Advance Journal of Econometrics and Finance

Vol-4, Issue-1, 2026

Advance Journal of Econometrics and Finance

Online ISSN

2959-8990

Print ISSN

2959-8982

https://ajeaf.com/index.php/Journal/About

Name of Publisher: SCHOLAR CRAFT EDUCATION & RESEARCH HUB

Review Type: Double Blind Peer Review

Journal Frequency: Quarterly Research Journal

Green Digital Capability and Sustainability Performance in Pakistan's Textile Sector: The Mediating Role of Circular Production Practices and the Moderating Role of Environmental Regulatory Pressure

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Abstract

Pakistan's textile sector faces mounting pressure from regulators, international buyers, and export markets to reduce resource intensity and demonstrate credible environmental performance. It remains unclear whether digital capability alone translates into measurable sustainability gains. Grounded in the natural-resource-based view, dynamic capabilities theory, and institutional theory, this study develops and tests a model in which green digital capability (GDC) improves sustainability performance (SP) through circular production practices (CPP), with environmental regulatory pressure (ERP) moderation of the conversion of digital capability into circular practices. A structured questionnaire was distributed to 340 managers holding production, operations, sustainability, environmental-health-and-safety, supply-chain, quality, and digital-transformation roles across textile firms in Faisalabad, Lahore, Karachi, Multan, and Sialkot, selected through a convenience sampling procedure; after data screening, 298 usable responses were retained (response rate = 87.6%). Data were analyzed in IBM SPSS using exploratory factor analysis, hierarchical regression, bootstrapped mediation, and moderated regression. Measurement checks supported the six-factor structure of the instrument (KMO = 0.937; Bartlett's $\chi^2(1378) = 8674.21$, $p < .001$; Cronbach's $\alpha = 0.878–0.920$), and Harman's single-factor test indicated no dominant common-method factor (30.2% of variance). Green digital capability significantly predicted circular production practices ($\beta = 0.505$, $p < .001$) and sustainability performance ($\beta = 0.614$, $p < .001$); circular production practices in turn predicted sustainability performance ($\beta = 0.722$, $p < .001$). Circular production practices partially mediated the relationship between green digital capability and sustainability performance (indirect effect = 0.227; 95% bootstrap CI [0.172, 0.288]), accounting for 45.4% of the total effect. Environmental regulatory pressure significantly strengthened the relationship between green digital capability and circular production practices ($B = 0.394$, $p < .001$; $\Delta R^2 = 0.066$), with the simple slope for green digital capability rising from 0.244 under low regulatory pressure to 0.728 under high regulatory pressure. All five hypotheses were supported. The findings show that digital capability generates sustainability value mainly by enabling circular production, and that this conversion is contingent on the strength of the regulatory and buyer-driven institutional environment. The study contributes an integrated account of how digitalization drives sustainability performance in an emerging-economy, resource-intensive manufacturing context and offers guidance to textile managers, regulators, and export policymakers seeking to strengthen circularity and environmental compliance.

Keywords: *green digital capability; circular production practices; environmental regulatory pressure; sustainability performance; textile industry; Pakistan; natural-resource-based view; institutional theory; convenience sampling.*

1 1. Introduction

The textile industry is the most water-intensive sector of the global economy, and Pakistan's textile industry is one of the largest formal employers in the country; it is firmly at the heart of the contestation between economic significance and pollution. The sector is estimated to contribute a considerable proportion of national processing industrial emissions and freshwater withdrawals, and a significant percentage of processing units still release poorly treated effluent, which has been a consistent area of study for domestic regulators, development researchers, and Civil Society (CS) (Farmanesh et al., 2025). Now domestic regulators and also international buyers focused on energy utilization, water consumption, chemical discharge, wastewater and solid textile waste, and increasing dependence of textile exports from Pakistan on Environmental, Social, and Governance (ESG) credentials is reported by industry bodies, with preferential accesses to trade, such as Generalized System of Preferences (GSP+) status, being attached to environmental performance (Akhtar & Urooj, 2024). Similarly, Exporters' associations have begun publicly demanding carbon-neutral production and greater climate action across the value chain to sustain market access (Pakistan Readymade Garments Manufacturers and Exporters Association [PRGMEA], 2025). To meet the demand, the textile industry has been investing in digital technologies for environmental monitoring, optimization of resources, intelligent scheduling in production, and visibility of the entire supply chain; and commentators refer to examples of algae-based fibers, water-free dyeing processes, and digitally coordinated recycling collaborations in the textile sector (Khalid, 2025). But to achieve better sustainability results from the introduction of digital tools, the technology must become ingrained in new operational practices.

There has been an increasing number of studies advancing the linkage between Digitalization, Green Innovation, and the application of the Circular Economy in manufacturing, particularly in the Textile and Apparel industries. Recent research has investigated the adoption intentions of Digital Transformation in the Pakistani Textile (Zahra et. al., 2025) using an extended Unified Theory of Acceptance and Use of Technology (UTAUT2), finding that constructs of effort expectancy, performance expectancy, facilitating conditions, etc., influence firms' behavioral intention of adopting digital technologies to change the way they operate. Extrapolating from the non-OE context of manufacturing, complementary evidence has identified that the capabilities of artificial intelligence and the process of green innovation are strategically related to their ability to drive sustainable business performance and competitiveness (Farmanesh et al., 2025). Outside of Pakistan, work in the literature of Industry 4.0 indicates that IoT sensing, big data analytics, and CPS can be organized in the form of “smart factory” architectures enabling environmental sensing and adaptive production control in real-time, thereby providing a foundation for technological development building green digital capability (Kagermann et al., 2013). Recent data from the Chinese manufacturing sector show that the green digital transformation capability positively contributes to sustainable innovation performance mainly by transforming the environmental strategy of a company, and in turn, green digital transformation capability greatly depends on the readiness of the circular economy and innovation capability of the company (Wu et al., 2026); other studies demonstrate that applying digital technology can positively influence the green product innovation performance mainly through the green dynamic capabilities which include opportunity sensing, knowledge search, etc. (Shuang et al., 2026); and others have found that technological capability and environmental strategy are complementary and jointly influence the performance of the company innovative for green innovation as an intermediate mechanism (Li et al., 2025). These studies, however, focus on either the determinants of digital capability, the overall capabilities of digital technologies, or Chinese textile companies operating under substantially different buyer and regulatory environments. They do not examine the organizational mechanism by which digital capability translates into sustainability performance, particularly in the context of Pakistan's textile industry.

Three gaps drive the current study. Firstly, there was a scarcity of empirical analyses examining how green digital capability leads to sustainability outcomes in the context of the textile sector in Pakistan specifically, and, more generally, digital adoption intention. Second, in this context, circular production practices such as reduce, reuse, recycle, material recovery, waste valorisation or closed-loop production have not often been analyzed as a direct link between digital capability and sustainability outcomes, even though these practices are the ones most relevant to material resource efficiency for textile producers and a significant number of reference papers have confirmed that such practices also lead to measurable improvements in environmental, costs and operational performance (Garza-Reyes et al., 2026; Pan et al., 2024).

This study proposes and tests an integrated model: the relationship between green digital capability (GDC) and sustainability performance (SP) is both direct and indirect via circular production practices (CPP), and ERP strengthens the relationship between GDC and CPP. Building on the natural-resource-based view theory, the dynamic capabilities theory, and institutional theory, the model not only highlights the internal capability pathway through which digitalization can lead to sustainability performance but also identifies the external institutional context in which this pathway is the strongest. Because the model is designed to be estimated using IBM SPSS (via exploratory factor analysis, hierarchical and interaction regression, and bootstrapped mediation), it is accessible to researchers and practitioners who lack access to covariance- or variance-based SEM software.

The rest of the article is as follows: The theoretical framework is presented in Section 2. Literature related to the topic is discussed in Section 3, and the study hypotheses are formulated. The research design, sample question measures, and the analytical process using SPSS are described in Section 4, which covers aspects of the questionnaire distribution and sampling procedure. Data from 298 textile-firm managers were used to test measurement validity and the hypothesis. Results of these tests are reported in Section 5. The findings are presented in Section 6; theoretical and managerial implications in Sections 7 and 8; limitations and suggestions for future research in Section 9; and the conclusion in Section 10.

1.1. Research Objectives

The study has five objectives, namely:

(1) To determine the effect of green digital capability on sustainability performance;

(2) To determine the mediating role of circular production practices between green digital capability and sustainability performance;

(3) to examine the moderating role of environmental regulatory pressure on the relationship between green digital capability and circular production practices.

2. Literature Review and Hypothesis Development

2.1. Digital Technology for Green Production and Capabilities

Manufacturing companies are now adopting digital technologies, such as sensors, data analytics platforms, and digital supply chain visibility, to reduce their environmental footprint and facilitate sustainability reporting. Evidence from the Pakistani textile industry clearly indicates that effort expectancy, performance expectancy, facilitating conditions, and firm-level lean thinking influence the intention to adopt such digital technologies (Zahra et al., 2025), thereby confirming that digitalization is an active organizational priority in this context. Meanwhile, artificial intelligence and green innovation competencies are positively correlated with sustainable business performance and competitive advantage, and, more generally, in emerging markets (Farmanesh et al., 2025), implying that the sustainability impacts of digital capabilities may be potential but are more likely to be achieved indirectly through mediating organizational practices. The same picture emerges at the industry level: while fine-tuned investments in circular practices, such as recycled-fiber partnerships and blockchain-enabled traceability programs, are reported, they are often undertaken alongside investments in digital capabilities, suggesting that, in the practitioners' own eyes, they are complementary rather than mutually exclusive.

The operational nature of the circular economy in manufacturing is circular production practices, including systematic waste reduction, reusing production waste, recycling and material recovery, using recycled inputs, waste-minimizing product and process design, and closed-loop cooperation with suppliers and customers (Pan et al., 2024). One conceptual consolidation of the circular-economy paradigm highlights the importance of redesigning the company's products, processes, and business models to minimize the use of virgin materials and energy supplies, in such a way that is greatly dependent on the measurement and traceability infrastructure provided by a digital tool (Geissdoerfer et al., 2017). Green Digital capability is theorized to be a direct precursor to circular production practices, as it provides the necessary monitoring, measurement, and decision-support infrastructure to identify waste streams, track material flows, and optimize resource use. This reasoning is consistent with green supply-chain management research evidence, which has long confirmed the need for a necessary preconditioning phase represented by internal environmental management capability (including monitoring and information systems that enable it) as a prerequisite to more sophisticated practices, like eco-design and closed-loop recovery (Sarkis et al., 2011; Zhu & Sarkis, 2004).

Hypothesis 1 (H1): Green digital capability has a significant positive effect on circular production practices.

Green digital capability can also provide direct sustainability benefits beyond its support for achieving circularity, such as real-time monitoring to save energy or water, or better decision-making not specifically for circularity. Evidence from manufacturers with ISO 14001 certification and from practices that support a sustainable supply chain (SSC) shows that a firm's digital capability not only directly affects sustainability performance but also indirectly manifests through SSC practices (Huang & Huang, 2026).

Hypothesis 2 (H2): Green digital capability has a significant positive impact on sustainability performance.

2.2. Circular Production Practices & Sustainability Performance

Circular production practices lead to benefits in material and energy efficiency, lower compliance risks, revenue generation from reprocessed materials, and changes in stakeholder perception, all of which align with the environmental, economic, and social pillars of sustainable performance. The third part of this study's hypothesis that circular economy practices rooted in waste and pollution prevention and elimination bring about substantial improvements in both environmental and cost-reduction outcomes as well as in social, financial, and operational performance outcomes is supported by the large-scale meta-analyses of research at the manufacturing firms' level (Pan et al., 2024). At the firm level, evidence from Italian manufacturers further finds that the adoption of the circular economy is correlated with improvements in firms' performance (Mazzucchelli et al., 2022). A multi-method study of Italian small and medium enterprises confirms that the circular economy, when operationalized through tangible waste management and material recovery activities, is linked to improved corporate performance (Mura et al., 2020). Findings among leather industry manufacturers in Bangladesh, a resource-intensive, export-oriented institutional environment which shares many traits with Pakistan's textile industry, indicate that sustainable manufacturing and CE practices are promoted by a cluster of regulatory, market, and technological enablers and that it is linked to better environmental and operational performance in the kind of institutional settings explored in this study (Moktadir et al., 2018). More recent evidence reinforces this argument and demonstrates that the use of practices related to the circular economy, such as digital technologies (e.g., blockchain) that facilitate a greater degree of traceability, is correlated with firms' financial performance (Sun et al., 2025), reinforcing the complementary nature of both digital and circular investments that this research's mediation model aims to test.

Hypothesis 3 (H3): Circular production practices positively affect sustainability performance.

Linking green digital capability to improvements in environmental, economic, and social conditions is unlikely to occur on its own without a shift in operating practices; it is theorized that the pathway here, circular production practices, is the means by which digital capability transforms into better conditions. The mediating effect of this logic is similar to some results in the literature on digital technology and green innovation, which found only an indirect relationship between digital technology application and green innovation outcomes, mediated by the construction of green dynamic capabilities as intervening constructs (Shuang et al., 2026).

Hypothesis 4 (H4): Green digital capability positively affects sustainability performance, mediated by circular production practices.

2.3. Moderating effect of Environmental Regulatory Pressure

According to institutional theory, the extent to which green digital capability can translate into actual circular production practice is expected to depend on the degree of regulatory and buyer-driven institutional context. Here, certification-based evidence from the textile industry is instructive, since studies on the effects of adopting ISO 14001 (environmental management) in the European textile and apparel value chains have revealed a strong relationship between formal environmental management certification and better sustainable value-chain outcomes, but concluded that such a relationship is contingent on network and institutional contexts across the industries and not uniform for all firms (Curkovic & Sroufe, 2011; Graafland, 2018; Zimon, 2019); research finds that green supply chain management between green supply chain practices and environmental outcomes is an intermediate layer of green innovation, and that institutional-normative context conditions link (Abu Seman et al., 2019). Looking specifically at the Pakistani textile sector, previous empirical syntheses reveal that textile companies' environmental-management activities are positively related to the level of regulatory pressure; effective voluntary-environmental activities and foreign-buyer pressure are also positively correlated when the average level of regulatory and market pressure is high (Akhtar & Urooj, 2024; Menguc et al., 2010; Sattar & Urooj, 2022). In a low-environmental regulatory pressure scenario, firms might maintain digital capabilities solely for productivity reasons. Still, in a high-environmental-regulatory-pressure scenario, they are more likely to repurpose it for circular production.

Hypothesis 5 (H5): Environmental regulatory pressure positively moderates the relationship between green digital capability and circular production practices.

Sustainability performance is considered a three-dimensional phenomenon that incorporates environmental, economic, and social performance in line with the triple-bottom-line tradition. Therefore, the impact of circular production on sustainability performance has broken down further:

H3a: Circular production practices have a positive impact on environmental performance.

H3b: Circular production practices have a positive effect on financial performance.

H3c: Circular production practices have a positive impact on social performance.

2.4 Theoretical Framework

The natural-resource-based view (NRBV) is a variant of the resource-based view of the firm that posits that pollution-prevention, pollution-product stewardship, and sustainable-development-related capabilities can become sources of competitive advantage (Hart & Dowell, 2011; Hart, 1995). The NRBV appears to build on the previous logic based on resources that are valuable, rare, and difficult to imitate (Barney, 1991), and is similar to the dynamic-capabilities logic that focuses on the abilities of the firm to sense, reconfigure, and adapt to the changing environment (Teece et al., 1997; Porter & van der Linde, 1995). Following the NRBV rationale, this study conceptualizes the implementation of circular production capabilities as a routinized practice that transforms the potential of green digital capability into actual sustainability performance. Institutional theory has been proposed to explain why organizations respond to pressures arising from structural conditions characteristic of their institutional environment (DiMaggio & Powell, 1983). Institutional-environmental scholarship reveals that firms' environmental management practices have systematic responses to coercive pressure from legislation and enforcement, to normative pressure from professional and industry norms, and to mimetic pressure from imitation of successful peers (Delmas & Toffel, 2004); additional tests show that market-facing pressure (including demand from foreign buyers) interacts with regulatory pressure to determine the level of a firm's proactive environmental management, and that such proactivity in turn drives the firm's financial performance (Menguc et al., 2010; Freeman, 1984). The overall description of the proposed model is considered consistent when viewed through all three lenses. Both NRBV and dynamic capabilities theory suggest that the internal capability pathway would be a green digital capability that enhances circular production practices, thereby improving sustainability performance. From a stakeholder-consideration perspective, institutional theory suggests that the pathway is likely stronger when environmental regulatory pressure is high, as firms are more likely to focus on digital innovation to support circular production practices. This structure is summarised in Figure 1: it shows that green digital capability has a direct link to sustainability performance; between green digital capability and sustainability performance, mediated by circular production practices; on the other hand, there are some moderation relationships between green digital capability and circular production practices, determined by environmental regulatory pressure.

3. Materials and Methods

The study design was a quantitative (explanatory) cross-sectional survey, suitable for testing directional and moderate mediation hypotheses in a single wave of data collection. Items were measured across all constructs on five-point Likert scales (1 = strongly disagree, 5 = strongly agree) that were validated by the literature. Managers and senior employees of spinning, weaving, dyeing and finishing, garment manufacturing, composite textile and textile exporting companies were targeted in the main textile cluster areas (Faisalabad, Lahore, Karachi, Multan and Sialkot) of Pakistan. Management of production, operations, sustainability, environmental health and safety, supply chain, quality control, or digital transformation are allowed to participate. The questionnaires were collected via a convenience (non-probability) sampling process. (Garza-Reyes et al., 2026; Sekaran & Bougie, 2016).

During the study period, within the data collection window, 340 questionnaires were distributed across the 5 textile clusters. A total of 306 were returned, with the data subsequently screened for consent, sector eligibility, respondents' knowledge of the firms' environmental and digital practices, minimal tenure within the organization, and completeness of response to the Likert items, yielding a final 298 responses (90.0%) for analysis, which represents a usable response rate of 87.6% relative to those distributed. At the screening stage, 8 questionnaires were excluded due to substantial missing data, straightlining across the full scale, or failing to meet the minimum tenure criterion. The 298 usable responses obtained surpass the minimum sample-size advice in multiple-regression and moderated-mediation designs with the number of predictors employed by this study (Cohen, 1988; Hair et al.,2019) and are quite comparable with sample sizes from similar manufacturing and circular-economy surveys published in the literature, ranging from approximately 197 to 486 respondents (Garza-Reyes et al., 2026; Ghaithan et al., 2023).

Table 1. Respondent and Organizational Profile (N = 298).

Variable	Category	n	%
Gender	Male	214	71.8
	Female	78	26.2

	Other / prefer not to disclose	6	2.0
Age	Under 25	24	8.1
	25–34 years	100	33.6
	35–44 years	98	32.9
	45–54 years	52	17.5
	55 years or above	24	8.1
Education	Bachelor's degree	86	28.9
	Master's degree	96	32.2
	MS / MPhil	47	15.8
	PhD / professional / other	55	18.5
	Intermediate or below	14	4.7
Position	Senior executive / director	21	7.0
	General manager	27	9.1
	Departmental / functional manager	63	21.1
	Assistant / deputy manager	68	22.8
	Supervisor / team leader	63	21.1
	Professional / technical employee	51	17.1
Department	Production / operations	96	32.2
	Quality assurance	50	16.8
	Environmental sustainability	37	12.4
	Supply chain / procurement	30	10.1
	Marketing / export	24	8.1
	Information technology	22	7.4
	Other (HR, finance, etc.)	39	13.1
Firm size (employees)	Fewer than 50	20	6.7
	50–249	79	26.5
	250–499	74	24.8
	500–999	78	26.2
	1,000 or more	47	15.8

Firm age	10 years or less	49	16.4
	11–20 years	80	26.8
	21–30 years	70	23.5
	More than 30 years	99	33.2
Subsector	Garment manufacturing	60	20.1
	Dyeing and finishing	48	16.1
	Spinning	38	12.8
	Knitting	37	12.4
	Composite textile manufacturing	36	12.1
	Weaving / home textiles / other	79	26.5
ISO 14001 certified	Yes	186	62.4
	In progress	28	9.4
	No / do not know	84	28.2
International buyer environmental requirement	Yes	225	75.5
	No / do not know	73	24.5
City	Faisalabad	97	32.6
	Karachi	70	23.5
	Lahore	53	17.8
	Sialkot	32	10.7
	Multan	25	8.4
	Other city	21	7.0

Note. Percentages are rounded to one decimal place and may not sum to exactly 100% within each category due to rounding.

Digital environmental monitoring and data-driven resource optimization, as well as smart production and digital supply chain visibility, were included in the green digital capability (GDC, 10 items). Circular production practices (CPP, 12 items) captured reduce, reuse, and recycle behaviors, material recovery and waste valorization practices, and closed-loop production behaviors, in line with the most prominent ways of operationalizing circular economy behaviors in the literature of the manufacturing sector (Geissdoerfer et al., 2017; Pan et al., 2024). The institutional-environmental management literature distinguishes between coercive and market pressures, which were tapped by environmental regulatory pressure (ERP, 8 items): environmental legislation, environmental compliance inspections, buyer requirements, and regulatory enforcement. Sustainability performance was assessed as a second-order composite score based on the triple bottom line concept, comprising environmental performance (ENP: 8 items), economic performance (ECP: 7 items), and social performance (SOP: 8 items). All items were responses to the 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The control variables included firm size, firm age, export intensity, ISO 14001 certification status, and textile subsector; all analyses were performed in IBM SPSS Statistics. Data screening (missing values, out-of-range Likert responses) was followed by exploratory factor analysis (principal-axis/principal-component extraction with varimax rotation) to verify the six-factor measurement structure. It was followed by an internal consistency reliability analysis using Cronbach's alpha (Nunnally, 1978). Pearson correlation analysis was used between all study variables. Simple linear regression was used to test hypotheses H1–H3, while hypotheses H3a–H3c were tested using the same procedure for each sustainability dimension. Mediation (H4) was examined using Baron and Kenny logic (Baron & Kenny, 1986) and bootstrapped indirect-effect estimation (5,000 resamples) following the SPSS-based indirect-effects procedure originally developed by Preacher and Hayes and subsequently extended in Hayes' PROCESS macro (Model 4) (Hayes, 2018). Moderation (H5) was tested using mean-centered predictors entered into a hierarchical regression (Hayes' PROCESS Model 1), with the interaction term (GDC × ERP) entered after the main effects, and simple slopes analysis conducted at ±1 SD of the moderator. Statistical significance was set at $p < .05$ throughout.

4. Results

4.1. Measurement Validation

Factorability was assessed before interpreting the factor structure; the Kaiser–Meyer–Olkin measure of sampling adequacy was close to the recommended level (0.937, minimum acceptable KMO = 0.862) and the correlations among the items also had a significant Bartlett's test of sphericity, $\chi^2(1378) = 8674.21$, $p < .001$, which together indicated that the correlation matrix was suitable for factor analysis (Kaiser, 1974). The six-factor solution derived by principal-component analysis with varimax rotation accounted for 57.5% of total variance; all of the items loaded most highly (⩾0.57) on their intended factor, and no problematic items were found by principal-component analysis (PCA) to have high loadings on two or more factors. Internal consistency reliabilities were good to excellent for all constructs (Table 2) and exceeded the conventional requirement of 0.70 (Nunnally, 1978).

Table 2. Reliability and Factor-Analytic Summary.

Construct	Items	Cronbach's α	Min. item-total r	Max. item-total r
Green Digital Capability (GDC)	10	0.914	0.661	0.730
Circular Production Practices (CPP)	12	0.920	0.631	0.707
Environmental Regulatory Pressure (ERP)	8	0.914	0.694	0.737
Environmental Performance (ENP)	8	0.889	0.616	0.700
Economic Performance (ECP)	7	0.878	0.618	0.710
Social Performance (SOP)	8	0.885	0.610	0.720

Note. KMO = 0.937; Bartlett's $\chi^2(1378) = 8674.21$, $p < .001$; six-factor solution explained 57.5% of cumulative variance; Harman's single-factor test = 30.2% (below the 50% common-method threshold).

1.1.1 4.2. Descriptive Statistics and Correlations

Construct-level indicates that values are grouped around the midpoint of the scale (M range = 3.21-0.29), with an acceptable amount of dispersion (SD range = 0.45-0.61), and skewness and kurtosis values that fall within ±1, thereby supporting the use of parametric regression-based tests. Table 3 shows that all bivariate correlations of the substantive variables in the study were positive. Statistically, significant ($p < .01$ or $p < .05$), with sustainability performance demonstrating the highest levels of correlation with the extent to which environmental performance ($r = 0.831$) and economic performance ($r = 0.809$) have been incorporated into an organization's practices; and green digital capability was most strongly correlated to extent of incorporation of sustainability performance ($r = 0.614$) and circular production practices ($r = 0.505$). None of the inter-construct correlations were close to the usually accepted criterion of potential concern for discriminant validity (Fornell & Larcker, 1981), with which we endorse the distinctiveness of the six measured constructs.

Table 3. Construct Descriptive Statistics and Pearson Correlations (N = 298).

Variable	M	SD	GDC	CPP	ERP	ENP	ECP	SOP	SP

GDC	3.25	0.55	1	0.505**	0.146*	0.503**	0.487**	0.475**	0.614**
CPP	3.26	0.52		1	0.248**	0.667**	0.564**	0.491**	0.722**
ERP	3.24	0.61			1	0.260**	0.284**	0.219**	0.321**
ENP	3.22	0.56				1	0.555**	0.427**	0.831**
ECP	3.29	0.58					1	0.359**	0.809**
SOP	3.21	0.55						1	0.743**
SP	3.24	0.45							1

*Note. ** p < .01, * p < .05 (two-tailed). GDC = Green Digital Capability; CPP = Circular Production Practices; ERP = Environmental Regulatory Pressure; ENP = Environmental Performance; ECP = Economic Performance; SOP = Social Performance; SP = overall Sustainability Performance (composite of ENP, ECP, SOP).*

1.1.2 4.3. Direct-Effect Hypothesis Tests (H1–H3)

All three direct-effect hypotheses were supported by simple linear regression. Green digital capability had a significant direct influence on the adoption of circular production practices (H1: β = 0.505, t = 10.06, p < .001, R2 = .255), accounting for about 25.5% of the variance in adoption. Green digital capability also showed a considerable direct positive relationship with overall sustainability performance, with H2: β = 0.614, t = 13.40, p < .001, R^2 = .377. Circular production practices showed the greatest significant prediction of sustainability performance (H3: β = 0.722, t = 17.97, p < .001, R^2 = .522). Results of the supplementary analyses, having broken down sustainability performance into each of its three dimensions (H3a, H3b, and H3c), indicated that circular production practices significantly predicted environmental performance (β = 0.667, p < .001, R^2 = .445), economic performance (β = 0.564, p < .001, R^2 = .318), and social performance (β = 0.491, p < .001, R^2 = .241); green digital capability followed the same pattern as in each of the three dimensions (Table 4). All reported effect sizes are larger than the medium-to-large effect sizes commonly used as references in behavioral research (Cohen, 1988).

Table 4. Regression Results for H1–H3 and H3a–H3c.

Path	B	SE	β	t	p	R^2	Decision
H1: GDC → CPP	0.482	0.048	0.505	10.06	< .001	0.255	Supported
H2: GDC → SP	0.499	0.037	0.614	13.40	< .001	0.377	Supported
H3: CPP → SP	0.615	0.034	0.722	17.97	< .001	0.522	Supported
H3a: CPP → ENP	0.709	0.046	0.667	15.40	< .001	0.445	Supported
H3b: CPP → ECP	0.620	0.053	0.564	11.74	< .001	0.318	Supported
H3c: CPP → SOP	0.515	0.053	0.491	9.70	< .001	0.241	Supported

1.1.3 4.4. Mediation Analysis (H4)

Bootstrapped results indicated there were three significant path models: green digital capability significantly predicted circular production practices (path a: B = 0.482, p < .001); circular production practices significantly predicted sustainability performance controlling for green digital capability (path b: B = 0.471, p < .001); and the direct relationship of green digital capability to sustainability performance remained significant, albeit reduced after the inclusion of circular production practices (path c′: B = 0.272, p < .001; total effect: B = 0.499). Results of the bootstrapped indirect effect indicated a value of .227 (95% CI [.172, .288]) that does not contain zero, thereby confirming the indirect effect as statistically significant. The direct path from green digital capability to sustainability performance was significant even after the mediator, which indicates that the relationship between green digital capability and sustainability performance is partially mediated, meaning that it is mediated by circular production practices as a mechanism of action but not completely (about 45,4% of the direct path effect is mediated through circular production practices) (Table 5). H4 is supported.

Table 5. Mediation Analysis Results (H4): GDC → CPP → SP.

Path	B	SE	t	p
a: GDC → CPP	0.482	0.048	10.06	< .001
b: CPP → SP (controlling for GDC)	0.471	0.036	13.06	< .001
c: Total effect, GDC → SP	0.499	0.037	13.40	< .001
c′ : Direct effect, GDC → SP (controlling for CPP)	0.272	0.034	7.91	< .001

Indirect effect (GDC → CPP → SP) = 0.227, 95% bootstrap CI [0.172, 0.288]; proportion of total effect = 45.4%—conclusion: partial mediation — H4 supported.

1.1.4 4.5. Moderation Analysis (H5)

Means-centered predictors were used to test the relationship between green digital capability and circular production practices, with environmental regulatory pressure as the moderator. The interaction term (GDC × ERP) was a positive, significant predictor of circular production practices (B = 0.394, SE = 0.072, β = 0.259, t = 5.45, $p < .001$), in addition to the positive, significant effect of green digital capability (B = 0.486, $p < .001$) and environmental regulatory pressure (B = 0.172, $p < .001$). The model with the interaction term had a better fit than the model with just main effects ($\Delta R^2 = .066$, F change = 29.71, $p < .001$). The main-effects-only model accounted for 28.6% of the variance in circular production practices, whereas the model with interactions accounted for 35.1%. Simple-slopes analysis revealed that the effect of green digital capability on circular production practices monotonically increased with the level of regulatory pressure: At low regulatory pressure (−1 SD), the slope was 0.244 ($p < .001$); at mean regulatory pressure, it was 0.486 ($p < .001$); and at high regulatory pressure (+1 SD), it was 0.728 ($p < .001$) roughly tripling the effect with increases in regulatory pressure. This pattern supports the hypothesis: the stronger the environmental demands for regulation, the stronger the effect on increasing the relationship between 'green Digital' and 'circular production practice'. H5 is supported.

Table 6. Moderated Regression Results (H5): GDC × ERP → CPP.

Term	B	SE	β	t	p
GDC (centered)	0.486	0.046	0.509	10.65	< .001
ERP (centered)	0.172	0.041	0.201	4.23	< .001
GDC × ERP	0.394	0.072	0.259	5.45	< .001

Model $R^2 = .351$, Adj. $R^2 = .345$, $F(3,294) = 53.06$, $p < .001$; ΔR^2 for interaction term = .066, F change = 29.71, $p < .001$, relative to the main-effects-only model ($R^2 = .286$).

Table 7. Simple Slopes of GDC → CPP at Values of the Moderator (ERP).

ERP Level	ERP Value	Simple Slope (B)	SE	t	p
Low (−1 SD)	2.63	0.244	0.060	4.09	< .001
Mean	3.24	0.486	0.046	10.65	< .001
High (+1 SD)	3.85	0.728	0.067	10.82	< .001

1.1.5 4.6. Summary of Hypothesis Testing

Table 8. Summary of Hypothesis Test Outcomes.

Hypothesis	Relationship	Key Statistic	p-value	Decision
H1	GDC → CPP	β = 0.505	< .001	Supported
H2	GDC → SP	β = 0.614	< .001	Supported
H3	CPP → SP	β = 0.722	< .001	Supported
H3a	CPP → Environmental Performance	β = 0.667	< .001	Supported
H3b	CPP → Economic Performance	β = 0.564	< .001	Supported
H3c	CPP → Social Performance	β = 0.491	< .001	Supported
H4	CPP mediates GDC → SP	Indirect effect = 0.227, CI [0.172, 0.288]	—	Supported (partial mediation)
H5	ERP moderates GDC → CPP	B(interaction) = 0.394	< .001	Supported

2 5. Discussion

The results provide clear empirical evidence supporting a more holistic explanation of digitalization as a driver of sustainability performance in Pakistan's textile industry, combining NRBV and dynamic capacity theory with institutional theory. As hypothesized in H1 and H2, green digital capability had a significant and positive relationship with both circular production practices and sustainability performance, suggesting companies that invest in infrastructure to monitor the environment, optimize resources based on environmental data, and have supply chain visibility are more likely to adopt circular production practices and to achieve better environmental, economic, and social results. This aligns with previous evidence showing that the adoption of Digital Transformation is a priority on the agenda among textile stakeholders in Pakistan (Zahra et al., 2025) and that AI-related capabilities are positively associated with sustainable performance in other manufacturing contexts in emerging markets (Farmanesh et al., 2025). It is also largely in line with recent Chinese manufacturing evidence that green digital transformation capability affects sustainable innovation performance mostly through environmental strategy and readiness for the circular economy instead of an automatic blanket effect from the introduction of digital technology (Wu et al., 2026) and Chinese evidence that green digital technology's contribution to green innovation largely takes place through green dynamic capabilities as examined in the present study, but in a rather different sector and institutional context.

The key result of the study from a theoretical perspective is that the relationship between green-digital capability and sustainability performance is partially mediated (H4), accounting for 45.4% of the total effect. This means that green digital capability can have benefits to sustainability through circular routines and a residual, non-circular path – such as direct savings in energy or water through real-time monitoring that are not inherently circular, nor do they involve reuse, recycling, or closed-loop cooperation. This partial-mediation phenomenon is largely similar to related capability–practice–performance studies in Taiwan's manufacturing industry, which yielded a similar pattern, finding that digital capability directly impacts sustainability performance while also influencing it indirectly via an intervening mechanism of sustainable-supply-chain practices, and not via a single, fully mediated path (Huang & Huang, 2026). Although circularity plays an important role in knowing when digital investment provides an environmental benefit, the significant direct effect that persists when the indirect effect of circular production is accounted for warns of assuming that digitalisation always and automatically leads to an environmental benefit, whenever a circular-economy programme is included, that a circular-economy program always and automatically leads to an environmental benefit whenever a digitalization program is included. This discovery also aligns with the meta-analytical findings that practices toward the circular economy, based on waste and pollution avoidance, consistently yield better outcomes than on several dimensions (Pan et al., 2024), including potential other positive sustainability effects of digitalization alone.

The moderation result (H5) confirms the prediction of institutional theory, which holds that when a firm is under environmental regulatory pressure, the internal capability approach is strengthened rather than supplanted. Across low and high regulatory pressures, results show a near triple increase in the slope of the GDC-CPP relationship, suggesting that firms use digital capabilities to implement circular practices more efficiently under stronger regulatory pressures. This aligns with institutional views which see that institutional and normative pressures push embedded organisational capability – in the form of management systems – in direction of externally valued ends (Delmas & Toffel, 2004; DiMaggio & Powell, 1983), and with certification findings that the sustainability benefits of a formal environmental management system like ISO 14001 are dependent on the institutional or network environments of the management system (Curkovic & Sroufe, 2011; Graafland, 2018; Zimon, 2019). It is also in line with the Pakistan specific evidence that environmental-management efforts of the textile companies can be driven systematically by regulations and cloth requirement pressures of foreign buyers (Akhtar & Urooj, 2024; Menguc et al., 2010; Sattar & Urooj, 2022), as well as with the overall argument of the "Porter hypothesis" that moderate pressure can lead to innovation instead of just increasing the cost of complying (Porter & van der Linde, 1995). In practice, it means that companies that do not face stringent regulatory or buyer pressure may not use their DW to the fullest, despite the technical possibility of doing so, for the circular purpose.

Results of (H3a–c) demonstrate that circular production practices have the greatest impact on environmental performance (β = 0.667 followed by economic performance (β = 0.564) and social performance (β = 0.491). This means that the most immediate reductions in material, energy, and waste flows on the path to circularity also benefit the economy and society. This aligns with the cross-industry meta-analysis of circular-economy practices, which revealed more consistent impacts of waste- and pollution-elimination practices on environmental outcomes, and more variable impacts on cost, social and financial performance, depending on the combination of practices (Pan et al., 2024). The relative strength of the social-performance pathway reveals that circular production practices can't completely replace specific occupational health, safety, and community initiatives.

6. Theoretical Implications

This research extends the natural-resource-based view and dynamic capabilities theory by empirically showing that green digital capability functions as an organizational strategic resource, whose sustainability value is significant, though not exclusively, manifested in circular production routines, thereby offering a testable mechanism for a capability-outcomes claim. Second, it bridges institutional theory and digital sustainability by demonstrating that regulatory and buyer pressure are not independent influencing factors but rather an amplifying boundary condition within an internal capability pathway. It also contributes to a growing literature around the linkages between digitalisation and circular-economy practice, revealing how these forces were complementary forces rather than substitutes for sustainability performance that while digital capability is an input to the practices of circular economy, it also provides an independent sustainability benefit which would also resonate in other study areas, such as in Chinese and Taiwanese manufacturing, albeit with differential changes in the types and degree of effect on sustainability performance; and thereby extends the literature to a South Asian, export-oriented, resource-intensive manufacturing context, where institutional forces at play (compliance regimes, buyer audits, GSP+ trade preferences) differ materially from those studied previously.

7. Managerial and Policy Implications.

For textile managers, digital investment should explicitly be coupled with investment for the circular production of textiles; for instance, waste stream monitoring dashboards that relate to re-use recovery flows, rather than seen as a stand-alone efficiency project; because most of the digitalization sustainability payback is delivered through the circular route. However, circular activities play the greatest role in environmental performance. If the primary management goal is to meet regulatory or buyer requirements, focus on digitally enabled waste-stream and material-recovery activities rather than on overall digitalization investments. The moderation result suggests that as part of regulatory policy and export-policy making, a focus on increasing and rigorously enforcing environmental compliance regimes, as well as continued environmental sourcing requirements on the buyer side, may help maximize returns to digital investments of firms without additional technology subsidy. For companies that currently lack strong regulatory or buyer pressure, the findings indicate the potential for under-realised returns on investments into the circular economy; the use of voluntary certification (e.g., ISO 14001) or active buyer engagement could be a way to have an internal answer to regulatory pressures in the sense that discipline in the form of strong regulation could potentially substitute for a measure that is otherwise missing in the supply chain. The study shows that ISO 14001 certification and other environmental management systems can partly overcome the lack of formal regulation in supply chains, where regulatory enforcement is uneven. Overall, the export competitiveness of Pakistan's textile sector is quickly gaining traction with the recognition of its ESG credentials and preferential trade status; the digital–circular combination identified here is best viewed internally not as an environmental cost center but as an investment to deliver value in the right export market.

8: Limitations and Future Research

There are several caveats to these findings. the cross-sectional design, strong causal inferences could not be drawn; longitudinal or panel data would permit more rigorous testing to determine whether the GDC–CPP–SP pathway is unidirectional and stable. Although analyzing all data in SPSS is a conscious decision for accessibility and replicability, the full set of model fit diagnostics (e.g., CFI, RMSEA, SRMR) is available only for covariance- or variance-based structural equation modeling. Future research would pay attention to further moderators, such as firm size, export intensity, ownership structure, and the generalisability of the moderated-mediation pattern found in this study to other manufacturing sectors that are export-oriented and have circular characteristics, such as the leather and leather-goods sector, where a similar circularity and regulatory dynamics have been reported in South Asia.

9. Conclusion

This research explored the mediating and moderating effects of green digital capability and sustainability performance in Pakistan's textile industry, using a convenience sampling technique to distribute questionnaires within textile clusters, with 298 returned from managers of textile firms. It yielded a moderated mediation model based on the natural-resource-based view (NRBV), dynamic capabilities theory, and institutional theory. All five hypotheses were supported. These findings highlighted that the institutional environment for textiles, including regulations, customer preferences and requirements, as well as the digital capabilities used by the industry in its circular production routines, plays a crucial role in enhancing environmental compliance, boosting competitiveness, and improving the circularity of the textile industry in Pakistan.

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