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EXPLORING THE SUSTAINABILITY BENEFITS OF DIGITAL TRANSFORMATION: THE MEDIATING ROLE OF GREEN INNOVATION IN MANUFACTURING ORGANIZATIONS IN PAKISTAN

Avais Tauqir*[1], Muhammad Usman[2], Hannan Afzal[3]

*[1] *Ph.D. Scholar, Department of Business Administration, University of Sialkot, Sialkot, Pakistan*
[2,3] *Assistant Professor, Department of Business Administration, University of Sialkot, Sialkot, Pakistan*

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Avais Tauqir

Abstract
Digital transformation has become a critical priority for companies looking to become more sustainable in their business operations and overcome technical change and environmental challenges. This study investigates the relationships between digital transformation capabilities, green innovation (GIN), and sustainable business performance (SSP) of manufacturing organizations in Pakistan with the mediation of GIN. Specifically, it explores the relationship between digital exploitation capabilities (DXL), digital exploration capabilities (DXP), digitalization strategy adoption (DAS), and digital leadership capabilities (DLP) and GIN. Based on the dynamic capabilities theory, the study views GIN as a process for transforming digital resources and capabilities into sustainable outcomes for the organization. Using convenience sampling, 724 managers of manufacturing organizations were selected as a sample group for collecting the survey data. The proposed relationship was analyzed using the model of partial least squares (PLS-SEM). The findings on the hypotheses show positive relations between the constructs proposed and a mediating role of GIN. The study adds to the digital transformation and SSP literature by connecting different aspects of the digital capabilities to sustainable innovation in green technology in the context of manufacturing in an emergent economy. The findings have implications for managers who wish to link digital investments, leadership and innovation of their environment with the long-term sustainability of their organization.

1. INTRODUCTION

Digital transformation is a crucial strategic imperative for companies to stay competitive, continuously innovate and ensure SSP. Artificial intelligence, big data analytics, cloud computing, industrial automation, and digital platforms have revolutionized the way organizations run their activities, allocate their resources, create their products, and respond to stakeholders. However, the use of digital technology is not enough to ensure better organizational results; the value of digital investments relies on the capacities with which the technologies are being adopted and embedded in organizational strategies, processes and routines (Vial, 2019; Warner & Wäger, 2019). The research findings of recent years have increasingly linked digital transformation to sustainability (Xu et al. 2023, Chen & Wang, 2024), showing that when digitalization is supported by complementary organizational capabilities, it can enable innovation, resource efficiency and environmental performance. The developments have brought digital transformation capabilities to the forefront of the research agenda

for companies that aim to balance competitiveness and environmental and social responsibilities.

The manufacturing industry is also a relevant one because the manufacturing activities require high amounts of materials, energy, waste, and coordination with the supply chain. It is vital, therefore, that manufacturing organizations improve their productivity and manage various aspects such as environmental issues, regulatory requirements, resource limitations and evolving stakeholder expectations. These challenges are particularly relevant in Pakistan where manufacturers seek modernization and are at disparate technological readiness, investment and environmental management levels. Previous studies have explored the digital strategy and environmental performance of SMEs in Pakistan, GIN and SSP in manufacturing companies, and sustainability in SMEs (Haq & Huo, 2023; Ghazi et al., 2023). Another recent study on digital technologies for Pakistani manufacturing SMEs has explored the potential of digital technologies and their associated issues of organizational culture and innovation capacity (2024, Journal of Small Business and Enterprise Development). While the relevance of digitalization and sustainability has been clearly proven in these studies, it does not render unnecessary the investigation of how different digital transformation capabilities can be combined to create sustainable business outcomes.

This study is based on the difference between having digital resources and building the organizational skills needed to use them strategically. While digital investments can help improve processes and environmental monitoring, they can be underutilized if the technology is not in line with strategic priorities, leadership support is insufficient, or employees do not have the capacity to use digital information. Additionally, digital transformation may entail trade-offs, such as between exploitation (enhancing current technologies and processes) and exploration (experimentation, learning, and creating new technology options). Recent research has indicated that digital skills have a positive impact on GIN, though this may vary based on resources, managerial knowledge, and organizational circumstances (Cheng et al., 2024; Wang et al., 2024). Thus, a more nuanced analysis of digital exploitation, digital exploration, DAS and digital leadership is required to better explain the ways in which these capabilities can support organizational outcomes related to sustainability.

DXL are the ability of an organization to utilize digital technologies and existing knowledge to be able to optimize and enhance existing processes and to improve resource usage and reliability of operations. DXP relate to the ability to try out new technologies, sense opportunities and create new products, services or processes. Adopting digitalization strategy implies that digital priorities are embedded in the objectives, investments and operating plans of the organization. Digital leadership competencies are the skills that managers need to communicate a digital vision, engage resources, manage technology change, and foster an environment where digital innovation is encouraged. The dimensions are complementary but distinct capabilities. They are relevant to the literature on digital ambidexterity and SSP, which indicates that there is potential for digital exploitation, exploration, strategic digitalization and leadership to impact business outcomes (Chen et al., 2024). The current research expands this view to look at GIN as a potential mechanism that links each capability to SSP.

The research gap that is addressed here is the explanatory model of SSP in manufacturing sector which incorporates the four capabilities with the GIN in Pakistan. Previous research provides insights on Chinese manufacturing firms' digital transformation and eco-innovation (Xu et al., 2023); digital capability and GIN (Cheng et al., 2024); digitalization, GIN and sustainable corporate performance (Le et al., 2024). Other studies have examined the links between digital leadership and business model innovation and SSP (Chen et al., 2024). It is, therefore, inappropriate to suggest that there is no previous research on individual relationships in the international literature. On the contrary, the gap in the proposed research which can be considered defensible is to examine the proposed relationship between the dimensions of capability, the mediating role of GIN and the SSP in the specific

institutional and industrial environment of manufacturing organizations in Pakistan.

The justification of the suggested model is: Digital transformation capabilities can be a driver of sustainability in two ways: directly and indirectly. In addition to their ability to improve resource efficiency and reduce operational waste, exploiting capabilities might also stimulate the creation of environmentally improved products and production technologies, and explorative capabilities might foster the development of environmental technologies. DAS can integrate environmental goals with technology investments, and digital leadership can offer guidance and structure to undertake sustainability-related actions. GIN may bring these capabilities to organizational outcomes, by translating digital information, experimentation and operational knowledge to greener products, processes, and managerial practices. Research in manufacturing has shown that digitalization is an opportunity to foster eco-innovation and sustainable performance (Xu et al., 2023; Cheng et al., 2024; Rahmani et al., 2024), whereas GIN has been linked to organizational and environmental outcomes (Xu et al., 2023; Cheng et al., 2024; Rahmani et al., 2024). The rationale for testing both direct and indirect effects via GIN.

The study is limited to manufacturing organizations in Pakistan and questionnaires were collected from 724 managers (convenience sampling). The study concentrates on four digital transformation capabilities, perceptions of GIN and SSP at organizational level. It employed a partial least squares structural equation modeling (PLS-SEM) as an empirical modeling technique that was used for analyzing measurement and structural models and testing the proposed mediation relationships. The findings must be interpreted with caution for common-method bias, potential selection effects and limitations in causal inference and generalizability, due to the data collection process being a survey and the non-probabilistic sampling. The findings may provide valuable information on manufacturing firms in emerging economies, but should not be universally applied to other sectors and/or economies.

The main theory applied to the study is the dynamic capabilities theory. Teece et al. (1997) define dynamic capabilities as the organization's processes that enable the firm to integrate, develop and reconfigure its competencies in response to changing environments. Teece (2007) later identifies the three key processes of sensing, seizing, and transforming in which organizations react to opportunities and threats. If digital transformation is the lens adopted, then exploitation and exploration are complementary methods of using and developing organizational knowledge, whilst the adoption of digitalization strategy and digital leadership can support resource mobilization and organizational renewal. The possibility of GIN is a result of these processes; organizations need to find their way in the environment, invest in solutions with an environmental dimension and adjust products/processes to fully reap the benefits of GIN. The focus of recent digital transformation studies has also been on strategic renewal and dynamic capability development (Warner & Wäger, 2019; Chen et al., 2024).

Theoretically and practically this study is significant. It is theoretically structured to link four dimensions of digital transformation capabilities to GIN and to sustainability-related performance for the business, to understand whether GIN accounts for the link between digital capabilities and sustainability outcomes. It also introduces the dynamic capabilities approach to manufacturing in an emerging economy. The study could practically contribute to the understanding of manufacturing managers on the need to balance enhancement of digital systems with technological experimentation, the integration of the digitalization in the organization strategy, and building the support and leadership of GIN. Therefore, the aim of this study is to examine how DXL, DXP, DAS, and DLP affect GIN and SSP with the mediation of GIN in the proposed relationships.

2. Literature Review

2.1. Theoretical Understanding

Dynamic capabilities theory provides an understanding of how companies transform their

resources and capabilities to adapt to environments and remain competitive. The conceptual framework of dynamic capabilities was developed by Teece et al. (1997), who identified three core processes: sensing, seizing, and transforming that defined dynamic capabilities as distinct from operational capabilities. Teece (2007) expanded on the three core processes, where he added sensing and seizing to transforming. DIY skills are skills that help organizations adjust their resources, identify new opportunities and change their strategic direction in response to new or dynamic market or industry conditions, whereas routine skills support the efficient conduct of ongoing activities.

The theory has been found to be valid for explaining the capabilities of digital transformation, as digital technologies constantly redefine production, information processing, innovation and organizational coordination opportunities. Digital exploitation allows companies to reinforce existing processes, while digital exploration allows them to experiment and learn and build new knowledge. Adopting digitalization strategy brings coherence to investments and priorities, and digital leadership is the one that mobilizes resources and leads change in the organization. Such capabilities could help facilitate GIN by allowing organizations to spot environmental opportunities, create green products and processes and make operational decisions that support environmental sustainability.

The GIN can then contribute to the sustainable performance of the business, for example, by optimizing the use of resources, cutting waste, differentiating products and increasing relevance to environmental expectations. The suggested framework thus views the digital transformation capabilities as enablers for GIN and SSP. The next step is to consider GIN as a mediating process in which digital skills can achieve sustainability-related results. This theoretical argument aligns with the existing body of research on the relationship between dynamic capabilities, digital transformation, and organizational renewal (Teece, 2007; Warner & Wäger, 2019; Chen et al., 2024).

2.2. Sustainable Business Performance

SSP is a company's ability to maintain continuous economic viability while handling the environmental impacts and address the relevant social responsibilities. It is an extension of traditional financial measures to include outcomes related to resource efficiency, environmental management, stakeholder relationships and organization continuity. The triple-bottom-line view of sustainable performance includes the economic, environmental and social aspects (Elkington, 1997). For manufacturing companies, economic results can be profitability, productivity and/or long-term competitiveness; environmental results can be reduced emissions, waste reduction, and better resource use; and social results can be employee well-being, workplace safety, and responsible stakeholder engagement.

Digital transformation can help deliver sustainable performance in these ways: by increasing information availability, by enhancing operational coordination, by controlling operations and by enabling strategic responsiveness. For instance, digital monitoring can help detect inefficiencies in production, and data analytics can aid in resource planning and environmental management. The potential benefits, however, rely on the ability to successfully embed digital skills into organizational practice and sustainability goals. Studies on digital transformation and sustainable performance suggest that technological capabilities and complementary innovation mechanisms can be related to sustainable performance outcomes (Xu et al., 2023; Le et al., 2024; Chen & Wang, 2024). Furthermore, GIN could be of particular interest as it allows organizations to translate technologies and organizations into better products and processes in relation to the environment. SSP is the dependent variable in this study, defined as the economic, environmental and social results of manufacturing organizations.

2.3. Digital Transformation Capabilities

2.3.1. Digital Exploitation Capabilities

DXL are the ability of an organization to leverage existing digital technologies, knowledge and routines for improving operational efficiency, reliability and use of resources. These capabilities

mean using established processes to refine, adding value to existing data, and integrating digital tools into existing processes. A dynamic capabilities view of exploitation allows organizations to develop existing capabilities and to make existing processes more efficient. Digital exploitation in manufacturing can aid predictive maintenance, production scheduling, quality control, energy monitoring, and waste reduction. Exploitation capabilities could also enable organizations to discover possibilities for improving the process and operational accuracy. According to Chen et al. (2024), digital exploitation is an important aspect of digital transformation competencies with respect to SSP. Therefore, this study suggests that DXL could be useful to facilitate the utilization of existing digital resources and contribute to incremental environmental improvements, which could lead to GIN and SSP.

2.3.2. Digital Exploration Capabilities

Digital exploration capability is the capacity to trial new technologies, gain new knowledge and create new applications in the digital sphere in response to new market and environmental changes. Exploration focuses on experimentation, learning and finding opportunities outside of routine. For manufacturing companies, it can include proof-of-concept tests for new production systems that integrate smart technology, digital designs of a product, and new strategies for minimizing environmental footprint. These activities can help foster GIN by providing opportunities to create clean products, alternative materials or more sustainable production processes. But the exploration may involve extra investment and may not reap immediate operational gains. The study of digital exploration by Chen et al. (2024) focuses on the relationship between digital exploration and SSP, and the research on digital transformation and eco-innovation highlights the significance of the digital capabilities for sustainability-oriented innovation (Xu et al., 2023). This study thus regards digital exploration as a key competence towards both GIN and SSP.

2.3.3. Digitalization Strategy Adoption

The adoption of digitalization strategy is defined as to what extent an organization integrates digital technologies and digitalization goals into their overall business strategy, investment decisions and operation plans. It goes beyond the acquisition of digital tools, digital priorities should be linked to organizational goals, and the required resources, responsibilities and implementation processes are needed to support them. In manufacturing, the integrated implementation of a digitalization strategy can coordinate manufacturing technologies, data management, environmental monitoring, and innovation. Strategic alignment can help organizations invest in digital technologies that focus on waste reduction, energy efficiency, product enhancements, and future sustainability. Haq and Huo (2023) investigate the digital strategy use and environmental performance in Pakistani SMEs and the use of environmental performance in SMEs with digitalization strategy in relation to SSP by Chen et al. (2024). The present study builds upon this literature and suggests a positive relationship between the adoption of digitalization strategy and GIN and sustainable business performance.

2.3.4. Digital Leadership Capabilities

Digital leadership competencies are those of managers who demonstrate the ability to set a vision for digital, manage technological change, secure resources and synchronize digital transformation between organizational functions. Digital leaders educate employees about the rationale behind tech investments, enable business and tech teams to work together, and assist in learning throughout transformation efforts. Leadership can play a significant role in manufacturing organizations, particularly if digital projects involve altering existing production processes, job roles and environmental management. Digital leadership can help foster GIN by giving permission to experiment, by stressing the importance of sustainability goals and by investing in sustainable technological solutions. Digital leadership skills are also linked to SSP (Chen et al., 2024) and recent studies explore the link between digital leadership, GIN and business

sustainability (Zada, 2025). The present study, therefore, suggests that the digital leadership skills have a positive impact on GIN and SSP.

2.4. Green Innovation

GIN is the creation or application of products, processes, technologies or managerial approaches that mitigate environmental impacts or enhance resource efficiency. Green product innovation can be one or more of the following: Green designs, materials that are environmentally improved, recyclable products, or products which have a lower life cycle impact; Green process innovation can be one or more of the following: Cleaner production, reduction in energy use, improvement in waste management. In addition, organizational and managerial changes can constitute GIN that support environmental aims. A dynamic capability view of GIN is that it is an organizational strategy that leverages knowledge, resources, and practices to solve environmental problems.

Digital technologies can help create GIN, through the use of collecting environmental data, finding inefficiency in processes, trying different things out and coordinating across organizational lines. Empirical research has related digital transformation to eco-innovation and sustainable performance (Xu et al., 2023), and research has focused on digital capabilities and GIN (Cheng et al., 2024). Similarly, a meta-analysis of the evidence on GIN and environmental performance was conducted in 2024 (Rahmani et al., 2024). The current study's model of GIN as a mediator variable may account for the relationship between digital transformation capabilities and SSP.

2.5. Hypothesis Development

2.5.1. Digital Transformation Capabilities and Green Innovation

DXL can help foster GIN by helping organizations leverage existing operational knowledge and technologies to enhance environmental performance. Manufacturing businesses may also have useful production data, equipment-monitoring systems and process-control technologies available that can help them to detect energy waste, material losses, and excess waste. The exploitation of these resources can help in achieving incremental improvement in the environment and enable the adoption of greener production processes. In the context of the dynamic capabilities approach, there are two ways in which organizations could gain value from existing knowledge: by incorporating knowledge into the workflows and by evolving and enhancing their resource use (Teece, 2007).

The general connection between digital skills and GIN has been substantiated in recent research. Xu et al. (2023) investigated digital transformation and eco-innovation in manufacturing companies, while Cheng et al. (2024) examined digital capability and GIN performance. However, there are differences between exploitation and exploration. Most often, exploitation is used to extend existing technologies and routines, and so it is very applicable to incremental GIN, e.g. optimizing processes, minimizing material waste and optimizing product designs. Thus, a firm's ability to exploit technology for digital purposes should be expected to have a positive impact on its potential for GIN.

H1: Digital exploitation capabilities positively influence green innovation.

The DXP can also help drive GIN, by providing an opportunity for an organization to look for new technical solutions, try something different, or acquire knowledge outside of its routine operations. Exploration requires experimentation and generating opportunities for larger scale environmental improvement, while exploitation is about improving existing processes. Exploratory digital capabilities can be used to explore cleaner production technologies, materials, smart energy-management systems, and environmentally friendly product design.

Dynamic capabilities theory proposes that organizations need to recognize new opportunities and acquire new capabilities to adapt to the changing environment (Teece, 2007). In digital exploration, access to information is increased and experimentation with alternative technological approaches is made possible. The evidence of digital capabilities' relevance to sustainability-oriented innovation is provided by research on digital transformation and eco-innovation (Xu et al., 2023). Likewise, Jing et al. (2023) investigate

the relationship between digital competence and organizational agility in light of GIN performance on manufacturing companies. So, the higher digital capabilities an organization has, the higher rank in GIN will be acquired.

H2: Digital exploration capabilities positively influence green innovation.

Adopting digitalization strategy could support GIN through linking technology investments and organizational priorities to innovation and environmental goals. A well-defined digitalization strategy sets the course for technology procurement, investment of resources, cross-functional coordination and the execution of digital initiatives. Digital investments can be disconnected and not substantially improve the environment without strategic alignment. A coherent strategy, on the other hand, can help promote the use of digital resources for environmentally better production processes, sustainable product development and better environmental monitoring.

In a study on digital strategy and environmental performance of Pakistani SMEs, Haq and Huo (2023) found the issue of strategic digitalization to be relevant to environmental outcomes in SMEs. The study by Xu et al. (2023) also explores the link between digital strategy and digital capabilities in the context of eco-innovation and sustainable performance of manufacturing companies. The arguments of the aforementioned studies are in line with the overall one that the value of digitalization can be enhanced by combining it with the goals of the organization and innovation processes. Based on this, the adoption of digitalization strategy is expected to help in developing and implementing GINs.

H3: Digitalization strategy adoption positively influences green innovation.

Digital leadership competencies can support GIN by helping to provide strategic guidance, resource allocation, experimentation and coordination of organizational change for digital and environmental transformation. Managers determine whether or not digital efforts are given their due and if working staff are motivated to look for new technological possibilities. Additionally, leadership can play a part in ensuring that sustainability goals are incorporated into digital transformation initiatives, which helps to factor in environmental impacts when making decisions about innovation.

According to the dynamic capabilities approach, leadership is important in helping the organization sense, seize, and reconfigure to deal with technological and environmental changes (Teece, 2007). Digital leaders can spot opportunities for technologies and innovation that are environmentally friendly, approve investments in these technologies and make it easier to restructure routines to fit in new technologies. In recently exploring the relationship between digital capability and GIN performance, Cheng et al. (2024) exemplify the importance of managerial environmental awareness. Zada (2025) also investigates the Digital Leadership associated with GIN and Firm Sustainability. For this reason, it is hypothesized that digital leadership skills have a positive impact on GIN.

H4: Digital leadership capabilities positively influence green innovation.

2.5.2. Sustainable Business Performance and Green Innovation

GIN can enhance SSP by helping organizations to minimize environmental impacts while not reducing economic and social value. Green process innovation can help to reduce material waste, optimize material use and promote using energy more efficiently. Innovation in the green product can assist firms in satisfying environmentally aware customers, improving the differentiation of their products, and creating products that meet evolving environmental demands. These innovations, when executed properly, can also help keep organizations robust and resilient in the long run, enhance stakeholder relationships, and facilitate regulatory compliance. GIN has been found to be correlated with environmental and organizational performance. Xu et al. (2023) studied eco-innovation and sustainable performance in manufacturing companies and Ghazi et al. (2023) studied GIN and SSP in the manufacturing context of Pakistan. Rahmani et al. (2024) collected evidence of the relationship between GIN and environmental

performance and once again highlighted the need to consider the outcomes of environmental innovation. However, when it comes to GIN, there can be significant upfront development expenses, implementation issues, and uncertain short-term returns. So, its contribution to SSP relies on the firms' capacity to incorporate innovations into the functioning and value creation processes. Hence, the following hypothesis is proposed:

H5: Green innovation positively influences sustainable business performance.

2.5.3. Green Innovation as Mediator

Digital transformation capabilities can be expected to boost SSP both directly and indirectly, through their potential to develop and implement environmental improvements in products, processes and managerial practices, and this is where the role of GIN is brought in. Mediation is when there is a precursor that affects an intermediate construct, and then the intermediate construct affects the outcome. GIN in the current model is a process through which digital skills can be converted into value on sustainability.

DXL can enable access to the information and operational knowledge required to enhance the current production processes and GIN can transform these enhancements into tangible environmental and economic gains. DXP can enable experiments with new technologies and product designs, and GIN can turn into knowledge into solutions for sustainability. The adoption of digitalization strategy can support investments and organizational priorities to environmental innovation, and GIN can facilitate the realization of the sustainability benefits of this alignment. Digital leadership skills can facilitate resource mobilization, experimentation and coordination, thereby helping to achieve GIN to support organizational outcomes.

The overall plausibility of these relationships is supported by existing research. This article by Xu et al. (2023) explores the concepts of digital transformation, eco-innovation, and sustainable performance. Le et al. (2024) explore the mediating effect of GIN and green supply-chain management between digitalization and sustainable corporate performance. Additionally, Cheng et al. (2024) explore the link between digital capability and GIN. The findings of these studies suggest that environmental innovation could be one of the key ways in which digital resources can help to deliver on the SDGs. The following mediation hypotheses are suggested.

H6: Green innovation mediates the relationship between digital exploitation capabilities and SSP.

H7: Green innovation mediates the relationship between digital exploration capabilities and sustainable business performance.

H8: Green innovation mediates the relationship between digitalization strategy adoption and sustainable business performance.

H9: Green innovation mediates the relationship between digital leadership capabilities and sustainable business performance.

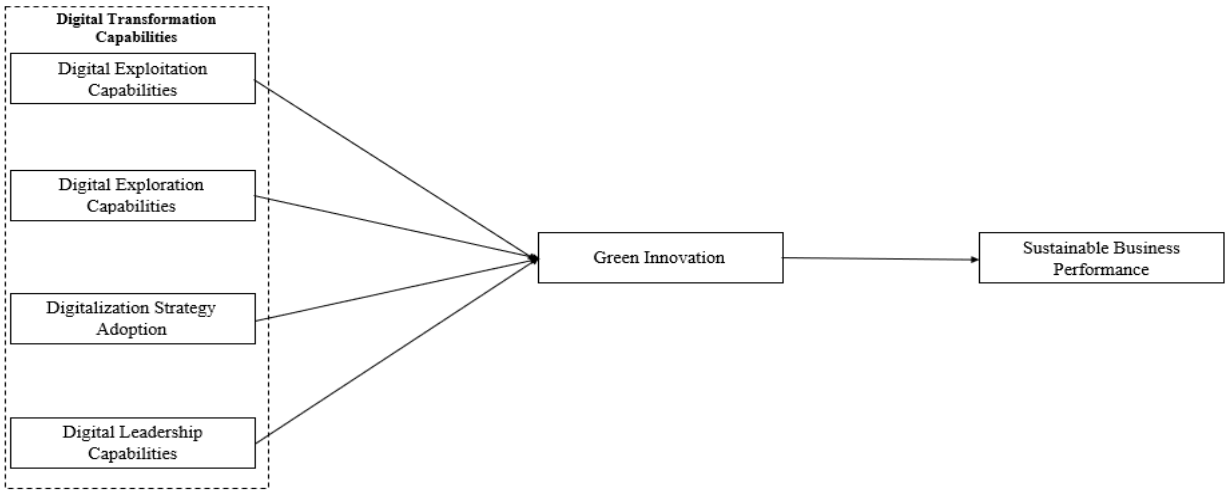


Figure 1: Theoretical Framework

3. Research Methodology

3.1. Research Design and Sample

This study used a quantitative approach with cross-sectional survey design to explore the relationship between digital transformation capabilities, GINs, and SSP in manufacturing organizations in Pakistan. Structured questionnaire was used for data collection, which involved 724 managers. The convenience sampling method was employed to select respondents that were easily accessible and able to provide information pertinent to the study variables.

Among the respondents, 548 (75.7%) were male. The largest proportion of participants, 307 (42.4%), belonged to the 31–35-year age group, while 343 (47.4%) held a 14 years qualification. In addition, 153 respondents belong to textile industry. Table 1 displays the respondents' specific demographic information.

Table 1: Respondents' Characteristics (N= 724)

Demographic Characteristics	Code	Frequency	Percentage of Total
Gender	Male	548	75.7
	Female	176	24.3
Age	21-30	131	18.1
	31-40	307	42.4
	41-50	180	24.9
	Above 50	106	14.6
Education	14 years	343	47.4
	16 years	258	35.6
	Above 16 years	123	17.0
Industry	Sports	137	18.9
	Leather	113	15.6
	Surgical	134	18.5
	Textile	153	21.2
	Agro-Processed Foods	106	14.6
	Others	81	11.2

3.2 Measures

A five-point Likert scale, with 1 denoting "strongly disagree" and 5 denoting "strongly agree," was used to measure the reflective measures of each construct. Three items were used to assess DXL, worded based on Chen et al. (2024). Three items were adapted from Chen et al. (2024) to assess DXP. The four items were taken from Chen et al. (2024) to measure DAS. DLP was assessed using five items from Chen et al. (2024). GIN was measured through four dimensions i.e., green product innovation, green technological innovation, green institutional innovation, and green environmental innovation. GIN is accessed with eighteen scale adapted from Li et al. (2022). SSP was represented in seven items of economic continuity, resource efficiency, environmental responsibility, value of employees and stakeholders, reputation, resilience and long-term growth (Chen et al., 2024).

3.3. Data Analysis

Data analysis was done in partial least square structural equation modeling (PLS-SEM). The analysis should be done in two steps. First, the measurement model should be validated with indicator loadings, internal-consistency reliability, average variance extracted and discriminant-validity diagnostics (where applicable by using the heterotrait–monotrait ratio). Second, the structural model should be evaluated using the collinearity diagnostics, path coefficients, bootstrapped confidence intervals, significance tests, explained variance (R^2) and effect sizes (f^2) and, where applicable, predictive relevance.

4. Results

4.1 Measurement Model Analysis

The reliability and validity results are displayed in Table 2. For every observed variable, the outside loadings and indicator reliability are measured. According to the results, all of observed variables have outer loadings greater than 0.60 and indicator reliabilities greater than 0.40 (Hair et al., 2019). Both composite reliability and Cronbach's alpha assess how effectively latent components are measured by observable variables (Hair et al., 2019). The reliability is confirmed by all values being greater than 0.708. When AVE is examined for convergent validity, all constructs meet the threshold, or are over 0.50, indicating no validity problems.

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Table 2: Measurement Model Analysis

Constructs	Item Code	Outer Loading	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
	Threshold	*> 0.600*	*> 0.708*	*> 0.708*	*> 0.50*
Digital Exploitation Capabilities	DXL1	0.788	0.725	0.821	0.632
	DXL2	0.700			
	DXL3	0.886			
Digital Exploration Capabilities	DXP1	0.847	0.783	0.790	0.696
	DXP2	0.838			
	DXP3	0.818			
Digitalization Strategy Adoption	DAS1	0.774	0.783	0.784	0.605
	DAS2	0.763			
	DAS3	0.783			
	DAS4	0.792			
Digital Leadership Capabilities	DLP1	0.758	0.842	0.845	0.613
	DLP2	0.798			
	DLP3	0.789			
	DLP4	0.793			
	DLP5	0.777			
Green Innovation	GPI1	0.772	0.945	0.946	0.519
	GPI2	0.706			

	GPI3	0.689			
	GPI4	0.711			
	GTI1	0.759			
	GTI2	0.739			
	GTI3	0.697			
	GTI4	0.666			
	GTI5	0.683			
	GII1	0.728			
	GII2	0.720			
	GII3	0.724			
	GII4	0.734			
	GII5	0.710			
	GEI1	0.692			
	GEI2	0.763			
	GEI3	0.758			
	GEI4	0.707			
Sustainable Business Performance	SSP1	0.695	0.862	0.865	0.548
	SSP2	0.782			
	SSP3	0.724			
	SSP4	0.751			
	SSP5	0.756			
	SSP6	0.724			
	SSP7	0.745			

4.2 Discriminant Validity

Discriminant validity was tested to establish whether the latent constructs were empirically distinguishable from one another. Following Hair et al. (2019), the Fornell-Larcker criterion was investigated. As per Fornell-Larcker criterion, the square root of the average variance recovered for each construct, as shown on the diagonal, exceeded corresponding inter-construct correlations. As presented in Table 3, all constructs satisfied this requirement, confirming discriminant validity.

Table 3: Discriminant Validity Analysis

Constructs	DXL	DXP	DAS	DLP	GIN	SSP
Digital Exploitation Capabilities (DXL)	0.795					
Digital Exploration Capabilities (DXP)	0.019	0.834				
Digitalization Strategy Adoption (DAS)	0.016	0.057	0.778			
Digital Exploitation Capabilities (DLP)	0.013	0.010	0.019	0.783		
Green Innovation (GIN)	0.222	0.263	0.235	0.285	0.720	
Sustainable Business Performance (SSP)	0.088	0.143	0.103	0.122	0.449	0.740

4.3 Structural Model Analysis

The variance inflation factor (VIF) was assessed to detect potential multicollinearity among the study variables. The results indicated no multicollinearity concerns, as all VIF values were below the recommended threshold of 3.3 (Hair et al., 2019). The significance of the hypothesized relationships was evaluated using the corresponding t-values and p-values, as reported in Table 4. The hypothesis was validated when the absolute t-value exceeded 1.96 at the 5% significance level (Haenlein & Kaplan, 2004). H1 proposed that DXL positively influence GIN that is accepted as $\beta = 0.224$, t value= 7.662, with $p < 0.000$. H2 proposed that DXP positively influence GIN that is accepted as $\beta = 0.279$, t value= 8.915,

with p < 0.000. H3 depicted that DAS positively influence GIN that is accepted as β= 0.256, t value= 7.724, p < 0.000. H4 proposed that DLP positively influence GIN that is accepted as β= 0.284, t value= 10.154, with p < 0.000. H5 depicted that GIN positively influence SSP that is accepted as β= 0.449, t value= 13.966, p < 0.000. The structural model results are also illustrated in Figure 2.

Table 4: Structural Path Analysis

No.	Hypotheses	Beta	T-Value	P Value	VIF	Effect Size (f^2)	R^2	Decision
H1	DXL → GIN	0.224	7.662	0.000	1.001	0.068	0.264	Accept
H2	DXP → GIN	0.279	8.915	0.000	1.004	0.105		Accept
H3	DAS → GIN	0.256	7.724	0.000	1.004	0.089		Accept
H4	DLP → GIN	0.284	10.154	0.000	1.001	0.109		Accept
H5	GIN → SSP	0.449	13.966	0.000	1.000	0.252	0.201	Accept
Mediation Analysis					**Confidence Interval**			
					2.5%	**97.5%**		
H6	DXL → GIN → SSP	0.100	6.653	0.000	0.073	0.133		Accept
H7	DXP → GIN → SSP	0.125	7.557	0.000	0.091	0.160		Accept
H8	DAS → GIN → SSP	0.115	6.765	0.000	0.086	0.152		Accept
H9	DLP → GIN → SSP	0.127	7.763	0.000	0.097	0.161		Accept

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4.4 Mediation Analysis

Mediation analysis is performed to measure the mediating role of GIN. H6 proposed that GIN mediate relation between DXL and SSP that is accepted as β= 0.100, t value= 6.653, with p < 0.000. H7 proposed that GIN mediate relation between DXP and SSP that is accepted as β= 0.125, t value= 7.557, with p < 0.000. H8 proposed that GIN mediate relation between DAS and SSP that is accepted as β= 0.115, t value= 6.765, with p < 0.000. H9 proposed that GIN mediate relation between DLP and SSP that is accepted as β= 0.127, t value= 7.763, with p < 0.000.

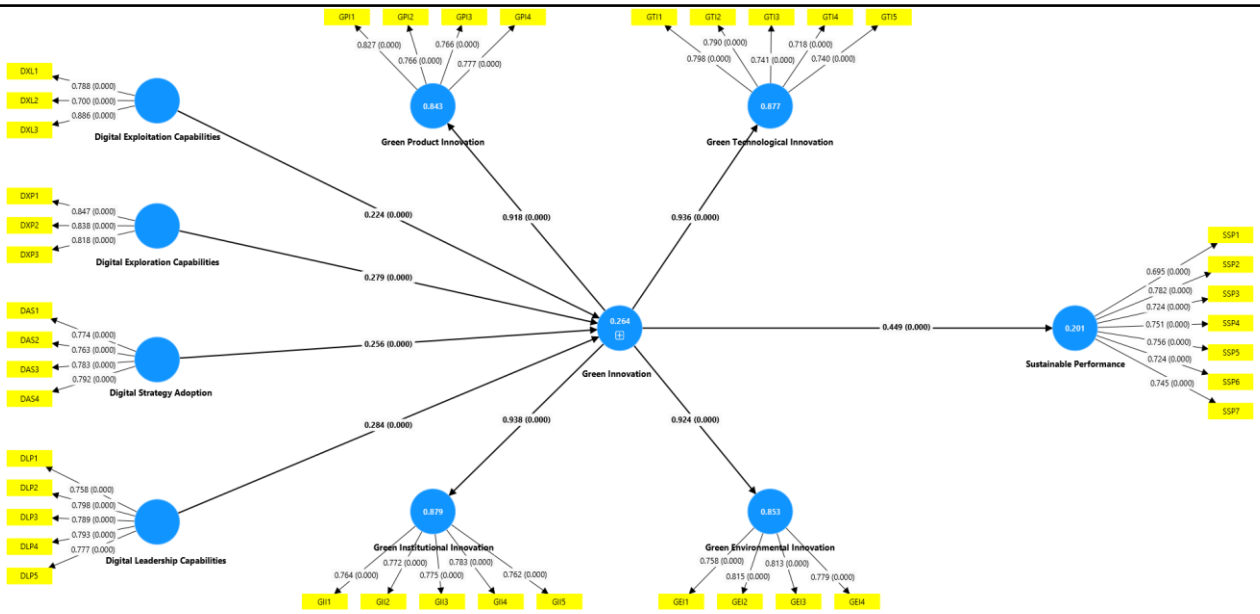


Figure 2: Structural Model

5. Discussion

The current research aimed to investigate the relationship between four digital transformation capabilities and GIN and SSP of manufacturing organizations in Pakistan. The results indicate that the four factors digital transformation capabilities i.e., digital exploitation, digital exploration, DAS, and DLP are positively related with GIN. A mediation effect was also reported for GIN between each of the digital transformational capabilities and SSP.

The support for H1 indicates that digital exploitation competencies can support GIN, in creating the use of the existing technological resources and operational knowledge. This interpretation aligns with the research on digital transformation and eco-innovation in manufacturing enterprises (Xu et al., 2023), and the research on digital capability and the relationship between GIN and performance (Cheng et al., 2024; Jing et al., 2023). Furthermore, the outcome aligns with other findings showing that digital transformation helps create GIN, but not necessarily in a linear fashion (Wang et al. 2024). The implication for manufacturing managers is that, if used as a means to recognize and correct inefficiencies in their operations, existing digital systems can help to improve the environment.

The support for H2 suggests that digital capabilities for exploration could help to foster GIN, enabling the use of technology to experiment, learn and create new solutions to environmental challenges. The interpretation is in line with digital transformation, eco-innovation, and sustainable innovation performance studies (Xu et al., 2023; Mao et al., 2024; Liu et al., 2025). Additionally, digital competence and organizational agility are highlighted as relevant to the GIN performance (Jing et al., 2023). Combined these findings indicate that exploratory digital capabilities could be useful in helping manufacturers to identify opportunities for improved products and processes in the context of the environment. But exploration is a matter of investment and can yield unpredictable returns – and in order to reap the benefits, it's crucial that organizations translate experimentation into breakthrough innovations.

Strategic alignment and managerial direction are emphasized in the support for H3 and H4, indicating their potential importance. Adoption of digitalization strategy can help align investments in technology and organization, and digital leadership can help free up resources, enable learning, and help to implement. This elucidation is in line with studies on digital strategy and environmental performance among

Pakistani SMEs (Haq & Huo, 2023), digital transformation and SSP (Chen et al., 2024), and digital leadership for GIN and sustainable business (Zada, 2025). Digitalization and sustainable innovation research also highlights the need for further linking of digital technologies to business needs and environmental conditions (Mao et al., 2024). Such findings imply that technological capabilities should be nurtured by some strategic direction and leadership instead of being built as standalone technological resources.

The positive relation between the support of H5 and SSP suggests that GIN has a positive correlation with SSP. GIN could enable organizations to enhance material and energy efficiency, waste reduction, product development for environmental enhancement, and meet the expectations of stakeholders. It is consistent with the findings from digital transformation and eco-innovation that are associated with sustainable performance (Xu et al., 2023), the relationship of digitalization and GIN with sustainable corporate performance (Le et al., 2024), and the evidence gathered from Pakistani manufacturing companies on GIN and SSP (Ghazi et al., 2023). The link between GIN and environmental performance (Rahmani et al., 2024), and between GIN and organizational sustainability outcomes (Cheah et al., 2024) is also explored in meta-analytical studies. These results corroborate the importance of environmental innovation as one of the factors that can contribute to the long-term organization performance.

Lastly, the support for H6–H9 indicates a possible explanatory mechanism between the four digital transformation capabilities and SSP which could be GIN. This finding is consistent with research that explores the mediating role of GIN between digitalization and sustainable corporate performance (Le et al., 2024); studies on digital transformation, GIN, and eco-innovation (Xu et al., 2023); and digital capability and GIN (Cheng et al., 2024). In addition, the results of related evidence from Pakistan highlight the importance of the GIN for achieving organizational sustainability outcomes (Ghazi et al., 2023; Azam & Jamil, 2024).

5.1 Theoretical Implications

This study will make a contribution to the literature in three ways. It starts by drawing on dynamic capabilities theory, which in turn helps to understand the potential relationships between four digital transformation capabilities and GIN and the performance of sustainable businesses. The study's focus on differentiation between exploitation, exploration, strategy adoption, and leadership adds a layer of granularity to the understanding of digital transformation, as opposed to considering it as a single undifferentiated construct. Second, it identifies GIN as a potential mediating mechanism through which digital capabilities influence outcomes related to sustainability. This method is to align digital transformation literature and research on environmental innovation and sustainable performance. Thirdly, the study broadens the empirical scope of digital transformation and sustainability research by studying manufacturing organizations in Pakistan. The findings on the hypotheses match the theoretical suggestion that digital resources need to be mobilized and reconfigured in organizations in order to create value for sustainability. However, the study's contribution should be presented as one of the many empirical tests of the individual relationships described in this study rather than as the first empirical test of the individual relationships.

5.2 Practical Implications

The results indicate some important practical implications for production managers. Improvement in use of existing digital technologies for production inefficiency detection, loss of materials, energy monitoring and operational reliability is a priority 1 objective for organizations. Second, managers should foster digital exploration, by being guided to experiment with new technologies, environmentally better-designed products and cleaner production processes. Third, digitalization needs to be integrated into the organizational strategy with clear goals, proper investment decisions and performance measurements which take into account business and sustainability results.

Fourth, digital leadership development should focus on digital knowledge, inter-functional working, workers learning and embedding environment in transformation programmes. Fifth, it is important that companies enable the development of GIN by providing the necessary resources and coordination for the implementation of environmental improvements, but not as an isolated activity. Last, manufacturers need to track economic, environmental and social metrics to evaluate digital efforts for the potential of providing equal and sustainable value. The implications are especially applicable to organizations with limited resources but will be determined by the size of the organization, type of industry, technical readiness and project-level evaluation.

5.3 Limitations and Future Research Recommendations

There are some limitations to this study. The cross-sectional survey design first, is a cross sectional design that will only be able to capture relationships at one point of time and will not be able to establish causalities or temporal precedence. Future research could focus on the development of digital competence and GIN over time and on the impact they have on sustainable performance. Secondly, because of convenience sampling, the 724 managers may not be representative. Stratified probability sampling by manufacturing industry, organizational size and geographic region could be considered for future research. Third, common-method bias and perceptual measurement error may be present due to relying on questionnaire responses. Energy efficiency, waste reduction, environmental compliance and financial performance could be combined with the survey results to provide objective measures of each of these four areas. Third, a single mediator is included in the model, and four digital capabilities are emphasized. Environmental turbulence, regulatory pressure, organizational culture, green dynamic capabilities, and green supply-chain management, etc. are the potential moderators or mechanisms that could be studied further in the future. Fifth, in order to determine whether the proposed relationships vary across industries and emerging and developed economies, research needs to be undertaken.

5.4 Conclusion

The purpose of this study is to explore the relationship among digital transformation capabilities, GIN, and SSP in manufacturing companies in Pakistan. It explored DXL, DXP, DAS and DLP as antecedents of GIN, mediated by GIN. The study involved 724 managers who completed questionnaires and examined the relationships proposed in the study using PLS-SEM. The reported findings of all thirteen hypotheses were confirmed.

The results indicate a possible link between the capabilities of digital transformation and outcomes of sustainability-related practices both directly and indirectly via the channel of GIN. The study offers a holistic view of the effective leveraging of existing digital technologies, technological experimentation, strategic alignment and leadership, as possible enablers for environmentally oriented innovation. The potential relevance of GIN as a linkage between digital transformation and economic, environmental and social outcomes is also emphasized.

The study adds value to the study of digital transformation and sustainability, as it focuses on digital transformation and sustainability relationship in the context of manufacturing in Pakistan.

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