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Bridging Big Data & Green Innovation in SMEs: Mediating Role of Green Organizational Learning and the Moderating Effect of Total Quality Management

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Abstract:
This study examines the mediating effect of green organizational learning capability in the relationship between big data analytics capability and green innovation dimensions in the manufacturing firms. It also studies the moderating effect of total quality management on the relationship between BDAC & GI. Questionnaires were used, cross-sectionally, to gather data from 219 Pakistani SMEs. In addition, SEM was used for analysis. The findings show positive association between BDAC and the GI, emphasizing the importance of BDAC and GI for the propagation of sustainable practices in manufacturing organizations. Further, GOLC was found to significantly moderate BDAC on GI association, and TQM moderated such association. This study presents empirical findings regarding the relationships between BDAC, GOLC, TQM and GI in Pakistani SMEs in terms of integrating Industry 4.0 technologies and improving sustainability.
Keywords: Green organizational learning capability; Big data analytics capability; Total quality management; Green innovation; Manufacturing SMEs.

1. Introduction

Green innovation (GI) is important to organizations that want to be sustainable and competitive in a dynamic market due to environmental degradation and tighter control. GI includes environmentally friendly products, processes and practices that mitigate ecological footprint and promote environmental objectives (Singh et al., 2020). SMEs have to embrace GI they drive growth of the economy in most of the emerging economies. Such businesses have to meet national and international levels of sustainability to make ends meet and prosper. The implementation of green innovation can impose financial and human resource limitations, a lack of a well-developed technology framework, and fragmented knowledge management systems on SMEs (Shahbaz et al., 2025).

With such limitations, the ability of big data analytics (BDAC) was a pioneer in the sustainability of organizations. BDAC is the capacity of an organization to gather, process, and leverage the big quantities of structured and unstructured data so as to make strategic choices and innovate (Ullah et al., 2022). BDAC assists businesses, in particular SMEs, to discover environmental opportunities, forecast regulatory trends, make the best use of resources and encourage sustainable innovation. There is some evidence of a positive relationship between BDAC and sustainability performance and others of mixed or inconclusive outcomes that do not confirm the support of BDAC to green innovation. Rather, data findings are evaluated, distributed and utilized through organizational internal competencies and contextual factors. Green organizational learning capacity (GOLC) assists companies to obtain, process, and utilize environmental data to be able to achieve sustainable innovation (Giannakos et al., 2022). Organizational learning is old but associated with innovation but the common solutions do not consider the environment. GOLC is an ecological-focused organizational learning to assist organizations to adjust to environmental shifts to create proactive sustainability strategies. The external green knowledge is recognized and internalized by the green absorptive capacity (GAC) and applied and reworked by the green transformative capacity (GTC) to innovate and renew on a strategic basis. A study shows that green organizational learning mediates creativity. It facilitates regulatory and market forces on radical green innovation within Pakistani firms (Akhtar et al., 2024).

Green transformative leadership boosts innovation and competitiveness (Suliman et al., 2023) according to study. Green organizational learning in Pakistan mediates green supply chain integration, BDAC, and GI (Alkhatib, 2024) and impacts sustainability performance. The BDAC-GI transition includes green entrepreneurship (Zameer et al., 2022). Despite these advances, GOLC's role as a BDAC and GI facilitator, particularly in resource-limited SMEs in emerging countries, is understudied. DCV frameworks explain this connection. DCV states that enterprises must have higher-order competencies to identify opportunities, make strategic movements, and reorganize resources to maintain competitive advantage (Pitelis & Wang, 2023). GOLC adapts BDAC data into green ideas for businesses. More than learning, organizational internal context affects long-term analytics results. TQM helps contextualize this process. TQM promotes innovation and sustainability through process efficiency (AlShehail et al., 2022).

As TQM promotes waste reduction, operational efficiency, and systemic quality improvement, it supports environmental goals. Nevertheless, TQM's moderating influence on BDAC and GI is unexplored to a great extent, particularly in SMEs, where the quality management system is less structured and execution is inconsistent (Albloushi et al., 2023). According to the DCV, this research explores how developing economy manufacturing SMEs can defeat resource and institutional limitations to become sustainable. According to Martínez-Peláez et al. (2023), research on Pakistani SMEs, a critical but environmentally vulnerable segment, offers rich insights into the utilization of digital technology and green capabilities in the face of systemic limitations. This research fills the gaps in digital transformation, organizational learning, and sustainable innovation by synthesizing BDAC, GOLC, and TQM as a theoretical model. Three questions guide research:

- Q1: What impact does BDAC have on green innovation?
- Q2: In what way does GOLC mediate BDAC-GI?
- Q3: To what extent does TQM moderate the BDAC–GI relationship?

This research has three key contributions. First, it proposes and tests an integrated model where GOLC mediates and TQM moderates the BDAC–GI relationship, applying the Dynamic Capabilities View (DCV) to the area of green innovation. Second, it enhances organizational learning literature by providing empirical evidence that GOLC is a multifaceted construct, encompassing both GAC and GTC, within the context of sustainability, which is underdeveloped (Albloushi et al., 2023). Third, it offers new empirical evidence from Pakistani manufacturing SMEs, a setting in which green innovation becomes progressively more important but as yet unevenly implemented owing to institutional and scarcity-related constraints (Zameer et al., 2022). Lastly, building on the AI-driven compliance frameworks used in anti-money laundering (AML) to detect risks and ensure regulatory adherence by Rajpoot & Raffat (2024), manufacturing SMEs can similarly leverage big data analytics to enhance green innovation, with green organizational learning mediating this transformation and Total Quality Management reinforcing its effectiveness

2. Literature review

2.1. Theoretical basis

The Dynamic Capabilities View (DCV) offers a solid theoretical approach to describe how green innovation (GI) can be attained by developing economy manufacturing SMEs. Even Resource-based theory predicts that DCV the competitive advantage in volatile and uncertain culture is determined by the capacity of an enterprise to find new opportunities, capitalize on them with the help of strategic move, and to re-arrange the internal resources and processes with an aim of transforming. Such a concept of dynamic capabilities comes in handy in sustainability because the environmental issues needed new innovations and adaptation all the time.

This view considers big data analytics capability (BDAC) to be a constitutive dynamic capability. BDAC assists organizations to view environmental trends and inefficiency in real-time with data monitoring, plan and make applicable decisions (seize), and restructure production and operations processes to reduce ecological footprint (Zhang & Yuan, 2023). Experiments have demonstrated that BDAC leads to innovation and operational flexibility, although its effect on the green innovation of resource-constrained SMEs of emerging economies remains to be researched (Sabharwal & Miah, 2021). The research closes the gap by discussing BDAC unexploited potential as a sustainability-based driver of transformation in manufacturing SMEs.

DCV suggests that organizational learning is advisable in building capacities with external pressure. This paper hypothesizes that BDAC and GI mediated by GOLC. GOLC evaluates, interpret, and use environmental data to make sustainable innovation. It assists companies to transform data-driven insights into green plans in the reconfigure phase of dynamic capabilities. GOLC is a two-dimensional construct that facilitates innovation and sustainability performance and has GAC and green transformative capacity (GTC), both defined by (Özgül & Zehir, 2023b). These features allow dynamic change and life-long learning to optimize big data to environmental objectives.

The study found that total quality management (TQM) moderates the effect of BDAC on GI, along with learning (Turi et al., 2023). DCV views TQM as an operational dynamic competence that improves organizational responsiveness, standardization, and continuous improvement. Employee empowerment, process improvement, defect reduction, and customer orientation create a disciplined, teamwork-oriented culture that supports innovation (Al-Khatib, 2023). A structured culture is critical for turning big data-driven insights into sustainable outcomes, with analytics-identified opportunities consistently translated into long-term value.

DCV, consisting of BDAC, GOLC, and TQM, is thus more comprehensive in terms of how dynamic capabilities fuel green innovation. The study highlights the importance that sustained change does not depend on digital assets, but is dependent on technological, cognitive, and administrative capabilities. It demonstrates that data alone do not yield green outcomes but that organizational learning and a quality infrastructure to facilitate action and accountability do (Arshad et al. 2022). This research extends the DCV by demonstrating that green innovation is a strategic by-product of data analytics, environmental learning, and quality management systems, rather than an inevitable by-product of new technologies. In the competitive manufacturing SME landscape in emerging economies, these characteristics work in conjunction with one another to make a firm more agile, responsive, and sustainable.

2.2. BDAC and GI

Green innovation (GI) is defined as new products, services and/or processes that diminish environmental impact (Albloushi et al., 2023). It is aimed at decreasing waste, pollution, and depleting natural resources by adopting sustainable technologies, and designing environmentally conscious products. In an environment where the world values environmental responsibility and consumers, investors, and stakeholders evaluate companies based on their environmental stewardship, incorporating green innovation into your overall business strategies ensures compliance with stringent regulatory environments while enhancing your market position (Ullah et al. 2022).

Recent academic research identified big data analytics capability (BDAC) as a key driver of green innovation (D. Yu et al., 2022). The Dynamic Capabilities View (DCV) (Yoshikuni et al., 2023) defines BDAC as a strategic organizational ability that allows companies to gather, analyze, and turn big data into useful insights, enabling adaptive and innovative responses to changing environments. BDAC appears to greatly effect product- and process-based green innovation (Munir et al., 2022). It also helps product developers generate ideas, analyze customer preferences in real time, and create environmentally friendly products. In operational systems, BDAC improves resource usage, real-time environmental performance tracking, waste minimization, and sustainable production systems (Sabharwal & Miah, 2021). BDAC's contribution to green innovation is new, although its overall impact on innovation is well known (Sabharwal & Miah, 2021). However, growing research suggests that BDAC helps firms manage environmental issues through wiser resource usage, sustainability opportunities, and data-driven environmental methods (Yu et al., 2021). This review proposes the following hypothesis:

H1: Big data analytics capability (BDAC) has a positive effect on green innovation.

2.3. GOLC Mediating Role

BDAC now an essential resource for firms that compete in complicated and information-intensive environments. BDAC is the capacity to process and produce meaningful insights that can inform strategic decision-making (Olabode et al., 2022). Beyond technical competence, BDAC is a higher-order organizational ability that refines knowledge discovery by discovering concealed patterns, forecasting trends, and converting actionable insight. However, green innovation (GI) quickly changes environmental policies, ecological threats, and mounting stakeholder pressures for sustainability (Ullah et al., 2022).

BDAC facilitates green innovation by allowing companies to track energy usage, monitor environmental performance, detect inefficiencies, and streamline production processes (Wu et al., 2024). Advanced analytics enable organizations to enhance operational effectiveness, reduce waste, and create environmentally friendly products and processes, directly supporting both process and product green innovation (Wang et al., 2021). But the presence of data and analytical tools alone will not ensure sustainable results. Embedding data-driven insights in tangible environmental improvements needs a strong organizational learning and adapting capacity.

Organizational learning (OL) is a company's capability for acquiring, sharing, and using knowledge across functions and levels to enhance performance (Gomes et al., 2022). In sustainability, the above concept develops into GOLC & company's capacity for procuring, assimilating, and utilizing environmental knowledge that reinforces sustainable practice. GOLC is a strategic focus on sustainability that allows companies to internalize environmental knowledge, develop an environmental culture, and align innovation with long-term sustainability objectives (Elmunsyah et al., 2023).

BDAC enhances GOLC by furnishing the technological platform and analytical means with which to collect, translate, and share environmental information throughout the enterprise (Ge & Zhao, 2022). Real-time data analysis increases sensitivity to environmental trends, regulatory shifts, and consumer needs, thus strengthening the learning processes of the firm. GOLC, in return, allows the organization to be able to process and respond to such insights efficiently, integrating green paradigms into everyday business activities as well as strategic undertakings. Strong GOLC companies can maximize the use of BDAC for innovation, as they have the absorptive as well as the adaptive ability to translate data into sustainable action.

Empirical evidence indicates that organizational learning is a crucial bridge between digital capabilities and innovation outcomes, especially in dynamic and uncertain environments like sustainability (Xu et al., 2022). Hence, GOLC not only facilitates green innovation but also serves as a mediating mechanism that enhances the effect of BDAC on GI. The connection between BDAC and green innovation is therefore direct as well as indirect; whereas BDAC produces useful environmental information, such information can only result in effective innovation if underpinned by an effective learning infrastructure. Without GOLC, facts can be held captive within a silo, be incorrectly interpreted, or severed from strategic sustainability goals (Xu et al., 2022). Through the integration of internal and external knowledge, GOLC enables resources and processes to be reconfigured in support of environmentally sustainable innovation. It closes the gap between data analytics and sustainable action so that technological capability is appropriately aligned with ecological objectives. On this theoretical and empirical basis, the following hypotheses are set:

H2: BDAC has a positive impact on GOLC.

H3: GOLC has a positive impact on GI.

H4: GOLC mediates association among BDAC and GI.

2.4. Total Quality Management Moderating Role

In a modern, competitive and sustainability-oriented business environment, TQM plays the leading role in streamlining organizational performance, operational performance, and long-term competitiveness (Antunes et al., 2021). TQM is globally known as a driver of excellence, which concentrates on constant improvement, satisfaction of customers, employee participation, and improvement of the processes. Interestingly, TQM is very sensitive to environmental goals because, like things, it promotes the minimization of wastes, effective use of resources, and managed system control in processes; therefore, it is an intuitive green management philosophy (Lim et al., 2022).

Although big data analytics capability (Zhang & Yuan, 2023) enables firms to extract valuable insights out of large data sets, its applicability will depend on the quality and reliability of the data. Bad quality data may lead to the falsification of analyst findings to wrong conclusions, and subpar performance in innovation. Therefore, institutions must establish effective quality mechanisms before they can achieve the potential of BDAC. TQM supports this necessity by making sure that data are accurate, consistent, and timely with standardized operations and rigorous monitoring systems (Lim et al., 2022). This process elevates the credibility of the data used in analytics through TQM, thereby improving the validity and impact of insights to be created in green innovation (GI).

Moreover, TQM fosters a team spirit, employee empowerment, and life-long learning, all of which facilitate programs successful execution (Waheed & Abbas, 2024). Everyone is encouraged to make suggestions, recognize weaknesses, and participate in problem-solving, allowing an environment in which data improvement thrives. The key features of TQM, i.e., quality management of suppliers, adherence to quality standards, etc., and supported by top management, are the keys to the successful implementation of BDAC in manufacturing. BDAC can significantly increase the level of system performance and strategic responsiveness (Ge & Zhao, 2022). TQM imposes the correspondence of BDAC and GI through augmented organizational infrastructure to examine and respond to the information. It has the role of a moderating factor that contributes to improved data insight for sustainable innovations. Within highly TQM-mature organizations, the fusion of BDAC results in more efficient environmental opportunity identification, quicker green solution implementation, and closer alignment between digital competency and sustainability goals (Wolniak & Grebski, 2023). Therefore, hypothesized that:

H5: TQM moderates' relationship among BDAC and GI, i.e., the positive influence of BDAC on GI is greater when TQM is at higher levels.

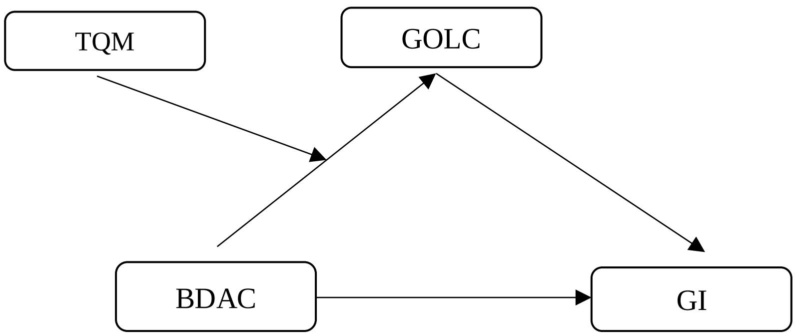

Figure 1: Conceptual Framework

3. Research Method:

3.1. Sample

Consistent with prior research, quantitative, cross-sectional data utilized and focused on BDAC, GOLC, and TQM on green innovation in Pakistani-based manufacturing SMEs are investigated. Peshawar, Islamabad, and Lahore SMEs are included in the sample. The sample was geographically focused but stratified based on manufacturing sub-sectors (e.g., food and beverage, wood products, textiles) in order to offer broad coverage of diversified SME environment in Pakistan. Basic random sampling was applied to sample each firm to achieve equal selection probability (Sekaran & Bougie, 2016). The systematic questionnaire was distributed. They were selected since they have a direct influence on strategic decision-making, innovation, and quality management, which guarantees the provision of relevant and appropriate responses (Hussain et al., 2020). Following the dispatched emailing of 300 questionnaires to the participants that met the requirements, 219 valid responses were obtained, which is a response rate of 73 percent that is above the norms of SME research (Hair et al., 2020). This last sample size meets the minimum requirement of structural equation modeling (SEM) based on G. Power a priori power analysis (Jobst et al., 2023). A minimum of 77 was calculated using a power of 0.80, alpha = 0.05, and an effect size of 0.15. The obtained sample (n=219) provides sufficient statistical power. Furthermore, the sample size is larger than the recommended 100 observations to perform PLS-SEM analysis and fits the research conducted in comparable situations in the past (Özgül & Zehir, 2023b), which guarantees its strength and relevance. Harman single-factor test was used by Podsakoff et al. (2024) to study CMB. The unrotated factor analysis revealed that only one factor explained less than half the variation, indicating that CMB is not issue.

Table 1 presents sample demographics. 43% of the organizations have more than ten years of experience in the industry, which reflects knowledge of the industry. 48% are small businesses and 52% are medium-sized (under 200 employees), a good population proportion. The industrial distribution presents 33 percent of respondents in the field of food and beverage and 21 percent in

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the wood and wood products. Diversity is provided by different industries such as paper, iron and steel, and textiles.

Table 1: Demographic Analysis

Category	Sub-Category	Number
Position	CEO	53
	Marketing-Executive	46
	Operation -Executive	27
	R&D-Executive	48
	Quality-Manager	45
Employees No.	5 – 74	105
	75 – 200	114
	Total	219
Established (Years)	5 – 10	70
	11 – 15	94
	>15	55
Sub-Sector Industry	Food/Beverage	73
	Paper/Paper Products	11
	Non-Metallic Mineral Products	3
	Plant/Machinery	14
	Motoring Products	5
	Textile/Wearing Apparel	15
	Wood/Wood Products	46
	Electrical/Electronic	22
	Iron/steel	30

3.2. Measures

Self-administered questionnaire was created utilizing scales from past research and tailored to Pakistani manufacturing SMEs. Hence, academic experts examined the study scale and pilot-tested the instrument with 15 SME managers for content and face validity. Pretest feedback led to minor phrasing and structural changes to improve clarity and context. Four items taken from (Al-Khatib, 2023) measured a firm's big data collection, analysis, and application. The multidimensional construct of GOLC was evaluated using six items, including three for GAC and three for GTC, from Özgül & Zehir (2023a). Four elements from (Fikri et al., 2022) assessed leadership, employee involvement, process development, and customer focus in TQM. Based on (Azam & Jamil, 2024), three items measured green innovation (GI), which involves eco-friendly product and process development. All constructs were measured on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

4. Data Analysis

Analytics was done on PLS-SEM. PLS-SEM is best suited to exploratory research, those with many dimensions, and those with intermediate sample sizes, in particular, where prediction is the primary objective (Hair, Sarstedt, Matthews, and Ringle, 2016; Sarstedt, Hair Jr., Cheah, Becker, and Ringle, 2019). It manages non-normal data distributions than CB-SEM, and it has greater statistical power in complex models. Measurement model analysis and structural model testing was part of the analysis..

4.1. Measurement Model

Indicator-loadings above 0.70 were used as a threshold for item retention, ensuring reliability and internal consistency (Hair Jr et al., 2020). Convergent-validity was confirmed by satisfying three established criteria: factor loadings greater than 0.70, composite reliability (CR) exceeding 0.70, and AVE above 0.50. As presented in Table 2, all constructs in the study met these threshold requirements, indicating strong convergent validity and adequate internal consistency of the measurement model. Discriminant validity was assessed, with values below 0.85 indicating adequate discriminant validity (Dirgiatmo, 2023).

Table 2: CR, AVE & F.L

Variable	Items	Loading	CR	AVE
BDAC	BDAC-1	0.76	0.91	0.718
	BDAC-2	0.89		
	BDAC-3	0.89		
	BDAC-5	0.81		
GAC	GAC-1	0.848	0.895	0.74
	GAC-2	0.866		
	GAC-3	0.866		
TGC	GTC-1	0.911	0.937	0.832
	GTC-2	0.92		
	GTC-3	0.905		
TQM	TQM-2	0.831		
	TQM-3	0.851		
	TQM-4	0.849		
	TQM-5	0.835		
GI	GI-1	0.91	0.9	0.75
	GI-2	0.898		
	GI-4	0.785		

Table 3 Discriminant Validity

Construct	1	2	3	4
BDAC				
GI	0.631			
GOLC	0.762	0.729		
TQM	0.549	0.347	0.655	

4.2. Study Model

The structural model tested hypothesized relationships. The coefficient of determination (R^2) indicated that the model explains 47.1% of the variance in GI and 34.0% in GOLC, which Chin (1998) classifies as moderate predictive power. Predictive relevance was further confirmed using the Stone-Geisser Q^2 criterion. Values of $Q^2 = 0.376$ for GI and $Q^2 = 0.328$ for GOLC exceed the threshold of 0.00, indicating acceptable predictive relevance (Trevethan, 2017). Path coefficients were estimated using bootstrapping with 5,000 resamples. Results support all hypotheses:

BDAC has a significant positive effect on GI (β = 0.674**). BDAC positively influences GOLC (β = 0.582**). GOLC significantly affects GI (β = 0.321**)

The indirect (mediated) BDAC effect on GI via GOLC is significant (β=0.187, t=3.205), supporting H4

The interaction term between BDAC and TQM is significant (β = 0.214, t = 3.876, $p < 0.001$), confirming H5 that TQM strengthens the BDAC–GI relationship

These findings demonstrate that TQM enhances BDAC efficiency in driving green innovation. The synergy between data analytics and quality management creates a supportive environment where environmental insights are more likely to be translated into actionable innovations.

Table 4 R^2, Q^2 & F^2

Construct	R^2	Q^2	f^2 (Effect Size from GOLC)	f^2 (Effect Size from BDAC)
GI	0.47	0.37	0.104	0.261
GOLC	0.34	0.32	—	0.516

Table 5 Hypothesis Testing

Path	β	t-value	p-value
H1: BDAC → GI	0.67	10.45	p<0.05
H2: BDAC → GOLC	0.58	9.92	p<0.05
H3: GOLC → GI	0.31	3.90	p<0.05
H4: BDAC → GOLC → GI	0.18	3.80	p<0.05

Table 6: Moderating Effect

Path	β	p-value	Decision
TQM × BDAC → GI	0.086	0	Supported

5. Discussion

This study analyzes how BDAC affects GI in manufacturing SMEs, focusing on GOLC and TQM. The study uses the Dynamic Capability View to show SMEs how to use digital capabilities and learning processes for sustainable innovation. H-1 is supported by BDAC's significant GI benefits. This supports an earlier study (Ge & Zhao, 2022) display sophisticated analytics, also help firms detect ecological inefficiencies, minimize surplus, and build sustainable goods and processes. BDAC helps SMEs make sustainability decisions by turning complex numbers into meaningful insights. It also improves firms' environmental and corporate responsibility reputations by increasing their response to regulatory and community demands.

BDAC positively influences GOLC development, supporting H-2 and previous findings (Ge & Zhao, 2022). This suggests that data-driven capabilities promote a sustained learning culture. As previously said, organizations with strong data infrastructure and analytical skills can better analyze and act on environmental data. GOLC can change quickly and align operations with environmental goals because of managerial abilities, technology frameworks, and cultural values that stress sustainability. These findings underscore the need to combine technical and human components in sustainable learning settings. In addition, GI is significantly improved by GOLC, in conjunction with H-3 and the result of our previous study (Zheng et al., 2022). Environmental sustainability, in particular, requires learning to innovate. Instead of conventional learning, GOLC emphasizes learning of environmental knowledge acquisition, dissemination, and utilization, which is needed for green technology and manufacturing. With its focus on adaptability and creativity in responding to environmental challenges, the well-cultivated learning culture grants organizations the agility to strategically adapt amidst sustainability-driven industries.

Hypothesis 4 shows that GOLC partially mediates the link between BDAC and GI, suggesting that robust learning mechanisms boost data analytics' impact on innovation. BDAC provides an opportunity identification technology framework, while GOLC ensures insights are digested, contextualized, and implemented efficiently across the firm. This mediating impact supports the DCV view that organizational learning is dynamic, helping organizations handle environmental complexity and innovate over time. This study shows how green learning links digital competences to sustainable performance (Ge & Zhao, 2022).

TQM also improves BDAC-GI correlation, supporting H-5. Quality management enhances green innovation promotion by analytics TQM increases data accuracy, develops continuous improvement, and integrates environmental objectives into everyday operations. Even advanced analytics might not produce much use case value if they are not implemented on such data platforms. This is critical for SMEs, which tend to have issues around data quality and digital sophistication. TQM and Big Data Analytics provide a formal platform for performing data-driven green activities. A holistic model provides a heuristic to conclude that it is not just digital tools that promote green innovation in SMEs but rather analytics, a learning culture, and quality management. In developing countries where the environmental regulations are becoming stringent like Pakistan, these results provide practical means of enhancing operational excellence and environmental stewardship in spite of budgetary constraints. This research demonstrates the role played by organizational learning and quality systems in this transition from data to innovation, thus increasing theoretical insight and practical application in sustainable business transformation.

5.1. Theoretical Implications

This paper contributes a number of theoretical innovations. First, it enhances the Dynamic Capability View (DCV) by illustrating how BDAC, GOLC and TQM facilitate GI in manufacturing SMEs. This suggests that dynamic competence is operationalized by the different organizational functions: BDAC senses opportunities in the environment, GOLC exploits opportunities and TQM transforms insights into sustained relationships. In this way, the triangle of capabilities provides insight into how businesses, particularly resource-constrained businesses, can build competencies around sustainability. The study makes a contribution to digital transformation as an enabler for circular economy and sustainable development in emerging markets. Second, it illustrates that by incorporating green absorptive capacity (GAC) and green transformational capacity (GTC), green organizational learning capability (GOLC) mediates BDAC and GI in a complex manner. This paradigm further develops organizational learning theory which hitherto neglected sustainability-oriented learning. In addition, this work empirically validates the role of GOLC in transforming data-driven insights into green solutions and advances scholars' understanding of how environmental learning cultures allow for strategic renewal and innovation. Thirdly, the contribution to quality management literature is about recognizing TQM as a BDAC-GI reinforcer. TQM has been extensively studied in operational settings, but its role in supporting sustainability-oriented innovation, especially with digital capabilities, has received little attention. This discovery shows that TQM may improve process efficiency and drive sustainable transformation, especially when data utilization requires consistent, high-quality execution. The study reorients green innovation discourse beyond external regulatory pressures and green technology availability. Internal organizational competencies like data analytics, environmental learning, and strict quality processes are key to sustainable innovation. This concept reframes green innovation as strategic capability development rather than compliance or technical execution, giving a more proactive and unified framework for future research and practice.

5.2. Practical Implications

This paper provides actionable recommendations for government and executives who are seeking to increase green innovation in Pakistan's manufacturing SME sector. First, managers should invest in BDAC that are key to sustainable innovation. This includes building digital infrastructure and employing or training data analytics and management professionals. Also important is an organizational culture based on data, where analytical findings feed into strategic and operational decisions. With a combination of technical and management know-how, SMEs could anticipate changes in the market and environmental issues. To maximize BDAC value, the organizational culture should be GOLC. By promoting knowledge transfer, environmental sensitivity, and adaptive learning, Pakistani SMEs can ensure long-term sustainability objectives while keeping short-term performance intact. GOLC helps organizations put data in context and create eco-friendly products and processes. Study indicates that total quality management (TQM) has a positive effect on BDAC's green innovation promotion. Thus, the managers should encourage quality-oriented practices such as continuous improvement, interdepartmental co-operation, and customer-oriented innovation. TQM combined with digital and learning methodologies produces a structured environment where sustainability efforts are begun, monitored, and developed to meet local and international requirements. Finally, tailored support initiatives from government agencies like SME Corp Pakistan can be altered. Financial incentives for technology adoption, subsidized data analytics and sustainability management training, and nationwide SME digital and green literacy initiatives are examples. Policies that promote quality frameworks will assist SME capacities in meeting national Industry 4.0 and green economy goals.

5.3. Limitations and Future Research

This study has some limitations that allow for additional investigation. The findings may be limited by the geographic scope, which is limited to Pakistani SMEs. Comparative studies of other South Asian or developing nations could illuminate regional green innovation patterns. Second, cross-sectional research designs make causal links difficult to establish; longitudinal studies are recommended to capture the changing relationships between big data analytics, organizational learning, and green innovation. Third, using self-reported survey results may add method bias or subjective distortions. Mixed-method research using interviews, case studies, or archive material could improve validity through methodological triangulation. Fourth, the study did not adjust for demographic or management criteria like education, tenure, or leadership experience that may affect organizational outcomes. Future research could use multi-group analysis to determine how individual-level factors mitigate the claimed correlations. Finally, green organizational learning culture (GOLC) needs theoretical elaboration as an emerging construct. To better understand its causes, future studies could use institutional theory or upper echelons theory to examine leadership styles, corporate culture, and institutional pressures.

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