heterogeneity tests. Both the Delta statistic (2.184, $p = 0.029$) and adjusted Delta statistic (2.417, $p = 0.016$) rejected the null hypothesis of homogeneous slope coefficients. This provides indication that the relationship of the explanatory variables to sustainability outcomes might be different across firms, instead of being consistently the same across the sample. The evidence of the slope heterogeneity therefore favors the application of an empirical framework that takes into account the variations among firms, and warns that any average relationship estimated in the sample should not be viewed as holding true for all firms in general.

Table 7. Hausman Specification Test

Test	χ^2 Statistic	p-value	Model Selection
Environmental Performance model	18.624	0.005	Fixed Effects
Sustainability Innovation model	21.387	0.003	Fixed Effects

Table 8. Pesaran–Yamagata Slope Heterogeneity Test.

Test	Statistic	p-value	Decision
Delta	2.184	0.029	Reject H_0
Adjusted Delta	2.417	0.016	Reject H_0

Table 9 reports the baseline firm- and year-fixed-effects estimates for EP and SI. DT was significantly and positively correlated with both outcomes, thus supporting H1 and H2. CSC was also positively associated with EP and SI, providing support for H3 and H4, but the value of the coefficients was reduced after the other controls are added. CC was not significantly associated with EP, providing no support for H5, but showed a positive and significant association with SI, supporting H6. DML was positively and significantly correlated with both outcomes, thus supporting hypotheses H7 and H8. MCI and FSSI were positively associated with EP, whereas their associations with SI were weaker. ER was positively associated with both outcomes. Positive associations were generally consistent across the two sustainability outcomes for DT, CSC and DML, while CC exhibited an outcome specific pattern.

4.1. *Variation in observations across models*

Observation counts differ among specifications depending on information and the variables in the models. The numbers of observations reported here are the numbers of established samples that Stata returned. The dynamic System GMM estimations use 1,690 firm-year observations for environmental performance and 1,565 for sustainability innovation, which coincide with the observation counts of the corresponding fully specified fixed-effects models.

Table 10 reports the dynamic System GMM estimates. The positive and significant coefficients of the lagged dependent variables indicate persistence in both EP and SI. DT was positively associated with both outcomes, and CSC was similarly positively associated with EP and SI. CC was not significantly associated with EP but was positively

associated with SI, whereas DML was positively associated with both EP and SI. FSSI was positively associated with EP but not significantly associated with SI, while ER was positively associated with both outcomes. The AR(1) tests were significant (both at the 0.003 and 0.004 levels), but the AR(2) tests were not (at the 0.284 and 0.317 levels) suggesting that there is no evidence of second-order serial correlations. The Hansen tests did not reject the overidentifying restrictions in either specification (p = 0.362 and p = 0.417). The EP and SI models used 28 and 27 instruments, respectively, relative to 200 firms. The overall pattern of the System GMM estimates is complementary to that after accounting for outcome persistence and possible dynamic endogeneity, subject to the GMM's instrument assumptions.

Table 9. Baseline Fixed-Effects Estimates

Variables	(1) Environmental Performance	(2) Environmental Performance	(3) Sustainability Innovation	(4) Sustainability Innovation
Digital Transformation	0.118*** (0.026)	0.103*** (0.025)	0.082*** (0.021)	0.074*** (0.021)
Corporate Sustainability Culture	0.067** (0.029)	0.052* (0.028)	0.061** (0.026)	0.055** (0.026)
Cultural Capital	0.031 (0.021)	0.027 (0.021)	0.044** (0.019)	0.039** (0.019)
Digital Media Literacy	0.074*** (0.019)	0.068*** (0.019)	0.056*** (0.017)	0.051*** (0.017)
Media Coverage Intensity	—	0.019* (0.011)	—	0.014 (0.010)
Financial Support for Sustainability Initiatives	—	0.043** (0.020)	—	0.031* (0.018)
Environmental Regulation	—	0.036** (0.017)	—	0.029* (0.016)
Firm Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Clustered Standard Errors	Yes	Yes	Yes	Yes
Observations	1,720	1,690	1,590	1,565
Within R^2	0.31	0.34	0.28	0.31

*Note: Standard errors are reported in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.*

Table 10. Dynamic System GMM Estimates

Variables	(1) Environmental Performance	(2) Sustainability Innovation
Lagged dependent variable	0.421*** (0.083)	0.367*** (0.071)
Digital Transformation	0.091*** (0.028)	0.063** (0.027)
Corporate Sustainability Culture	0.048* (0.027)	0.057** (0.025)
Cultural Capital	0.024 (0.020)	0.036* (0.019)
Digital Media Literacy	0.061** (0.026)	0.049** (0.022)
Media Coverage Intensity	0.015 (0.012)	0.011 (0.010)
Financial Support for Sustainability Initiatives	0.034* (0.019)	0.026 (0.017)
Environmental Regulation	0.029* (0.016)	0.025* (0.014)
Year Fixed Effects	Yes	Yes
Observations	1,690	1,565
Number of Firms	200	200
AR(1) p-value	0.003	0.004
AR(2) p-value	0.284	0.317
Hansen test p-value	0.362	0.417
Number of Instruments	28	27

However, since the mediation analysis applied to the observational panel data with no exogenous variation in the mediators, the induced effects of the indirect relations were interpreted as statistical rather than causal mediation effects.

Table 11A reports the estimated indirect associations through MCI. The indirect effects were small in magnitude, accounting for only 1.79%–3.77% of the corresponding total effects. EP bootstrap confidence intervals for DT and DML did not include 0, while the lower confidence limit for CSC was given as 0.000, which is to be interpreted with caution. For SI, the lower limit of support for DT, CSC and DML were also expressed as being equal to 0, so these results are treated as being preliminary rather than certain statistical support. The confidence intervals for CC also contained zero for both EP and SI, which supports no statistical evidence for the indirect associations. Overall, the MCI results indicate small indirect associations, with several of these effects providing only tentative evidence. These observations indicate only statistical indirect associations and are not causal mediated ones. Because the analyses were observational and neither an exogenous nature of the mediational variable nor clear temporal ordering was inferred, all the indirect effects estimated in this study are subject to the possibility of being affected by other unobserved variables, reverse causality, confounding, or omitted variables.

Table 11A. Indirect Associations through Media Coverage Intensity

Hypothesis	Independent Variable	Mediator	Dependent Variable	Path a	Path b	Direct Effect (c′)	Total Effect (c)	Indirect Effect (a × b)	95% Bootstrap CI	Proportion Mediated	Decision
H9	Digital Transformation	MCI	EP	0.158***	0.019*	0.103***	0.106†	0.003	[0.001, 0.005]	2.83%†	Supported
H9	Corporate Sustainability Culture	MCI	EP	0.089***	0.019*	0.052*	0.054†	0.002	[0.000, 0.004]	3.70%†	Tentative
H9	Cultural Capital	MCI	EP	0.036	0.019*	0.027	0.028†	0.001	[−0.001, 0.003]	3.57%†	Not supported
H9	Digital Media Literacy	MCI	EP	0.112***	0.019*	0.068***	0.070†	0.002	[0.001, 0.005]	2.86%†	Supported
H9	Digital Transformation	MCI	SI	0.158***	0.014	0.074***	0.076†	0.002	[0.000, 0.005]	2.63%†	Tentative
H9	Corporate Sustainability Culture	MCI	SI	0.089***	0.014	0.055**	0.056†	0.001	[0.000, 0.004]	1.79%†	Tentative
H9	Cultural Capital	MCI	SI	0.036	0.014	0.039**	0.040†	0.001	[−0.001, 0.003]	2.50%†	Not supported
H9	Digital Media Literacy	MCI	SI	0.112***	0.014	0.051***	0.053†	0.002	[0.000, 0.004]	3.77%†	Tentative

Table 11B. Mediation Effects of Financial Support for Sustainability Initiatives

Hypothesis	Independent Variable	Mediator	Dependent Variable	Path a	Path b	Direct Effect (c′)	Total Effect (c)	Indirect Effect (a × b)	95% Bootstrap CI	Proportion Mediated	Decision
H10	Digital Transformation	FSSI	EP	0.211***	0.043**	0.103***	0.112†	0.009	[0.002, 0.018]	8.04%†	Supported
H10	Corporate Sustainability Culture	FSSI	EP	0.226***	0.043**	0.052*	0.062†	0.010	[0.002, 0.020]	16.13%†	Supported
H10	Cultural Capital	FSSI	EP	0.074**	0.043**	0.027	0.030†	0.003	[−0.002, 0.008]	10.00%†	Not supported
H10	Digital Media Literacy	FSSI	EP	0.193***	0.043**	0.068***	0.076†	0.008	[0.002, 0.016]	10.53%†	Supported
H10	Digital Transformation	FSSI	SI	0.211***	0.031*	0.074***	0.081†	0.007	[0.001, 0.014]	8.64%†	Supported
H10	Corporate Sustainability Culture	FSSI	SI	0.226***	0.031*	0.055**	0.062†	0.007	[0.001, 0.015]	11.29%†	Supported
H10	Cultural Capital	FSSI	SI	0.074**	0.031*	0.039**	0.041†	0.002	[−0.001, 0.006]	4.88%†	Not supported
H10	Digital Media Literacy	FSSI	SI	0.193***	0.031*	0.051***	0.057†	0.006	[0.001, 0.013]	10.53%†	Supported

Interestingly, CC was found to have positive direct relationships with SI in the base model and the dynamic model, without having statistically significant indirect relationships via MCI. This difference implies that association between CC and SI was not carried through the media pathway explored here. This association can also be effected through other organizational, knowledge-based or innovation-related channels, which were not directly tested. So, this result does not constitute evidence of a suppression effect alone; further statistical evidence is needed.

Table 11B reports the statistically estimated indirect associations involving FSSI. The bootstrap confidence intervals excluded zero for DT, CSC, and DML for both EP and SI, providing statistical support for H10. In contrast, the confidence intervals for CC included zero for both outcomes. Thus, FSSI showed statistically supported indirect associations for DT, CSC, and DML but not for CC. This pattern was fairly similar to the MCI results and was found to be more consistent for the indirect associations for digital, organizational, information-related, than for CC. These results reproduced only an indirect association, statistically, and did not provide evidence of a financing mechanism. The relationships found in the MCI analysis may be reflective of omitted variables, reverse causality, confounding, and uncertain temporal ordering, as was described.

Table 12. Moderating Effect of Environmental Regulation

Variables	(1) Environmental Performance	(2) Sustainability Innovation
Digital Transformation	0.105*** (0.027)	0.071*** (0.022)
Corporate Sustainability Culture	0.051* (0.029)	0.056** (0.025)
Cultural Capital	0.028 (0.021)	0.041** (0.019)
Digital Media Literacy	0.065*** (0.020)	0.052*** (0.018)
Environmental Regulation	0.031** (0.015)	0.026* (0.014)
Digital Transformation × Environmental Regulation	0.044** (0.019)	0.031** (0.012)
Corporate Sustainability Culture × Environmental Regulation	0.027* (0.015)	0.022* (0.013)
Cultural Capital × Environmental Regulation	0.018 (0.014)	−0.025* (0.014)
Digital Media Literacy × Environmental Regulation	0.036** (0.016)	0.029** (0.013)
Firm Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Clustered Standard Errors	Yes	Yes
Observations	1,640	1,525
Within R^2	0.37	0.33

Table 12 shows that the relationships between organizational capabilities and sustainability outcomes are conditional on levels of environmental regulation. For EP, the DT × ER, CSC × ER, and DML × ER interactions were positive and statistically significant, whereas the CC × ER interaction was not statistically significant. For SI, the DT × ER, CSC × ER, and DML × ER interactions were also positive and statistically significant. For SI, the CC × ER interaction was negative (β = −0.025, SE = 0.014) but only reached significance at the 10% level; results were not interpreted as a clear moderation effect, but rather as tentative evidence that at higher levels of ER the CC–SI association weakens. Overall, the results indicate that the positive associations of DT, CSC, and DML with sustainability outcomes tend to become stronger at higher levels of ER. In contrast, the CC × ER result for SI provides only tentative evidence that the positive association between CC and SI may weaken as ER increases. A possible explanation is that DT and DML might provide more easily-available technological and informational resources under increased regulatory requirements, while CSC might be more distinctly linked to formal sustainability requirements. CC may operate differently owing to cultural and/or knowledge-based materials that rely on relying on organizational discretion and informal procedures. Under stronger regulatory constraints, these forms of discretion may be reduced, potentially weakening the CC–SI association. However, because the effect of the CC × ER interaction was not strongly statistically significant, this interpretation should be viewed with caution and should not be considered a strong finding.

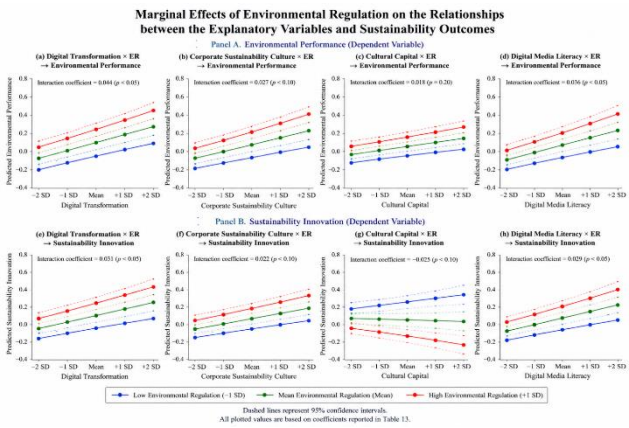

Figure 4. Marginal Effects of Environmental Regulation on Sustainability Outcomes

Figure 4 presents the marginal effects of the organizational capabilities across levels of ER. Panel A shows the conditional associations with EP, while Panel B shows those with SI. DT, CSC and DML had positive marginal-effect slopes which increased in magnitude with increases in ER, implying stronger positive conditional associations at higher ER levels. The corresponding slopes for CC were statistically indistinguishable from zero for EP. However, for SI, the CC slope was a decreased positive slope with

increasing values of ER similar to the negative CC × ER interaction that was reported in **Table 12**. The marginal-effects plots, therefore, confirmed that ER increased the DT–, CSC–, and DML–sustainability associations, but this conditional relationship varied depending on associations with CC. The plotted slopes should represent the expected slope at the reported low, mean, and high ER values, or the percentile values, not as an indication of a cause-and-effect control mechanism.

Table 13. Robustness and Alternative Specifications

Variable	Baseline FE	Lagged FE	System GMM	Alternative EP
Panel A. Environmental Performance				
Digital Transformation	0.118***	0.103***[1]	0.091***	0.109***[1]
Corporate Sustainability Culture	0.067**	0.058**[1]	0.048*	0.061**[1]
Cultural Capital	0.031	0.026[1]	0.024	0.028[1]
Digital Media Literacy	0.074***	0.067***[1]	0.061**	0.069***[1]
Firm Fixed Effects	Yes	Yes	No	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,720	1,640[1]	1,690	1,610[1]
Panel B. Sustainability Innovation				
Digital Transformation	0.082***	0.074***	0.063**	0.063**
Corporate Sustainability Culture	0.061**	0.055**	0.057**	0.057**
Cultural Capital	0.044**	0.039**	0.036*	0.036*
Digital Media Literacy	0.056***	0.051***	0.049**	0.049**
Firm Fixed Effects	Yes	Yes	No	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	1,590	1,565	1,565	1,520

Note: *** p < 0.01, ** p < 0.05, * p < 0.10. *The Lagged FE, System GMM, and Alternative SI specifications were estimated separately. The coefficients reported in the Alternative SI and System GMM columns coincide at the displayed three-decimal precision for the four focal variables, despite being obtained from different specifications and estimation samples. The reported values and observation counts are those returned by the respective Stata estimations.*

The robustness tests in **Table 13** are executed on different estimates of lagged fixed-effects, System GMM and alternative specifications of the outcome. For EP, DT remained positive in all specifications and statistically significant, and for CSC, and DML, they were also positive and statistically significant. The correlations of CC with EP, on the other hand, were statistically insignificant in the specifications reported. Retained positive associations for SI, DT, CSC, CC, and DML for the robustness specifications, though with varying levels of statistical significance for different variables and estimators. The Lagged FE estimates are in accord with the FE counterparts to the degree of accuracy that is presented, and the Alternative SI coefficients are identical to the System GMM estimates to three decimal places. These specifications are approximate only and the reported regression coefficients and sample sizes correspond to those reported by the Stata estimations. Overall, the directions of the coefficients are roughly consistent, supporting the argument against restricting the principal associations to one specification. However, these robustness checks are sensitivity rather than exclusion, and they do not rule out potential endogeneity or omitted variable bias and other limits to causal identification.

5. Discussion, Conclusion, and Implications

5.1. *Discussion*

The results offer a differentiated outlook on the organizational capacities and institutional contexts related to the outcomes and consequences of sustainability performance across Chinese listed industrial companies. DT, CSC, and DML were consistently associated with EP and SI, whereas CC was associated with SI but not EP. MCI and FSSI had statistically significant indirect associations by the pathways tested in the case of DT, CSC, and DML, but not CC; ER influenced associations differently by ability. While these patterns build on DCT by identifying sustainability roles related to the capabilities, they also support the Institutional Theory, as the regulatory conditions are shown to affect these associations (Abdelfattah *et al.*, 2025; Nguyen *et al.*, 2025; Rehman *et al.*, 2025). All findings were interpreted as association, given the panel design of the observation.

The positive relationships between DT and EP and SI were aligned with the positive correlation of digital technologies with environmental management, resource efficiency, and sustainability-oriented innovation (Elia *et al.*, 2024; Feliciano-Cestero *et al.*, 2023). A DCT view supports the argument that digital transformation can be associated with sustainability when companies leverage and reassemble technologic and information resources to meet the evolving environmental needs (Lei & Zhang, 2026). Its association with both EP and SI indicates that DT may be relevant to both environmental improvement and sustainability-oriented innovation.

CSC also showed positive associations with EP and SI, consistent with research emphasizing sustainability-oriented values and organizational practices (Assoratgoon & Kantabutra, 2023; Hossain *et al.*, 2022). The results of this discovery indicate that sustainability can be introduced in both the form of organisational orientations and technological investment. The finding can therefore

identify an important sustainability-oriented condition, but is not a complete representation of the CSC construct.

CC showed a distinct pattern, with a significant association with SI but not EP. This can be explained by the fact that cultural and human-capital resources are associated with domain-specific learning, idea generation, and innovation, similar to prior literature that connected cultural and human-capital resources to organizational sustainability (Assoratgoon & Kantabutra, 2023). The lack of significant association between CC and EP should not be interpreted as lack of importance of cultural resources for environmental sustainability: in the observed measurement and sample, this association with CC was more related to innovation.

DML has been positively correlated with EP and SI, which aligns with studies focusing on the digital skills needed for accessing, evaluating, communicating, and applying information regarding sustainability (Lee *et al.*, 2025; Sergeeva *et al.*, 2025; Zhang *et al.*, 2024). While its pattern was similar to DT, its underlying capability was distinct: DML highlights individual capability in using and processing digital information, while DT highlights the capabilities of the technological resources of an organization (Lei & Zhang, 2026). They are therefore complementary dimensions of sustainability capacity, as indicated by their associations in parallel. However, because DML was measured using employees' computer use, the finding should not be generalized to the broader construct of critical digital media literacy.

These capabilities were further differentiated by these indirect analyses. MCI showed statistically supported indirect associations for DT, CSC, and DML but not CC. The pattern aligns with the study which focuses on the media visibility, transparency, and accountability, and sustainability communication (Ren *et al.*, 2026; Rong & Kim, 2024; Zou *et al.*, 2025). In the view of Institutional Theory, a high level of media visibility can expose enterprises to the pressure of stakeholders' questions and expectations of legitimacy. Findings, however, were indirect and statistically supported, and may have resulted from reverse causality, omitted variables, or confounding.

FSSI exhibited a similar trend: statistically significant indirect relationships in regard to DT, CSC and DML, but not CC. A potential explanation is that these capacities could rely more on how companies are able to move and leverage sustainability-related resources, in accordance with the idea of resource integration and reconfiguration of DCT. The data can, however, provide no evidence of a causal resource-mobilization mechanism. Remarkably, CC had a positive direct relationship with SI, while it did not have a statistically supported indirect relationship with either MCI or FSSI. This suggests that the CC–SI association was not captured by the two pathways examined. The pattern should not be interpreted as suppression or causal mediation; the pattern is likely to be relevant for other channels of learning, knowledge development, or innovation, but will not be tested.

The moderation results revealed that the institutional conditions did not function equally with respect to the capabilities. ER strengthened the positive associations of DT, CSC, and DML with EP and SI, whereas CC × ER was insignificant for EP but negative and significant for SI. This pattern aligns with the Institutional Theory concept on the innovation that considers the regulation as an external pressure influencing organizational responses (Meyer & Rowan, 2021). Regulatory pressure may be more readily aligned with the technological, information-processing, and sustainability-oriented organizational capabilities, which can be linked to monitoring, reporting, and compliance activities. Contrast this with CC, where tacit processes, informal learning and organizational discretion might play a more important role. A possible reason may lie in formal compliance, because greater formal compliance requirements might limit the latitude for the cultural resource to support innovation. This explanation is presented here tentatively since neither discretion nor informal knowledge processes were measured directly, nor were there any firm conditions that were not observed that may explain the negative interaction. Current studies also indicate that the regulatory pressure may elicit diverse organizational reactions.

This differential interpretation is corroborated by the marginal-effects results, where ER's coefficients became more positive for the conditional association of DT, CSC, and DML, but became more negative for the association of CC and SI. Regulatory pressure can then interact with resources that are easy to integrate into formal sustainability requirements, but are perhaps less familiar when applied to the more culturally embedded resources. This extends the institutional perspective, and proposes that regulatory pressure does not necessarily work uniformly across organizational capabilities.

In general, the robustness models and broad dynamic specifications maintained the direction and general pattern of the baseline associations, and slightly the dynamic models showed some persistence on both sustainability outcomes. Such results provide increased confidence in the robustness of the observed associations when these are repeated across different specifications, but do not resolve any uncertainty about reverse causality, time-varying omitted variables, measurement limitations or causal identification. Similarly, GMM diagnostics offer only specification-related evidence, and do not fully address endogeneity or provide definitive causal effects.

The findings overall suggest that the sustainability relevance of organizational capabilities will be related with the type of capability, the sustainability outcome and the institutional context. DT, CSC, and DML showed relatively broad associations with EP and SI, whereas CC displayed a more outcome-specific association with SI. Indirect analyses offered statistical evidence of MCI and FSSI as tested pathways for DT, CSC, and DML, but not for CC, while failing to demonstrate causation. ER strengthened several capability–sustainability associations but weakened the CC–SI association. The results elaborated DCT's concept of capability differences, while providing support for

Institutional Theory by showing that the regulatory environment can interact with organizational capabilities in differentiated ways.

5.2. *Conclusion and Implications*

In this study, we investigated links between DT, CSC, CC, and DML, and the relation between these indicators and EP and SI in the context of tested indirect pathways of MCI and FSSI and the moderating condition of ER. DT, CC, and DML were positively significantly related to both the sustainability outcomes, while the CC was outcome-specific significantly related with SI. The indirect analyses provided statistical support for MCI and FSSI as tested pathways for DT, CSC, and DML but not CC, and ER strengthened some capability–sustainability associations, while the negative CC × ER association with SI provided only tentative evidence of a weakening CC–SI association under higher levels of environmental regulation. Based on the observational panel design, it is important to consider these findings as associations and indirect or conditional causal relationships, rather than causal relationships.

The study is theoretically significant by building on the concept of Dynamic Capabilities Theory (DCT) by applying a differentiated perspective of organisational capabilities and sustainability outcomes. The results suggest that the technological, organizational and information-related capabilities have more general links to sustainability, while cultural capital has more specific links to sustainability innovation. The study also supports Institutional Theory as it shows that environmental regulation can shape the association between capability and sustainability in different ways depending on organizational resources. From an empirical perspective, the study combines technological, organizational, cultural, informational, media, financial and regulatory dimensions under one umbrella at the same time providing evidence on the relationship between their associations and environmental performance and sustainability innovation. In context, the research contributes to the stream of evidence with respect to the Chinese-listed industrial companies under current digital transformation and changing environmental demands, but the results cannot be easily extended to unlisted companies, different industries, or other local context settings.

The findings indicate that from a management attention point of view, the firms can gain from the associations of investments in digital technologies and investments in environmental monitoring, resource efficiency and sustainability-focused innovations, as well as integrating sustainability into practices and fostering digital and sustainability-related capacities of employees. The association between CC and SI with the outcomes supports the idea that there are culture-specific and knowledge-based resources that need to be considered, not taken for granted, in innovation related activities, and not all at once. The indirect findings further suggest that the visibility of the media and financial means related to sustainability may be relevant to some capability–sustainability relationships, but should not be seen as causal mechanisms. Therefore, managers can consider sustainability communication, stakeholder engagement and resource utilization in addition to capability development. For policy makers, the differentiated-moderation results indicate that the impacts of environmental regulation on organizational capabilities might not be the same. Specifically, the negative CC × ER association with SI was significant only at the 10% level and should therefore be interpreted as tentative evidence of a possible weakening of the CC–SI association under higher environmental regulation. This trend, combined with the statistically insignificant CC × ER interaction on EP, requires continued study and could not be interpreted as compelling evidence for the necessity of environmental regulation to limit the power of cultural capital. The policies in the regulatory and digitalization sectors could therefore provide value by giving consideration to the internal capacity to incorporate differences, whilst providing adequate flexibility for knowledge and innovation related activities.

5.3. *Limitations and Fture Research Directions*

The results should be carefully interpreted in light of the following limitations: First, measurement limitations can impact the construct validity as several variables are based on secondary or proxy measures. CSC is proxied by renewable energy adoption (thus not fully capturing organizational values, norms, routines, or employee practices) and CC is represented by a selected cultural/knowledge-oriented dimension of employment (and may not fully capture the broader construct of critical digital media literacy); DML is measured by the behaviors of employees with respect to computer use, not the broader application of DML. These limitations may also affect the interpretation of the indirect and moderation analyses. To enhance construct validity, future research should utilize multidimensional indicators, employee and managerial assessments, surveys and richer organizational assessment data. Second, no causal inferences are made by using the observational panel design. While firm fixed effects, System GMM and alternative specifications do deal with some of the issues of unobserved heterogeneity and dynamic dependence, they do not completely remove these issues of reverse causality, omitted variables, or residual confounding. Internal GMM instruments also identify only under their assumed conditions, and should not be considered as ultimate evidence of causal validity. Future research can benefit from instrumental-variable studies, exogenous policy shocks and natural experiments, or difference-in-differences designs, as applicable.

Third, the indirect effects do not require causal specification (mediation) since the observational design does not provide adequate temporal ordering and exogenous variation in MCI and FSSI. Longitudinal designs with more precise temporal dimensions and more comprehensive data capturing communication of sustainability, financial support, and organizing related processes could be used to test these pathways more rigorously in future research. Last, the sample consists of 200 industrial listed companies from China that are observed between 2013 and 2023, thus restricting the generalizability to unlisted firms, other industries, and

other national contexts. Future studies might allow for the use of longer panels and cross-industry or cross-country samples, as well as test whether these relationships differ across levels of state and private ownership, regulatory conditions, technological conditions, and market structures. Further research on sustainability communication, stakeholder engagement, sustainability disclosure, organizational discretion, sharing of knowledge and greenwashing can help explain the variations in sustainability associations of various capabilities and the different interactions or moderating effects of environmental regulation.

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