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How digital capabilities and credit access influence green innovation performance in small and medium enterprises in resource constrained settings

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Abstract

This study investigates how small and medium-sized enterprises (SMEs) transform digital capabilities into green innovation within volatile, uncertain, complex, and ambiguous (VUCA) markets, and how access to credit shapes that process. Guided by the Technology–Organization–Environment framework, the Resource-Based View, and Dynamic Capabilities Theory, The study surveyed 428 Ugandan SMEs and analyzed the data using covariance-based structural equation modeling (SEM) and multi-group analysis for credit access using SPSS AMOS Version 26. Green Technical Know-How, Process Compatibility with Green Technologies, Green Digital Readiness, ICT Infrastructure, Green Digital Orientation, and Firm Size all enhance digital value realization capability (DVRC), which emerged as the sole direct driver of green innovation performance (GIP). Competitive Pressure was the strongest antecedent of DVRC, while Observability and Government Green Policy Support showed no significant effects. Credit access operates as a critical boundary condition. Without credit, readiness factors (process compatibility and digital readiness) substitute for liquidity and are the only technological paths that raise DVRC. With credit, specialized know-how, and competitive pressure become decisive, the ICT → DVRC effect strengthens, and DVRC's impact on GIP nearly doubles. Five indirect capability-to-performance paths via DVRC are significant only, or much larger, for credit-enabled firms. The findings position DVRC as the conversion engine that turns digital inputs into green outcomes, but show that its payoff is unlocked only once a minimum liquidity threshold is crossed. Policymakers should couple digital capability programs with inclusive green finance, while SME managers should emphasize readiness under constraint and invest in know-how when financing becomes available.

Keywords Digital value realization capability, Green innovation performance, Perceived value of sustainable investment, Sustainable investment decision, Small and medium-sized enterprises



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1 Introduction

Amid intensifying global pressure to decarbonize, firms now weave sustainability into core strategy. Industry 4.0 technologies such as IoT, big data, cloud computing, and blockchain are now linked with circular economy practices and long-term green investment behaviors, enabling firms to optimize resource use and minimize ecological footprints [1–3]. SMEs are increasingly integrating sustainability into core strategy, and behavioral frameworks for socially responsible investment help explain how managers evaluate green projects [4]. SMEs, though typically constrained by scale and capital, are beginning to leverage these digital tools to enhance operational transparency and product innovation [5, 6]. However, challenges such as the high cost of green inputs, infrastructure deficits, and risk aversion often hinder their capacity to translate digital adoption into tangible sustainability outcomes [7]. In developing economies, these barriers are compounded by weak policy incentives and limited institutional support, further complicating green transformation efforts among SMEs [8]. The current business environment is increasingly characterized by volatility, uncertainty, complexity, and ambiguity (VUCA) a term originally coined in military strategy and now used to describe dynamic, unpredictable conditions in business ecosystems [9]. For example, SMEs in Uganda often face abrupt policy shifts, fluctuating input prices, and rapidly evolving customer expectations, all of which exemplify VUCA contexts.

Emerging evidence suggests that internal digital capabilities can help SMEs overcome these barriers, with firm-specific knowledge and technological competencies serving as catalysts for sustainable innovation [10–13]. The Resource-Based View (RBV) emphasizes that such capabilities, when valuable, rare, and hard to imitate, can provide a sustained competitive edge. Moreover, digital readiness has been linked to improved access to green finance and more proactive adoption of eco-innovation practices [14, 15]. At the same time, strategic frameworks such as green supply chain management have shown promise in facilitating coordinated sustainability responses across SME networks [16, 17]. Yet, most of these insights are derived from studies in advanced economies or among large enterprises, where digital infrastructure, governance support, and financing are comparatively abundant.

This presents a critical gap: existing literature lacks integrated, theory-driven models explaining how SMEs in resource-constrained settings, especially in Africa, can convert digital capabilities into green innovation outcomes. Prior studies often examine isolated factors (e.g., digital orientation, green culture, or green credit) without capturing how these variables interact within dynamic environments [18–20]. Moreover, the majority of empirical work omits two crucial constructs: (i) Digital value realization capability (DVRC) a firm's ability to strategically deploy and align digital assets for sustainability and (ii) access to credit as a moderating factor that can activate or constrain green innovation. Even where studies address digital transformation or green innovation, few adopt a comprehensive theoretical lens combining the Technology–Organization–Environment (TOE) framework, RBV, and Dynamic Capabilities (DC) theory, despite their complementary value in explaining capability development and context sensitivity.

To address these gaps, this study proposes a holistic conceptual model linking digital capabilities and contextual enablers to Green Innovation Performance (GIP), with DVRC as the mediating mechanism and credit access as a moderator. DVRC captures a firm's dynamic capacity to reconfigure digital resources for value creation, a

key determinant in sustainability transitions. Drawing from TOE, we hypothesize that technological, organizational, and environmental factors shape DVRC, while RBV and DC theory explain how DVRC enables firms to align internal competencies with green innovation goals. We further argue that access to credit enhances these effects, enabling SMEs to invest in technology, training, and infrastructure necessary for eco-innovation [21–23]. This model is particularly relevant in developing contexts like Uganda, where SMEs constitute over 90% of private sector enterprises and contribute approximately 80% of manufactured output and 75% of employment [24]. Uganda has also developed forward-looking frameworks to accelerate digital transformation and innovation-led growth, notably the Fourth Industrial Revolution Strategy and the Digital Uganda Vision, which aim to position digital technologies as a core enabler of inclusive development and sustainability transitions [25, 26]. However, practical gaps in policy implementation, infrastructure, and access to financing continue to hinder green transformation among SMEs.

We empirically test this model using Structural Equation Modeling (SEM) on data from 428 SMEs in Uganda. The study is guided by three questions: (1) To what extent do internal digital capabilities enhance GIP among resource-constrained SMEs? (2) How does DVRC mediate the path between digital capabilities and GIP? (3) In what way does credit access moderate the indirect effects of digital capabilities on GIP via DVRC? Constructs include indicators such as green technical know-how, ICT infrastructure, digital readiness, and perceived process compatibility, alongside access to credit and observed green innovation outcomes (e.g., eco-product launches, environmental compliance).

This study makes several contributions. First, it offers a novel theoretical integration of TOE, RBV, and DC theories to explain how internal capabilities and external enablers interact to drive sustainable outcomes among SMEs. Second, it advances the literature by conceptualizing and empirically validating DVRC as a critical mediator linking digital resources to green innovation. Third, it identifies credit access as a boundary condition that determines whether internal competencies translate into performance gains. Fourth, it addresses a persistent geographical gap by focusing on SMEs in a developing African context an underexplored yet high-impact setting for sustainability transitions. Practically, the findings inform SME policy design, credit schemes, and digital capability-building efforts aimed at accelerating green transformation in emerging markets.

The remainder of the paper is organized as follows: Sect. 2 presents the theoretical background and hypotheses. Section 3 details the research design and methods. Section 4 reports empirical results, while Sect. 5 discusses implications. Section 6 concludes with theoretical contributions, practical insights, and directions for future research.

2 Literature review

2.1 Theoretical review

The convergence of digital transformation and environmental sustainability is reshaping SME competitiveness. This review draws on the TOE framework, the RBV, and DC theory to explain how digital capabilities influence GIP. These perspectives highlight how internal digital resources, mediated by DVRC and moderated by credit access, can be strategically deployed to drive sustainable innovation in SMEs.

2.1.1 Technology–organization–environment (TOE) framework

The TOE framework developed by Tornatzky and Fleischer [27] remains foundational in understanding technology adoption processes. It emphasizes that firms are influenced by three interrelated contexts: the technological environment (e.g., ICT infrastructure and digital maturity), the organizational context (e.g., managerial support and digital readiness), and the external environment (e.g., regulatory conditions and stakeholder pressures). Within this framework, the technological context facilitates digital transformation, while the organizational dimension encompasses internal enablers such as technical knowledge and strategic orientation [5, 28]. Empirical studies affirm that integrating a digital-green strategy attuned to market, policy, and operational contexts strengthens innovation outcomes [28]. Furthermore, internal capabilities such as green knowledge acquisition, when combined with external forces like competition or CSR expectations, drive eco-innovation [29–31]. Nonetheless, TOE is critiqued for overemphasizing initial adoption stages, with less focus on post-adoption value creation and sustained innovation an especially limiting gap for SMEs in resource-constrained contexts where digital tools must continually generate environmental and performance value.

2.1.2 Resource-based view (RBV)

The RBV provides a complementary lens by centering on firm-specific resources that are valuable, rare, inimitable, and non-substitutable as sources of competitive advantage [32, 33]. In the SME context, these resources may include technical know-how, green competencies, or proprietary digital systems [34]. RBV underscores that digital transformation can enhance environmental performance only when these resources are strategically configured. For example, firms with higher digital capabilities and an innovation-oriented mindset have been shown to engage in sustainable business model innovation, thereby strengthening corporate environmental responsibility [35]. However, RBV has been criticized for its static nature it explains what resources matter but not how firms adapt them in changing environments [36]. Recent evidence suggests that firms must continuously renew their capabilities to remain competitive, especially in eco-innovation domains [5, 37]. Thus, while RBV identifies internal assets as critical, it must be extended by dynamic frameworks to capture how resource deployment evolves in volatile or uncertain sustainability landscapes.

2.1.3 Dynamic capabilities theory

Dynamic Capabilities (DC) theory extends RBV by explaining how firms integrate, build, and reconfigure internal and external competencies in dynamic environments [34, 38]. DC theory highlights the importance of sensing opportunities, seizing them through innovation, and transforming routines to sustain performance [39, 40]. This is especially relevant for SMEs navigating the dual pressures of environmental responsibility and digital disruption. For instance, absorptive capacity, a key dynamic capability, mediates the relationship between digital transformation and green innovation in energy-sector SMEs, enabling firms to translate digital insights into action [37]. Further, studies show that digital transformation enhances green innovation performance through environmental resource integration [41]. Nevertheless, DC theory often overlooks financial realities, such as access to credit, which is crucial for resourcing innovative activities in

SMEs. Without adequate financing, SMEs may struggle to enact dynamic capabilities, limiting the realization of green innovation goals despite strategic intent and awareness [42, 43].

2.1.4 Toward an integrated framework

To make the distinct theoretical roles explicit, the study clarifies that, the TOE framework pinpoints where digital-green initiatives take root by mapping technological readiness, organizational support, and external pressures that spur adoption [27]; the RBV specifies what firm-specific assets matter such as valuable green know-how and data-driven routines that can yield a defensible advantage [32, 33]; and DC theory explains how those assets are continuously sensed, seized, and reconfigured to meet shifting sustainability demands [34, 39].

By synthesizing TOE, RBV, and DC perspectives, this study advances an integrated model where DVRC functions as the mediating conduit through which digital investments translate into Green Innovation Performance. DVRC captures a firm's capacity to reconfigure digital resources for strategic and environmental value creation, bridging gaps left by each individual theory. TOE emphasizes adoption conditions, RBV focuses on asset possession, and DC emphasizes renewal and deployment processes. DVRC ties these dimensions together by articulating how digital inputs are converted into innovation outcomes. Evidence supports this integration: DVRC mediates the link between digital transformation and sustainability success, especially in firms with strong innovation orientation [44]. Additionally, green product and process innovation contribute to competitive and environmental performance when underpinned by DVRC [45, 46]. As such, DVRC represents a vital mechanism that enables SMEs to transform digital and environmental investments into sustainable, scalable value, particularly when institutional and financial ecosystems offer adequate support.

2.2 Hypothesis building

2.2.1 Technological capabilities and DVRC

Grounded in the TOE framework and enriched by RBV and DC perspectives, technological capabilities are seen as essential enablers of DVRC. While the possession of digital tools is important, their strategic value emerges only when firms can convert them into meaningful outputs that improve GIP [10, 11, 47]. This conversion process is at the heart of DVRC, which enables the transformation of digital assets into sustainable business value [34, 35, 48]. Within this context, five key technological dimensions are emphasized: GTKH, PCGT, GDR, OB, and ICT Infrastructure [27, 49]. Digital orientation, digital maturity, and digital intensity have been shown to determine financial success in digital transformation settings [50]. GTKH refers to the firm's domain-specific know-how in designing and implementing digital-driven green solutions. Studies show that such expertise only delivers innovation outcomes when embedded in a capability like DVRC [5, 44, 51, 52]. Similarly, PCGT reflects how well digital technologies align with existing systems and routines. High compatibility reduces resistance and accelerates adoption, thereby reinforcing a firm's ability to reconfigure digital assets in support of sustainability [27, 53, 54].

GDR represents an organization's cultural and strategic preparedness to adopt eco-oriented digital technologies. Though critical, GDR alone cannot produce outcomes unless

it is operationalized through DVRC, which converts readiness into actionable innovation [6, 55]. Observability, meanwhile, denotes the extent to which the benefits of digital adoption are visible and measurable. Empirical evidence illustrates its practical force: Bhatia and Kumar report that Indian Tier-2 automotive suppliers publicly shared “green KPI” dashboards, and the resulting transparency fast-tracked budget approvals for additional eco-digital upgrades [13]. In Taiwan’s semiconductor SMEs, real-time shop-floor energy-saving displays triggered peer imitation across plants, strengthening learning loops that underpin DVRC [49]. When outcomes are clearly observable, they reinforce management commitment, encourage replication, and strengthen DVRC as a capability that supports learning and performance [27, 49].

ICT Infrastructure serves as the backbone of all digital transformation initiatives, enabling integration, automation, and collaboration [27, 56]. Studies confirm that robust ICT systems are vital, but their contribution to GIP materializes only when processed through DVRC, which acts as the conversion engine for digital investments [57, 58]. Collectively, these five dimensions define the core technological enablers of DVRC. TOE highlights that adoption alone is insufficient without internal capability, while RBV and DC theories stress the need to dynamically deploy valuable resources. Thus, firms that fail to realize the value embedded in their digital investments will struggle to achieve green innovation.

Accordingly, we propose the following hypotheses:

H1a: GTKH positively influences DVRC.

H1b: PCGT positively influences DVRC.

H1c: GDR positively influences DVRC.

H1d: OB positively influences DVRC.

H1e: ICT positively influences DVRC.

2.2.2 Environmental factors (GPS & CP) and DVRC

Drawing on the TOE framework, this analysis recognizes that environmental factors shape not only technology adoption but also interact with internal capabilities, as emphasized by the RBV and DC perspectives. Specifically, GPS and CP are posited as pivotal external drivers that enhance a firm’s DVRC by creating favorable conditions for leveraging and reconfiguring digital resources [59–63]. From an RBV standpoint, digital tools and infrastructure constitute valuable and potentially unique resources, but their strategic benefit depends on the firm’s ability to mobilize and integrate them effectively. GPS strengthens this capability by offering regulatory incentives, fiscal subsidies, and supportive public policies that reduce the risk and cost of digital investment. As highlighted by researchers [64, 65], such institutional support is especially critical for SMEs, enabling access to resources required for digital and green transformation. Moreover, alignment with government initiatives mitigates uncertainty, improving the likelihood of successful digital integration [54]. Accordingly, we hypothesize that strong GPS facilitates DVRC by allowing firms to convert external support into innovation-enhancing processes.

Complementing this, DC theory emphasizes a firm’s ability to sense, seize, and reconfigure resources in response to environmental changes [37, 66]. In this view, CP acts as a trigger for strategic renewal. In dynamic markets, firms face mounting demands to innovate and differentiate, prompting rapid adoption of digital technologies. One study

[67] demonstrates that intense competition increases digital investments, which in turn accelerate the development of DVRC. TOE theory reinforces this by positioning competitive forces as key environmental enablers that push firms to optimize internal resource deployment. CP thus drives the continual adaptation of digital assets, a core function of DVRC aligned with DC theory. From an integrated TOE–RBV–DC perspective, GPS acts as a resource enabler, and CP as a change accelerator both essential for converting digital investments into actionable value through DVRC.

Accordingly, we propose:

H2a: GPS positively influences DVRC

H2b: CP positively influences DVRC

2.2.3 Organizational factors (GDO & firm size) and DVRC

Drawing on the TOE framework and informed by RBV and DC theory, organizational-level enablers such as GDO and Firm Size are critical to shaping DVRC. GDO captures a firm's strategic intent to align digital technologies with sustainability objectives and is treated as an intangible strategic resource (RBV) whose effectiveness depends on the firm's ability to reconfigure routines (DC) via DVRC. Top leadership culture and a strategic sustainability orientation critically influence SMEs' ability to pursue green development [68]. Firms that embed environmental goals within their digital transformation agenda are better positioned to reconfigure and deploy digital assets in eco-innovative ways, enhancing their capacity to deliver environmental value [54, 56, 69–71]. Empirical studies confirm that GDO improves innovative outcomes and sustainability performance, especially when supported by a digital-savvy organizational culture [6]. Within this model the three theories play complementary but distinct roles: TOE flags GDO as an organizational-context condition that triggers change; RBV treats GDO as an intangible strategic resource that is valuable, rare, and hard to imitate; and DC theory explains how this orientation becomes actionable by reconfiguring routines through DVRC under dynamic conditions.

In Indian [69] show that apparel SMEs with pronounced GDO adopted closed-loop design platforms that cut textile waste by 18 percent. [70] report that Chinese textile firms leveraged a strong digital-green culture to re-platform legacy looms with IoT sensors, boosting energy efficiency by 12 percent, while [71] find that South-African manufacturers with high GDO used AI-driven demand forecasting to lower scrap rates and enhance green innovation performance. These cases underscore how GDO, when situated in supportive cultures, materially strengthens DVRC and downstream eco-innovation. In SMEs, where strategic focus and resource flexibility are vital, GDO plays a catalytic role in transforming technology into green outcomes through DVRC. Entrepreneurial leadership shapes SMEs' performance by strengthening internal organizational factors such as digital readiness and culture [72]

Firm size also significantly influences DVRC, as larger firms typically possess more extensive resources financial capital, infrastructure, and skilled personnel that facilitate advanced digital adoption and innovation [35, 45, 58, 64]. These attributes contribute to the strategic integration of digital systems and enhance the firm's capacity for green transformation. Moreover, larger SMEs often invest in internal knowledge systems and collaborative ecosystems that underpin capability development and reinforce DVRC [73, 74]. Nonetheless, smaller firms can leverage their agility, faster decision-making, and

adaptability to experiment with digital tools and reconfigure assets efficiently an essential feature of dynamic capabilities [67]. Thus, both large and small firms can enhance DVRC, albeit through different organizational pathways. Together, GDO and FS represent essential organizational dimensions that determine how effectively digital capabilities are translated into environmental innovation via DVRC.

Accordingly, we hypothesize:

H3a: GDO positively influences DVRC.

H3b: FS positively influences DVRC.

2.2.4 Digital value realization capability and green innovation performance

Digital value realization capability is conceptualized here as a firm's repeatable, system-level capacity to orchestrate heterogeneous digital assets, align those assets with strategic sustainability objectives, and translate the resulting data, process efficiencies, and stakeholder insights into verifiable environmental and financial value [44, 54, 70]. Anchored in the TOE framework and enriched by the RBV and DC theory, DVRC is positioned as a strategic mechanism through which firms convert digital investments into GIP. DVRC reflects a firm's ability to reconfigure, deploy, and align digital resources such as infrastructure, skills, and knowledge systems to achieve sustainability outcomes. From an RBV perspective, the strategic value of digital tools materializes only when internal capabilities operationalize them toward competitive and environmental goals [34, 41, 75]. DC theory further highlights DVRC as a dynamic capability that enables firms to sense, seize, and transform opportunities into eco-innovative results [11, 54, 76]. Within the TOE framework, DVRC bridges internal readiness with external sustainability demands by enabling firms to adapt digital technologies to meet green imperatives. Empirical studies show that firms with strong DVRC demonstrate higher levels of green innovation, resource efficiency, and environmental compliance [5, 44, 77]. Additionally, DVRC supports continuous learning, agility, and strategic reconfiguration, key to innovation in uncertain environments [78, 79]. This capability is particularly vital for SMEs, which must convert limited digital assets into meaningful environmental performance gains to stay competitive and compliant.

Thus, we hypothesize that:

H7: DVRC positively influences GIP.

2.2.5 Mediating role of DVRC between technological factors and green innovation performance

Digital transformation today demands more than the adoption of innovative technologies—it requires the dynamic capability to convert digital resources into sustained environmental value. Within the TOE framework and informed by RBV and DC theory, DVRC is conceptualized as a strategic mediator that enables firms to transform technological resources into GIP. Specifically, DVRC captures the capacity to absorb, reconfigure, and deploy digital enablers such as GTKH, PCGT, GDR, OB, and ICT infrastructure in ways that drive eco-innovation outcomes [5, 34, 44, 47].

Dynamic capabilities like DVRC are essential for adapting to fast-evolving market and technological environments. Without such capabilities, even advanced technologies may remain dormant or poorly utilized [34, 80]. Evidence suggests that DVRC acts

as a conversion engine, bridging the gap between digital readiness and environmental impact. For instance, firms with effective digital transformation mechanisms are more likely to achieve superior green outcomes when they possess a strong DVRC that facilitates the strategic deployment of technological inputs [5, 44]. Compatibility, in particular, enhances the mediating strength of DVRC by ensuring that new digital technologies integrate smoothly with existing workflows, thereby improving internal efficiency and enabling their use in sustainable initiatives [47, 54].

Furthermore, GDR alone cannot deliver environmental value without DVRC translating this readiness into action. As noted in recent studies, high digital preparedness only leads to innovation when operationalized through mechanisms like DVRC [6, 69, 81]. ICT infrastructure also underpins this process, offering the backbone for communication, collaboration, and data management. However, as shown by [37, 57], such infrastructure needs to be leveraged through DVRC to drive green transformation. Simply having access to digital tools is insufficient; the firm must possess the internal capability to exploit them strategically.

Finally, the TOE framework reinforces that internal resources interact with environmental pressures in shaping innovation trajectories. DVRC allows firms to align internal capabilities with external factors such as competition, policy shifts, and stakeholder expectations [47]. This integrative capacity makes DVRC not only a mediator but also a critical enabler of resilience and innovation under dynamic conditions.

Accordingly, we propose the following hypotheses:

H4a: GTKH positively influences GIP through DVRC.

H4b: PCGT positively influences GIP through DVRC.

H4c: GDR positively influences GIP through DVRC.

H4d: OB positively influences GIP through DVRC.

H4e: ICT positively influences GIP through DVRC.

2.2.6 Mediating role of digital value realization capability between environmental factors and green innovation performance

In the context of sustainable digital transformation, environmental factors such as CP and GPS are critical external enablers of GIP. Within the TOE framework [82], CP reflects external market forces that compel SMEs to innovate and digitize to maintain relevance [23, 83], while GPS encompasses regulatory incentives and institutional support aimed at facilitating green-oriented digital adoption [84, 85]. However, insights from the Resource-Based View (RBV) [32] and Dynamic Capabilities (DC) theory [34] caution that the presence of external enablers does not inherently lead to performance unless firms possess the capability to internalize and act on them. DVRC plays this mediating role by enabling firms to interpret environmental signals, reconfigure digital assets, and align their innovation systems with sustainability goals [22, 40].

Empirical studies confirm that CP and GPS only lead to improved GIP when operationalized through dynamic internal mechanisms. For instance, firms with high DVRC can translate CP into targeted eco-innovations and leverage GPS to build efficient, green digital processes [64, 86, 87]. DVRC also facilitates strategic responsiveness, allowing firms to sense market needs under CP and apply digital tools for sustainable differentiation [62, 88, 89]. Likewise, GPS may grant access to resources, but it is through DVRC that such inputs are transformed into tangible green innovations [67, 84]. DVRC thus

represents a critical pathway through which environmental pressures are converted into innovation outcomes.

Accordingly, we propose the following hypotheses:

H5a: GPS positively influences GIP through the mediating role of DVRC.

H5b: CP positively influences GIP through the mediating role of DVRC.

2.2.7 Mediating role of DVRC between green digital orientation and GIP

Green Digital Orientation reflects a firm's strategic intent to integrate digital transformation with environmental sustainability, fostering a culture that values both innovation and ecological responsibility. While GDO establishes the strategic foundation, its influence on GIP is contingent on the firm's ability to operationalize this orientation through DVRC. DVRC, as a dynamic capability, enables the absorption, reconfiguration, and deployment of digital resources toward eco-innovation outcomes. Studies show that firms with strong GDO are more inclined to invest in digital infrastructure and green competencies [11, 54], but the realization of these investments depends on their ability to extract and apply value through DVRC [35]. DVRC enhances strategic agility and fosters the internal transformation processes necessary for translating green digital intentions into measurable innovation results. Empirical evidence affirms that the interaction between digital and green strategies, when mediated by DVRC, contributes significantly to sustainability performance and competitive advantage [69, 76]. Thus, DVRC plays a pivotal role in bridging the gap between strategic digital orientation and green performance, ensuring that intent leads to impactful execution. Accordingly, we hypothesize:

H6a: GDO positively influences GIP through its positive impact on DVRC

2.2.8 Credit access as a moderator of capability–DVRC–GIP pathways

Access to credit plays a critical role in enabling SMEs to translate digital and green ambitions into actionable innovation outcomes. Financial capital is essential for procuring digital tools, strengthening ICT infrastructure, and investing in employee training, research and development, and strategic sustainability initiatives [86, 90, 91]. Grounded in the TOE framework, Resource-Based View (RBV), and Dynamic Capabilities (DC) theory, this study positions credit access as a vital environmental factor moderating the pathways between internal capabilities, DVRC, and GIP. Financial constraints are widely recognized as major barriers to green innovation [92, 93], while access to credit mitigates these limitations and empowers SMEs to invest in the resources needed to develop dynamic digital capabilities [86, 94].

Empirical studies confirm the moderating impact of credit access on the relationship between digital transformation and innovation. For instance, [94] demonstrated how restrictive green credit policies dampened innovation among polluting enterprises, while [86] showed that targeted green credit mechanisms promote sustainability performance through more efficient resource allocation. These findings underscore that credit access not only improves liquidity but enhances the firm's ability to reconfigure internal resources an essential tenet of RBV and DC theory. Furthermore, [95] found that firms committed to sustainability were more likely to secure financing, particularly when backed by strong governance structures, and [96] confirmed that access to green finance stimulates technological innovation, though regional disparities affect these outcomes.

Credit access also enhances the influence of external factors such as GPS and CP) on DVRC and GIP. As shown in [97], access to funding amplifies the effectiveness of government support and external partnerships in promoting digital transformation. Similarly, [98] found that credit access favored larger, diversified firms in Kazakhstan, though the benefits were less pronounced for smaller enterprises. These findings support earlier work by [35, 99, 100], which emphasized that innovation capabilities must be paired with sufficient financial resources to yield sustainability gains. In sum, access to credit strengthens the firm's capacity to deploy key technological and organizational capabilities such as GTKH, Perceived Compatibility with PCGT, GDR, OB, and ICT infrastructure through DVRC, leading to higher GIP. Credit also enhances the capacity to operationalize external support (GPS, CP) and strategic orientations (GDO). Firms with better financial access can more effectively convert digital investments into sustainability outcomes through robust DVRC. Thus, we hypothesize:

Specifically, we hypothesize that:

H8a: The positive relationship between GTKH and DVRC is stronger for firms with access to credit.

H8b: The positive effect of PCGT on DVRC is amplified by credit availability.

H8c: The influence of GDR on DVRC is enhanced in the presence of access to credit.

H8d: The positive relationship between OB and DVRC is stronger for firms with access to credit.

H8e: The impact of ICT on DVRC is more pronounced when firms have access to credit.

H8f: The positive influence of GPS on DVRC is amplified by access to credit.

H8g: The relationship between CP and DVRC is strengthened in firms with access to credit.

H8h: The influence of GDO on DVRC is stronger when firms have access to credit.

H8i: The positive effect of DVRC on GIP is more pronounced for firms with better access to credit.

2.2.9 Moderated mediation effects of credit access on capability–DVRC–GIP pathways

Access to credit has emerged as a crucial moderator in the indirect pathways linking internal digital and green capabilities to GIP through DVRC. Drawing on the TOE framework, alongside RBV and Dynamic Capabilities theory, credit access is conceptualized as an enabling external factor that empowers SMEs to convert technological and strategic inputs into sustainable innovation outcomes. In resource-limited contexts, such as emerging economies, firms often face legal, managerial, technical, and economic challenges to adopting green innovation practices [101]. Credit access alleviates these challenges by enabling investments in advanced digital tools, sustainability-focused R&D, and workforce capacity-building that drive both competitiveness and environmental performance.

Empirical research reinforces this moderating role. In China, for example, restrictive Green Credit Guidelines have been shown to constrain innovation among high-polluting enterprises [94], while favorable credit conditions significantly enhance sustainability outcomes by influencing both technological innovation and credit resource allocation [86]. When firms can access credit, they are better positioned to modernize systems, adopt eco-technologies, and unlock the mediating potential of DVRC. These financial enablers increase the likelihood that digital and green capabilities such as GTKH,

Perceived PCGT, and GDR translate into tangible innovation outcomes via DVRC [86, 94]. In South Africa, SMEs with environmental sustainability commitments were more likely to access finance directly or indirectly through improved financial performance, particularly when supported by good corporate governance [95]. Similarly, Chinese evidence highlights that green finance policies positively impact technological innovation and firm performance, with the extent of benefit depending on the region's digital maturity and policy environment [96].

Credit access also facilitates the transformation of internal strategic capabilities into innovation results. While digital-green strategic orientation, green knowledge acquisition, and organizational digital readiness are known predictors of GIP [102, 103], their effects are amplified when financial support enables the acquisition of ICT infrastructure, employee upskilling, and process digitization. Such support expands the firm's strategic resource base a core idea in RBV and enhances the firm's ability to dynamically reconfigure these resources per DC theory. For example, access to credit can improve digital process compatibility and readiness, reinforcing DVRC and thereby magnifying its mediating effect between internal capabilities and GIP [98, 100].

Moreover, external environmental factors such as GPS and CP interact synergistically with credit access to shape GIP outcomes. In Oman, firms responded more positively to policy incentives when backed by sufficient financial resources [64]. Under heightened CP, SMEs with financial access are more responsive and proactive in implementing digital solutions for environmental innovation [67]. Similarly, a strong GDO has been found to drive innovation only when supported by the financial means to execute transformation strategies [6]. Collectively, these insights affirm that credit access not only enhances internal resource deployment through DVRC but also strengthens the influence of environmental enablers on green innovation (Fig. 1).

Thus, we hypothesize that:

H9a: The indirect effect of GTKH on GIP via DVRC is stronger for firms with access to credit.

H9b: The indirect effect of PCGT on GIP via DVRC is amplified by credit availability.

H9c: The indirect effect of GDR on GIP via DVRC is enhanced in the presence of access to credit.

H9d: The indirect effect of OB on GIP via DVRC is stronger for firms with access to credit.

H9e: The indirect effect of ICT on GIP via DVRC is more pronounced when firms have access to credit.

H9f: The indirect effect of GPS on GIP via DVRC is amplified by access to credit.

H9g: The indirect effect of CP on GIP via DVRC is strengthened in firms with access to credit.

H9h: The indirect effect of GDO on GIP via DVRC is stronger when firms have access to credit.

Table 1 synthesizes eight influential studies on digitalization, green innovation, and SME performance. Collectively, they confirm that digital tools, strategic orientations, and green credit can spur sustainability, yet results diverge over when these levers work, varying with policy, competition, and firm size. No study operationalizes DVRC to explain how digital inputs become eco-outcomes, nor tests credit access as a moderating

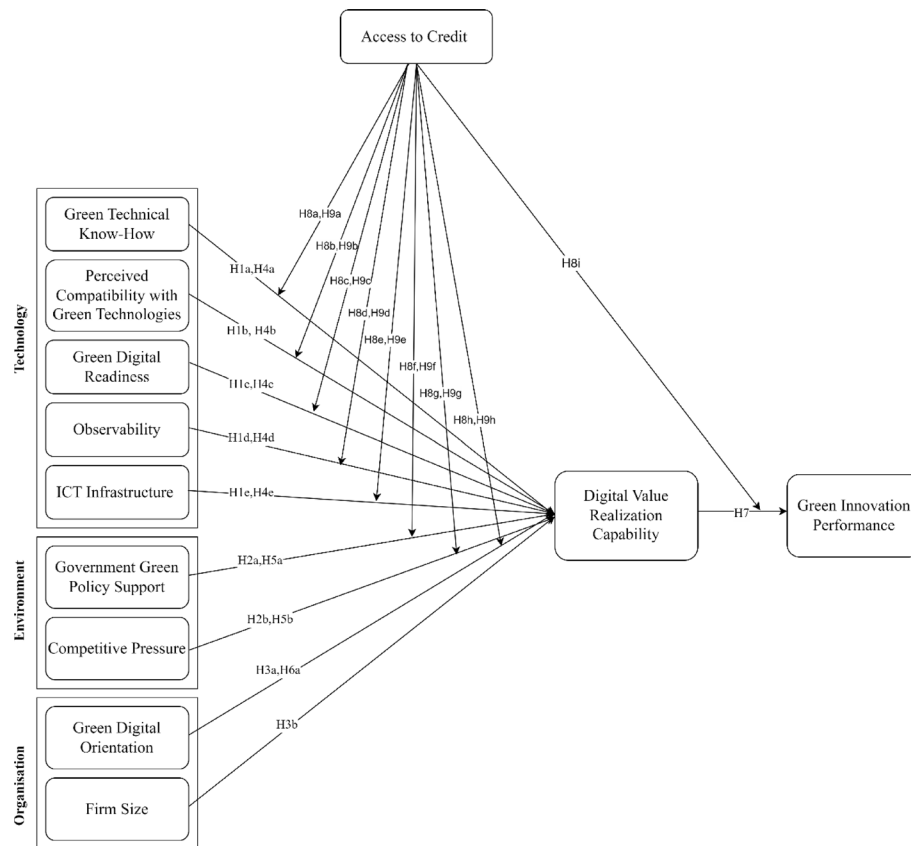


Fig. 1 Conceptual framework illustrating hypothesized relationships among capabilities, DVRC, and GIP, with Credit Access moderating direct and indirect paths. Hypotheses include direct (H1a–H3b), mediation (H4a–H6a), moderation (H8a–H8i), and moderated mediation effects (H9a–H9h)

boundary condition; external forces such as government support or rivalry are analyzed separately from internal capabilities. African evidence is scant despite SMEs facing VUCA conditions within an entrepreneurial landscape. These empirical, theoretical, and geographical gaps motivate our integrated TOE–RBV–TOE–RBV–Dynamic-Capabilities model, embedding DVRC and credit-moderated mediation in Ugandan SMEs.

3 Methodology

3.1 Research design and sampling

This study adopted an explanatory research design with a quantitative approach and a cross-sectional time frame to examine how internal digital capabilities influence GIP among SMEs in Uganda. The design was suitable for testing hypothesized direct, mediated, and moderated relationships within a structural equation modeling (SEM) framework [104, 105]. Given the lack of a centralized and comprehensive SME database in Uganda, the sampling frame was constructed by consolidating data from multiple reliable sources. These included the Uganda Business Portal SME Directory listing 501 enterprises (<https://mybusiness.go.ug/Reports/SMEDirectory>), the Uganda Investment Authority (UIA) SME registry, and the Uganda Revenue Authority (URA) list of the Top 1000 Compliant SMEs for 2018–2019 (Scribd, 2019). From this merged dataset, 701 SMEs located in Kampala and Wakiso districts were selected based on the availability of traceable physical addresses or active contact information.

Table 1 Key empirical studies on digital capabilities and green innovation: unresolved gaps driving the present study

Authors	Context and sample	Theory/framework	Variables and method	Principal findings	Unresolved gaps that this study tackles
Luo et al. [35]	China; 2,315 listed firms	RBV; Dynamic-Capabilities	Perf.-aspiration surplus & digital capability (mod.) → SBMI → CER <i>Panel SEM</i>	Digital capability channels surplus resources into sustainable-business-model innovation, which heightens corporate responsibility	Examines only internal slackx tech synergy. Ignores DVRC, financing conditions, policy, or competitive pressures, and is confined to large firms, thus providing little insight into resource-constrained SMEs facing external shocks
Alraja et al. [64]	Oman; 669 SMEs	TOE	Tech/Org/Env factors → green HRM-marketing-innovation → sustainable performance <i>PLS-SEM</i>	TOE dimensions raise performance indirectly through green practices; technological compatibility and leadership dominate	Strong on adoption drivers, yet no RBV/DC layer, no DVRC, no credit-access test. External pressures are analyzed in isolation, not in combination with internal digital competencies, leaving cross-domain capability interactions unexplored
Li et al. [44]	China, multi-sector firms	RBV; Green-Capability	Digital transformation → green capability & stakeholder engagement → sustainability <i>Survey SEM</i>	Digitalization improves sustainability only when green capability and stakeholder ties are robust	Offers internal mediation, but omits external stimuli (government support, competition) and financial constraints that shape SME digitization. DVRC remains un-modelled, so the value-realization logic is incomplete
Yin et al. [54]	China; 562 manufacturing SMEs	Digital-Green Strategy; BMI	Digital-green orientation → DG business-model innovation → GIP <i>Hierarchical regression</i>	Orientation facets enhance green-innovation performance through efficiency- and integration-type BMI pathways	Captures strategic intent but lacks DVRC, credit-access, or policy/competition moderators, giving no guidance on how SMEs convert intention into results under liquidity or regulatory pressure
Çelik et al. [37]	Türkiye & Iran; 296 energy SMEs	Dynamic-Capabilities	DC → absorptive capacity → green-innovation adoption <i>Survey SEM</i>	Absorptive capacity mediates the DC-GI link; magnitude differs by national context	Highlights learning capability but excludes digital-infrastructure variables, DVRC, and financing moderators; cannot explain adoption gaps in cash-strapped, policy-volatile settings
Wu et al. [40]	China; 312 medical-equipment suppliers	RBV	Digital transformation → environmental resource-integration capability → GIP; managerial concern (mod.) <i>Survey SEM</i>	Digital transformation increases GIP directly and via resource integration; managerial concern heightens both paths	Focus on integration capability; DVRC and credit access omitted. External forces are restricted to an internal mind-set variable, leaving government or market pressures untested
Zhang et al. [94]	China; heavy-polluting firms	Policy/finance	Green-credit policy → green innovation-year panel regression	Mandatory green credit significantly stimulates innovation in polluters	Establishes a finance-innovation tie but no digital capability chain, no DVRC, no SME lens, no interaction with competition or ICT readiness, lacks the capability-finance coupling your study provides
Ding et al. [86]	China; multi-sector panel	Policy/finance	Green-credit policy → tech innovation & credit re-allocation → sustainability performance <i>Panel SEM</i>	Policy steers credit to innovative firms, boosting sustainability through technology upgrade	Maps credit allocation mechanism, yet ignores internal digital capabilities (DVRC), external market pressure, and African SME realities; cannot show credit as a moderator of capability-performance links

Table 1 (continued)

Authors	Context and sample	Theory/framework	Variables and method	Principal findings	Unresolved gaps that this study tackles
Present study (Uganda SMEs, n = 428)	Uganda: 428 manufacturing & service SMEs	Integrated TOE–RBV–DC, with digital value realization capability (DVRC) & credit-access moderation	Digital, organizational & environmental capabilities → Green Innovation Performance (GIP); credit access as moderator; SEM + multi-group analysis	DVRC fully mediates capability → GIP links; competitive pressure is the strongest driver; credit access amplifies DVRC → GIP and all significant indirect paths	Fills four gaps simultaneously: (i) introduces DVRC as a distinct “value-conversion” construct; (ii) embeds credit access as a boundary condition; (iii) integrates TOE, RBV & DC in one empirical model; (iv) contributes rare sub-Saharan evidence on SME greening

To determine the minimum sample size, Krejcie and Morgan's (1970) sample size table was used, indicating that at least 384 SMEs were needed to achieve a 95% confidence level with a $\pm 5\%$ margin of error. To account for possible non-response, a 20% buffer was added, setting the final target at 460 SMEs. Initial outreach was conducted through phone calls and Google Maps to verify locations, successfully tracing 200 SMEs between September and December 2024. For each confirmed SME, snowball and purposive sampling methods were applied to recruit two neighboring SMEs within the same locality, ensuring contextual similarity. Data were collected through face-to-face interviews with SME owners or senior managers, yielding 428 complete and valid responses a response rate of 93%. This sample was deemed sufficient for SEM-based analysis and supports robust estimation of complex structural models.

3.2 Measurement instruments and operationalization of constructs

The survey instrument was developed using Google Forms and included the auto-translation feature, enabling real-time translation into Luganda and Arabic to improve comprehension among diverse respondents in Kampala and Wakiso. This ensured inclusiveness for SME owners and managers with limited English proficiency. Measurement items were adapted from validated scales to ensure construct reliability and contextual alignment [27, 51, 82]. Constructs were operationalized using multi-item Likert-type scales, with digital capabilities assessed through GTKH, PCGT, GDR, and ICT infrastructure. DVRC captured the ability to transform digital tools into operational or environmental value, while GIP reflected eco-product development and environmental compliance. Credit access was treated as a binary moderator. The tool was pre-tested for clarity, and adjustments were made to suit local SME contexts, resulting in strong internal consistency and validity.

3.3 Data analysis procedures and structural model testing

Data collected via Google Forms were exported to Excel for cleaning, including checks for missing values, outliers, and inconsistencies. Descriptive statistics were computed in SPSS v27 to profile SME characteristics. Structural Equation Modeling (SEM) using AMOS v27 followed a two-step approach. First, the measurement model was assessed using Confirmatory Factor Analysis (CFA), examining standardized loadings, Composite Reliability (CR), Average Variance Extracted (AVE), and Fornell–Larcker criterion to establish construct validity. Model fit was evaluated using CFI, TLI, and RMSEA. Collinearity diagnostics were conducted in SPSS using Variance Inflation Factor (VIF) and tolerance values, confirming that multicollinearity was not a concern ($VIF < 2.0$). The validated measurement model informed the structural model, which tested hypothesized paths from digital capabilities to DVRC and DVRC to GIP. Mediation and multi-group SEM were used to assess the moderating role of credit access. Bootstrapping (5,000 resamples) tested the significance of indirect and moderated mediation effects.

3.4 Ethical considerations and consent process

This study received ethical approval from the Mildmay Uganda Research Ethics Committee (MUREC), under reference number REC-REF 0708–2024. Participants provided informed digital consent via Google Forms after being briefed on the study's purpose, voluntary participation, and confidentiality. No personally identifiable information was

collected. Data was stored securely and accessed only by the research team. The survey ensured anonymity, and participants could withdraw at any time without consequences.

Figure 2 presents a visual summary of the research methodology employed in this study, detailing the sequential steps from theoretical grounding and sampling to data analysis using Structural Equation Modeling and moderation testing.

4 Results

4.1 Background characteristics of surveyed SMEs and business owners

Table 2 highlights the characteristics of the surveyed SMEs and their owners, offering a promising foundation for sustainable investment and innovation. A notable 42.3% of businesses are led by women, indicating increasing gender inclusivity in entrepreneurship. The dominance of trading (73.6%) and service sectors (23.6%) reflects strong market engagement and customer-focused operations with favorable conditions for adopting digital and green solutions. Nearly half of the respondents are managers or supervisors (48.6%), suggesting a broad base of decision-makers with operational insight. Most firms (59.8%) are 1–5 years old, demonstrating adaptability and growth potential. Furthermore, 45.1% have access to credit, highlighting ongoing progress in financial inclusion. With 72.4% being small-scale enterprises, agility is a key strength. The diversity captured in Table 1 provides a robust basis for understanding multiple pathways toward sustainable innovation across SME types.

4.2 Measurement model

4.2.1 Construct reliability and validity assessment using confirmatory factor analysis

To assess the reliability and validity of the study constructs, a confirmatory factor analysis (CFA) was performed following established guidelines [106]. As presented in Table 3, all standardized item loadings exceeded the 0.60 threshold, AVE values were above the recommended minimum of 0.50, and composite reliability (CR) values were greater than 0.70. These results provide strong evidence of convergent validity and internal consistency. For example, the digital value realization capability (DVRC) construct yielded an AVE of 0.573 and CR of 0.866, while Observability (OB) demonstrated even stronger metrics with an AVE of 0.747 and CR of 0.921. Internal consistency across constructs was further confirmed through Cronbach's alpha, all exceeding 0.70.

Discriminant validity was assessed using both the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio (HTMT). Table 4 shows that the square root of AVE for each construct was greater than its correlations with other constructs, confirming classical discriminant validity. To reinforce this, HTMT values were calculated and are reported in Table 5. All HTMT values were significantly below the conservative threshold of 0.85, with the highest being 0.154 (between DVRC and OB), indicating strong discriminant validity across the model. Together, these findings validate the distinctiveness of the constructs and support the robustness of the measurement model in capturing the intended latent concepts.

4.2.2 Diagnostic tests for multicollinearity, common method bias, and factor structure assessment

Because the model included many variables, we conducted a collinearity test to ensure that multicollinearity did not bias our results. As shown in Table 6, predictors such as

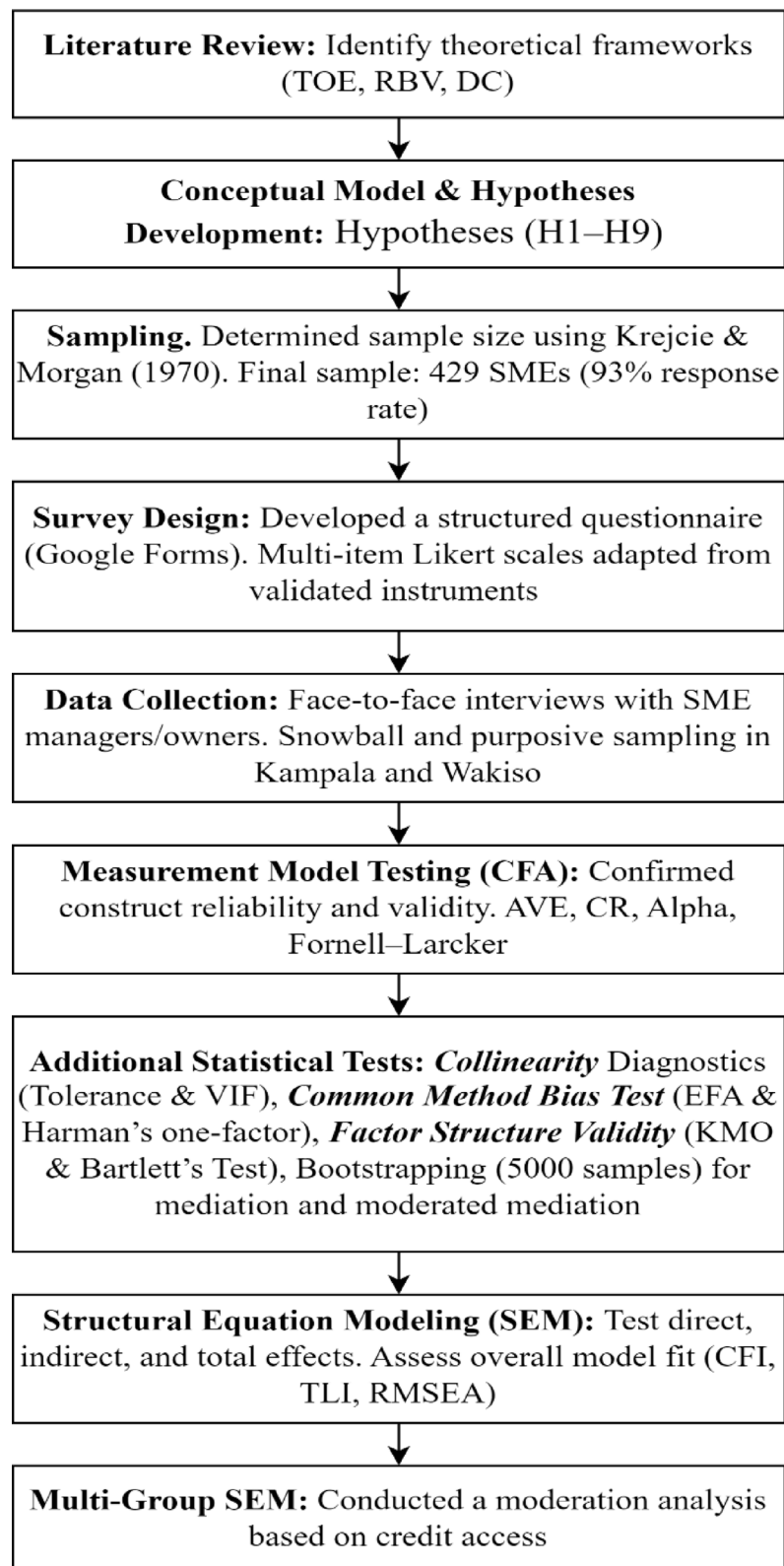
**Fig. 2** Research methodology flowchart

Table 2 Background characteristics of surveyed SMEs and business owners

Characteristic	Category	Frequency	Percent
Gender of the business owner	Female	181	42.3
	Male	247	57.7
Business sector	Manufacturing	42	9.81
	Service	71	16.59
	Trading	315	73.6
Role in business	Business owner	220	51.4
	Manager/supervisor	208	48.6
Age of firm	Less than 1 year	42	9.8
	1–3 years	142	33.2
	4–5 years	114	26.6
	More than 5 years	130	30.4
Access to credit	No	235	54.9
	Yes	193	45.1
Scale of business	Small (5–49 employees)	310	72.4
	Medium (50–99 employees)	118	27.5

GDR and ICT had tolerances above 0.60 and VIF values below 2.0, indicating minimal collinearity (103). We further performed an exploratory factor analysis (EFA) to assess the factor structure and mitigate common method bias. Table 7 demonstrates that the extracted factors explained sufficient variance. Lastly, Table 8 shows a Kaiser–Meyer–Olkin value of 0.874 and a significant Bartlett’s Test ($p < 0.001$), confirming data suitability for factor analysis.

4.3 Structural model analysis

4.3.1 Model fit evaluation and structural path analysis

Table 9 presents the model-fit indices, indicating an overall acceptable fit for the hypothesized structural model. The χ^2/df ratio is 3.329—slightly above the ideal ≤ 3 guideline yet still reasonable for models with high complexity and non-normal indicators [106]. The RMSEA of 0.074 (90% CI: 0.071–0.077) meets the < 0.08 benchmark, reflecting a satisfactory approximation error [106]. Although the incremental indices CFI (0.837), TLI (0.825) and NFI (0.873) fall a little short of the conventional 0.90 threshold, simulation evidence shows that for large, theory-driven SEMs containing many latent constructs (> 10) and observed variables (> 60), values above 0.80 can still denote acceptable fit when RMSEA and SRMR are within recommended bounds [106, 107]. To test robustness, we estimated a more parsimonious second-order model; CFI and TLI increased to 0.860 and 0.852, respectively, while all substantive paths remained significant, suggesting that the marginal shortfall primarily reflects model breadth rather than misspecification. Figure 3 displays the validated structural model, with standardized path coefficients linking key predictors (GTKH, PCGT, GDR, ICT, CP, GDO, GPS, OB, FS) to DVRC and, in turn, to GIP; all factor loadings are strong, supporting the hypothesized relationships.

4.3.2 Structural model: direct effects analysis

Table 10 presents the direct effects from the structural model, confirming several significant relationships among the study constructs. DVRC is significantly predicted by GTKH ($\beta = 0.116$, $p = 0.020$), GDO ($\beta = 0.122$, $p = 0.021$), PCGT ($\beta = 0.213$, $p < 0.001$), ICT ($\beta = 0.198$, $p < 0.001$), and GDR ($\beta = 0.099$, $p = 0.046$), providing support for H1a through H1e. These findings underscore the importance of technical expertise, digital

Table 3 Standardized loadings, convergent validity (AVE), composite reliability (CR), and internal consistency (Cronbach's α)

Construct	Item	Item narrative [27, 49, 51, 82]	Std. loading	AVE	Cronbach's α	CR
Digital value realization capability (DVRC)	DVRC1	We use digital tools to enhance service and outcomes	0.797	0.573	0.841	0.866
	DVRC2	Our digital tools align with performance goals	0.791			
	DVRC3	Digital adoption has improved our performance	0.608			
	DVRC4	We have skills to fully utilise digital systems	0.812			
Green digital readiness (GDR)	GDR1	We are ready to adopt green digital technologies	0.876	0.740	0.894	0.895
	GDR2	Systems support eco-friendly digital initiatives	0.869			
	GDR3	Staff are willing to adopt green digital tools	0.831			
ICT infrastructure (ICT)	ICT2	We have adequate hardware and software	0.902	0.631	0.834	0.913
	ICT3	Our ICT systems are well-integrated	0.662			
	ICT4	Reliable internet for digital operations	0.801			
Green technical know-how (GTKH)	GTKH1	Skills for green practices and technologies	0.826	0.660	0.880	0.885
	GTKH2	In-house green tech expertise	0.850			
	GTKH3	Staff can operate green technologies effectively	0.744			
	GTKH4	Staff are trained in eco-friendly processes	0.824			
Perceived compatibility with green tech (PCGT)	PCGT1	Green tech fits well with our operations	0.832	0.631	0.871	0.872
	PCGT2	Green tech needs minimal business changes	0.813			
	PCGT3	Green tech suits current tools	0.782			
	PCGT4	Green tech aligns with our values and goals	0.747			
Competitive pressure (CP)	CP1	Competitors' digital adoption pressures our firm	0.754	0.526	0.812	0.815
	CP2	We must digitize to stay competitive	0.795			
	CP3	Without digital tools, we risk market loss	0.690			
	CP4	Customers prefer digitally advanced businesses	0.655			
Green digital orientation (GDO)	GDO1	We commit to green digital technologies	0.709	0.556	0.786	0.789
	GDO2	We seek eco-friendly digital solutions	0.822			
	GDO3	Sustainability drives our digital strategy	0.699			
Observability (OB)	OB1	Benefits are visible in daily operations	0.920	0.747	0.901	0.921
	OB2	Benefits are measurable	0.910			
	OB3	Employees observe efficiency gains	0.930			
	OB4	Customers notice the eco-impact	0.670			
Green innovation performance (GIP)	GIP4	Green initiatives have led to cost savings & customer interest	0.822	0.641	0.880	0.877
	GIP3	Green innovations enhanced brand reputation & trust	0.821			
	GIP2	Implemented eco-efficient processes	0.803			
	GIP1	Products/services reduce environmental impact	0.752			
Firm size (FS)	FS1	Capital investment exceeds peers	0.753	0.602	0.816	0.820
	FS2	Revenue higher than similar firms	0.843			
	FS3	Employ more staff than peers	0.727			
Government green policy support (GPS)	GPS1	Policies support eco-friendly tech adoption	0.866	0.616	0.824	0.825
	GPS2	We benefit from green incentives	0.842			
	GPS3	Regulations guide green innovation adoption	0.615			

orientation, infrastructure, and perceived compatibility in enhancing firms' ability to realize value from digital initiatives. CP also has a strong positive influence on DVRC ($\beta = 0.333$, $p < 0.001$), supporting H2b, while FS exerts a moderate but significant effect ($\beta = 0.150$, $p = 0.004$), confirming H3b. However, GPS and OB do not significantly predict DVRC ($\beta = 0.019$, $p = 0.715$; $\beta = 0.078$, $p = 0.107$), thus rejecting H2a and H1d. Finally, DVRC significantly and positively predicts GIP ($\beta = 0.346$, $p < 0.001$), supporting H7 and

Table 4 Fornell–Larcker criterion for discriminant validity

Construct	GDR	OB	ICT	GTKH	PCGT	GPS	CP	DVRC	GIP	GDO	FS
GDR	0.859										
OB	0.156	0.865									
ICT	0.140	0.185	0.794								
GTKH	0.229	0.352	0.485	0.812							
PCGT	0.095	0.325	0.513	0.449	0.794						
GPS	0.346	0.112	−0.032	0.065	0.046	0.782					
CP	0.110	0.293	0.349	0.335	0.357	−0.036	0.726				
DVRC	0.244	0.284	0.414	0.381	0.420	0.107	0.414	0.757			
GIP	0.092	0.133	0.319	0.210	0.365	−0.025	0.418	0.303	0.801		
GDO	0.085	0.114	0.317	0.212	0.360	0.036	0.366	0.290	0.607	0.746	
FS	0.378	0.148	0.102	0.231	0.107	0.229	0.023	0.216	0.075	0.026	0.776

Table 5 HTMT matrix (Heterotrait–Monotrait ratios of correlations)

Construct	DVRC	GDR	ICT	GTKH	PCGT	CP	GDO	OB	GIP	FS	GPS
DVRC	1.000	0.107	0.107	0.080	0.068	0.087	0.087	0.154	0.067	0.082	0.115
GDR		1.000	0.099	0.051	0.065	0.135	0.115	0.093	0.059	0.087	0.095
ICT			1.000	0.093	0.090	0.107	0.104	0.130	0.088	0.098	0.123
GTKH				1.000	0.044	0.095	0.081	0.117	0.039	0.061	0.095
PCGT					1.000	0.078	0.071	0.126	0.035	0.053	0.100
CP						1.000	0.086	0.113	0.082	0.072	0.083
GDO							1.000	0.097	0.087	0.069	0.084
OB								1.000	0.097	0.075	0.089
GIP									1.000	0.065	0.090
FS										1.000	0.077
GPS											1.000

Table 6 Collinearity diagnostics for full model predicting GIP

Predictor	Tolerance	VIF
GDR	0.747	1.338
OB	0.794	1.259
ICT	0.605	1.653
GTKH	0.627	1.595
PCGT	0.599	1.669
GPS	0.847	1.181
CP	0.694	1.440
GDO	0.785	1.274
FS	0.806	1.241
DVRC	0.658	1.519

reinforcing its central mediating role in translating internal and contextual factors into enhanced green innovation performance.

4.3.3 Indirect effects of predictors on green innovation performance via digital value realization capability

Table 11 summarizes the indirect effects of various predictors on GIP through DVRC. Among organization and technological capabilities, PCGT exhibited a significant indirect effect on GIP (H4b: $\beta = 0.074$, $SE = 0.040$, $p = 0.047$), as did ICT Infrastructure (H4e: $\beta = 0.068$, $SE = 0.035$, $p = 0.043$), supporting both hypotheses. However, the indirect effects of GTKH, GDR, and OB were not significant (H4a: $\beta = 0.040$, $p = 0.120$; H4c:

Table 7 Exploratory factor analysis results for common method bias and factor structure

Factor	Initial Eigenvalues	Extraction sums of squared loadings
	Total	% of Variance
1	9.869	25.306
2	4.026	10.324
3	3.035	7.783
4	2.460	6.306
5	1.925	4.937
6	1.790	4.590
7	1.643	4.212
8	1.440	3.691
9	1.309	3.357
10	1.204	3.087
11	1.047	2.684

Table 8 KMO and Bartlett's test

Statistic	Value
Kaiser–Meyer–Olkin (KMO)	0.874
Bartlett's test of sphericity	
Approx. Chi-Square	10,684.238
df	741
Sig	0.000

Table 9 Model fit indices

Fit index	Observed value	Typical threshold
Chi-Square/df	3.329	≤ 3.0
RMSEA	0.074 (90% CI 0.071–0.077)	< 0.08
CFI	0.837	≥ 0.90
TLI (NNFI)	0.825	≥ 0.90
NFI	0.873	≥ 0.90
GFI	0.760	≥ 0.90
AGFI	0.730	≥ 0.90

$\beta = 0.034$, $p = 0.120$; H4d: $\beta = 0.027$, $p = 0.340$), suggesting that technical readiness alone may not translate into measurable green outcomes unless operationally aligned. For environmental variables, CP significantly influenced GIP through DVRC (H5b: $\beta = 0.115$, $SE = 0.050$, $p = 0.021$), while GPS showed no significant effect (H5a: $\beta = 0.006$, $p = 0.750$). Finally, GDO did not significantly affect GIP via DVRC (H6a: $\beta = 0.042$, $SE = 0.038$, $p = 0.270$). These findings reinforce DVRC's mediating role and highlight that only certain internal and external capabilities effectively convert into eco-innovation when channeled through value realization mechanisms.

4.3.4 Multi-group analysis: the moderating role of credit access on direct effects

To explore whether credit access moderates the relationship between digital capabilities, digital value realization capability, and green innovation performance, a multi-group SEM compared SMEs with and without credit (Table 12). Substantial differences emerged between these groups. For example, H8a was unsupported among credit-limited SMEs ($\beta = 0.056$, $p = 0.417$) yet strongly supported among those with credit ($\beta = 0.247$, $p < 0.001$), indicating that Green Technical Know-How drives DVRC more effectively when financing is available. Conversely, H8b and H8c PCGT, and GDR were

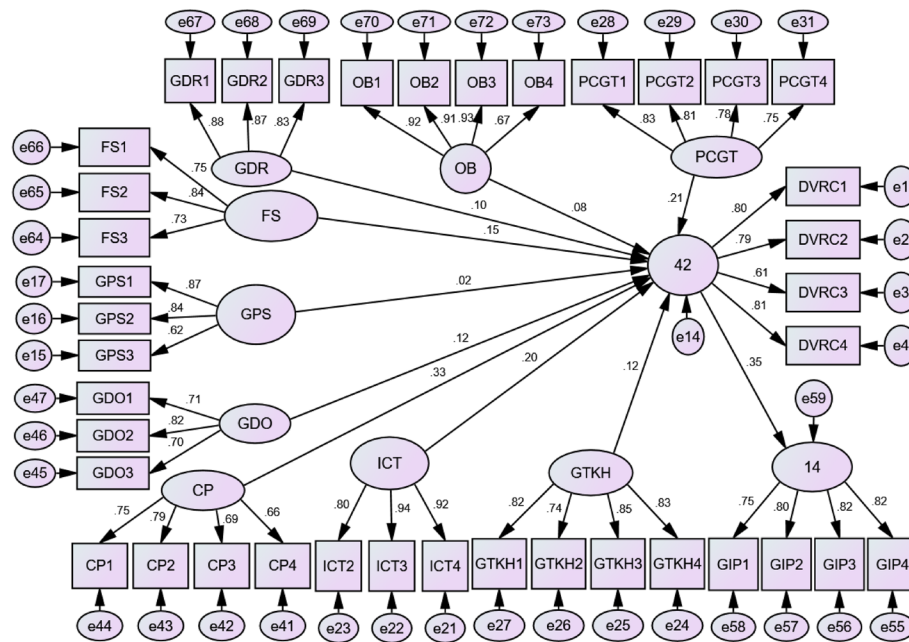


Fig. 3 Baseline model predicting DVRC and GIP. Baseline SEM model showing predictors of digital value realization capability (DVRC) and its effect on Green Innovation Performance (GIP). Constructs include GTKH, PCGT, GDR, OB, ICT, GPS, CP, GDO, and FS

Table 10 Direct effects

Hypothesis	Path	Std. β	SE	p-value	Supported?
H1a	GTKH → DVRC	0.116	0.073	0.020	Yes
H1b	PCGT → DVRC	0.213	0.089	<.001	Yes
H1c	GDR → DVRC	0.099	0.059	0.046	Yes
H1d	OB → DVRC	0.078	0.078	0.107	No
H1e	ICT → DVRC	0.198	0.079	<.001	Yes
H2a	GPS → DVRC	0.019	0.055	0.715	No
H2b	CP → DVRC	0.333	0.103	<.001	Yes
H3a	GDO → DVRC	0.122	0.094	0.021	Yes
H3b	FS → DVRC	0.150	0.060	0.004	Yes
H7	DVRC → GIP	0.346	0.081	<.001	Yes

Table 11 Indirect effects

Hypothesis	Indirect path	Std. Indirect	SE	p-value	Supported?
H4a	GTKH → DVRC → GIP	0.040	0.026	0.120	No
H4b	PCGT → DVRC → GIP	0.074	0.040	0.047	Yes
H4c	GDR → DVRC → GIP	0.034	0.022	0.120	No
H4d	OB → DVRC → GIP	0.027	0.028	0.340	No
H4e	ICT → DVRC → GIP	0.068	0.035	0.043	Yes
H5a	GPS → DVRC → GIP	0.006	0.019	0.750	No
H5b	CP → DVRC → GIP	0.115	0.050	0.021	Yes
H6a	GDO → DVRC → GIP	0.042	0.038	0.270	No

significant only for SMEs without credit, highlighting their reliance on internal readiness in the absence of external funds. Although ICT Infrastructure (H8e) was significant for both groups, it had a larger effect among credit-limited firms ($\beta=0.243$ vs. $\beta=0.143$), suggesting that ICT capabilities become even more crucial where loans are scarce.

Table 12 Multi-group analysis of direct paths to DVRC and GIP (moderation by access to credit)

Hypothesis	Path	Without credit			With credit		
		(Std. β)	<i>p</i> -value	Supported?	(Std. β)	<i>p</i> -value	Supported?
H8a	GTKH $\rightarrow$ DVRC	0.056	0.417	No	0.247	< 0.001	Yes
H8b	PCGT $\rightarrow$ DVRC	0.210	0.003	Yes	0.120	0.068	No
H8c	GDR $\rightarrow$ DVRC	0.150	0.030	Yes	0.063	0.329	No
H8d	OB $\rightarrow$ DVRC	0.127	0.058	No	0.021	0.741	No
H8e	ICT $\rightarrow$ DVRC	0.243	< 0.001	Yes	0.143	0.026	Yes
H8f	GPS $\rightarrow$ DVRC	-0.029	0.681	No	0.096	0.149	No
H8g	CP $\rightarrow$ DVRC	0.139	0.060	No	0.583	< 0.001	Yes
H8h	GDO $\rightarrow$ DVRC	0.015	0.839	No	0.186	0.006	Yes
H8i	DVRC $\rightarrow$ GIP	0.290	< 0.001	Yes	0.400	< 0.001	Yes

Table 13 Critical ratios for group differences across structural paths (moderation by credit access)

Structural path	CR (group difference)	Interpretation
GPS $\rightarrow$ DVRC	1.12	Not significant
ICT $\rightarrow$ DVRC	1.67	Not significant
GTKH $\rightarrow$ DVRC	2.42	Significant
PCGT $\rightarrow$ DVRC	-10.58	Significant
CP $\rightarrow$ DVRC	2.94	Significant
GDO $\rightarrow$ DVRC	1.68	Not significant
FS $\rightarrow$ DVRC	2.40	Significant
GDR $\rightarrow$ DVRC	-7.60	Significant
OB $\rightarrow$ DVRC	1.63	Not significant
DVRC $\rightarrow$ GIP	-6.81	Significant

From an organizational and environmental perspective, Competitive Pressure (H8g) and Green Digital Orientation (H8h) only predicted DVRC among credit-enabled SMEs, signifying that financial slack facilitates responsiveness to external pressures and strategic postures. Observability (H8d) and Government Policy Support (H8f) remained insignificant across both groups, indicating limited influence regardless of credit. Moreover, DVRC's direct impact on GIP (H8i) was stronger among SMEs with credit ($\beta = 0.400$ vs. 0.290), reinforcing the notion that available financing amplifies green outcomes.

Formal group-difference tests (Table 13) confirm that GTKH (CR = 2.42), PCGT (CR = -10.58), CP (CR = 2.94), GDR (CR = -7.60), Firm Size (CR = 2.40), and DVRC $\rightarrow$ GIP (CR = -6.81) are all moderated by credit access. Consequently, SMEs without credit rely more on internal readiness, whereas credit-enabled firms utilize specialized know-how and external demands to strengthen DVRC. Figures 4 and 5 further reveal that, under tighter constraints, PCGT and GDR prevail, while GTKH and Competitive Pressure assume greater importance when credit is available. That underscores credit's pivotal role in transforming digital capability deployment into tangible green innovation outcomes for SMEs, especially in highly resource-constrained settings.

Figure 6 synthesizes the multi-group SEM results in a single forest plot, displaying every direct-path coefficient ($\beta \pm 95\%$ CI) for firms without credit (left axis) and with credit (right axis). The chart shows which predictors retain influence across groups, e.g., ICT $\rightarrow$ DVRC, which switch on only under financial slack, e.g., GTKH $\rightarrow$ DVRC, CP $\rightarrow$ DVRC, and how the DVRC $\rightarrow$ GIP link itself strengthens once credit is available.

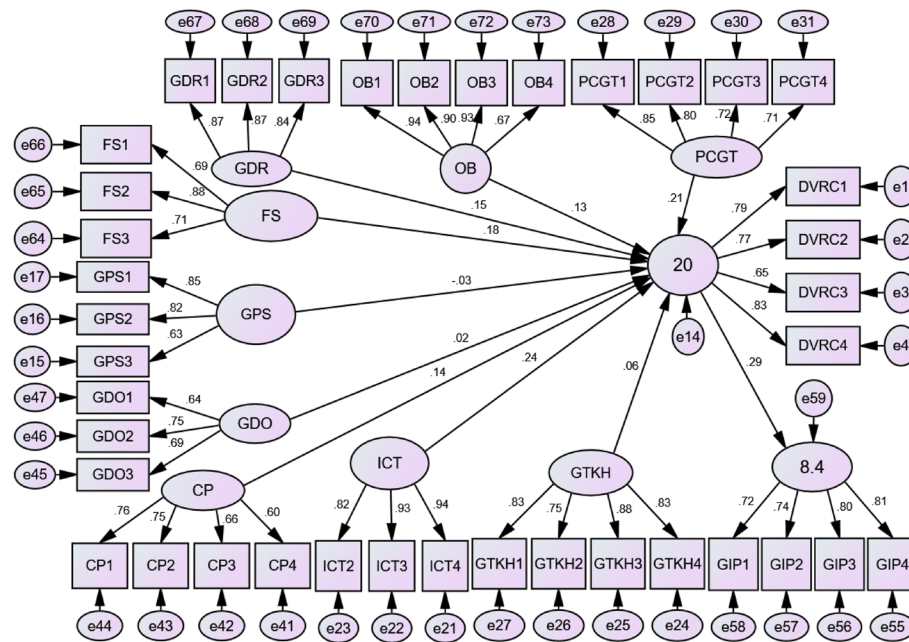


Fig. 4 Structural model—SMEs without credit. Standardized estimates for the DVRC and GIP model among firms lacking credit access

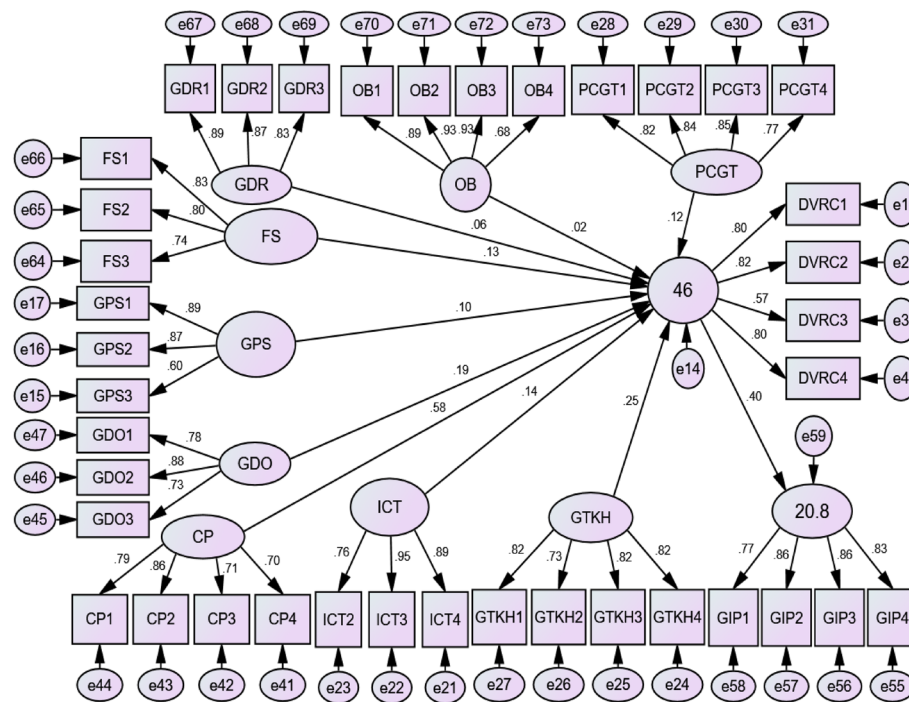


Fig. 5 Structural model—SMEs with credit. Standardized path estimates showing direct effects of internal and contextual factors on DVRC and subsequent impact on GIP among SMEs with access to credit

4.3.5 Multi-group indirect effects analysis: moderation by credit access

Table 14 presents the moderated mediation findings, revealing whether credit access conditions the indirect links between various predictors and green innovation performance through digital value realization capability. Compared to the baseline indirect

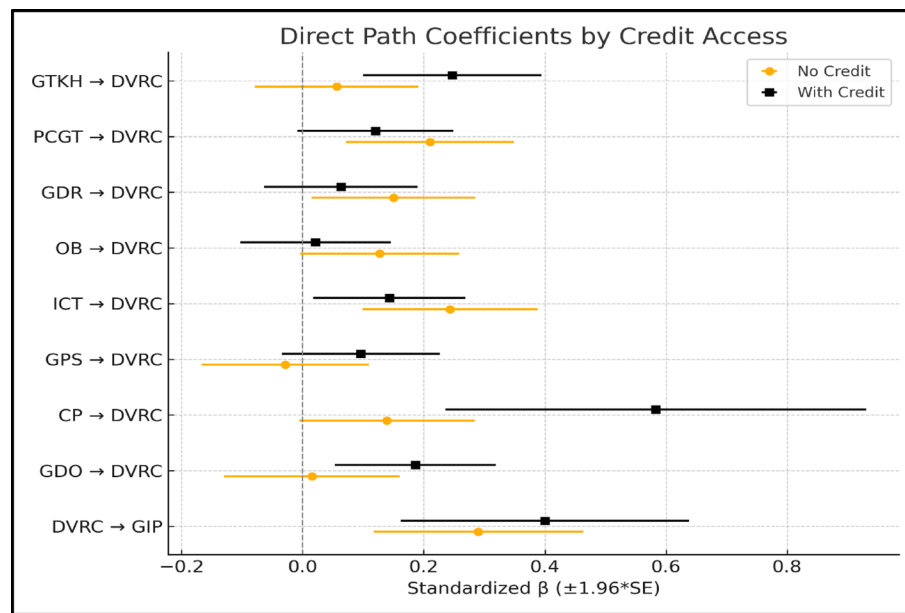


Fig. 6 Forest plot of standardized direct-effect coefficients ($\beta \pm 1.96$ SE) on DVRC and GIP, comparing SMEs without credit access versus SMEs with credit access

Table 14 Indirect effects (moderated by credit access)

	Indirect path	Without credit			With credit		
		(Std. β)	<i>p</i> -value	Supported?	(Std. β)	<i>p</i> -value	Supported?
H9a	GTKH → DVRC → GIP	0.040	0.120	No	0.108	< 0.001	Yes
H9b	PCGT → DVRC → GIP	0.074	0.060	No	0.058	0.037	Yes
H9c	GDR → DVRC → GIP	0.034	0.120	No	0.015	> 0.05	No
H9d	OB → DVRC → GIP	0.027	0.340	No	0.006	> 0.05	No
H9e	ICT → DVRC → GIP	0.068	0.053	No	0.073	0.030	Yes
H9f	GPS → DVRC → GIP	0.006	0.750	No	0.036	> 0.05	No
H9g	CP → DVRC → GIP	0.115	0.021	Yes	0.249	< 0.001	Yes
H9h	GDO → DVRC → GIP	0.042	0.270	No	0.097	0.010	Yes

results in Table 9 where only PCGT (H4b), ICT (H4e), and CP (H5b) displayed significant indirect paths several variables that were previously non-significant became influential for SMEs with credit. Specifically, Green Technical Know-How (GTKH; H4a baseline: $\beta = 0.040$, $p = 0.120$) emerged as significant in the credit group (H9a: $\beta = 0.108$, $p < 0.001$), confirming that specialized knowledge can effectively drive GIP through DVRC when external financing is available. ICT (H9e) also remained significant among credit-enabled firms ($\beta = 0.073$, $p = 0.030$), aligning with its baseline importance ($\beta = 0.068$, $p = 0.043$) but indicating that the overall effect is primarily driven by SMEs able to secure credit.

For PCGT, the baseline model showed a significant indirect pathway (H4b: $\beta = 0.074$, $p = 0.047$), yet multi-group analysis reveals that it holds only for SMEs with credit (H9b: $\beta = 0.058$, $p = 0.037$), thus underscoring that operational compatibility is especially impactful when financial constraints are eased. Meanwhile, CP maintained its significance across both groups but was substantially stronger with credit (H9g: $\beta = 0.249$, $p < 0.001$ vs. 0.115 , $p = 0.021$), reinforcing the idea that external competition drives eco-innovation more effectively under favorable financing conditions. GDO also shifted

from non-significant at baseline (H6a: $\beta = 0.042$, $p = 0.270$) to significant with credit (H9h: $\beta = 0.097$, $p = 0.010$), suggesting that strategic commitment to green digital initiatives becomes more potent when liquidity is secured.

In contrast, GDR (H9c), OB (H9d), and GPS (H9f) remained non-significant across subgroups, indicating their limited indirect impact on GIP regardless of credit status. Overall, five moderated mediation hypotheses (H9a, H9b, H9e, H9g, H9h) are supported, highlighting how credit access can “activate” or amplify certain capabilities thereby enabling more robust digital-driven green innovation outcomes.

5 Discussion of results and conclusions

This study aimed to explore how internal digital capabilities influence GIP among SMEs, focusing on three objectives: the direct effects of technological and organizational capability dimensions on DVRC, the mediating role of DVRC in translating these capabilities into GIP, and the moderating effect of credit access on both direct and indirect relationships. Grounded in the TOE framework and enriched by the Resource-Based View and Dynamic Capabilities theory, the findings emphasize the interaction between internal competence and contextual enablers in shaping green innovation outcomes among resource-constrained SMEs in developing economies.

Regarding technological factors, the analysis confirmed that GTKH, PCGT, and ICT Infrastructure significantly enhance DVRC. These findings validate the TOE framework’s assertion that technological readiness forms the base layer of digital transformation. The strong effect of GTKH on DVRC supports the assertion by scholars such as [5, 44] that specialized technical knowledge facilitates firms’ ability to operationalize green innovation. Similarly, [108] emphasize the synergistic impact of Industry 4.0 expertise and circular economy orientation on strategic investment outcomes. PCGT’s positive impact on DVRC echoes studies like [54], which highlight the importance of compatibility between digital innovations and legacy systems in lowering adoption resistance and facilitating seamless transformation. ICT Infrastructure, as a digital backbone, was also a robust predictor, supporting the view that data systems, connectivity, and automation capacity are essential to green process innovation [57].

On the organizational front, GDR emerged as a significant predictor of DVRC, reinforcing arguments from [6, 103] that internal readiness, digital culture, and leadership orientation critically shape eco-innovation. Conversely, OB an environmental factor was not a significant predictor of DVRC, a finding that contradicts the assertions by [27] but aligns with [22], who noted that in resource-constrained contexts, firms prioritize cost-efficiency and operational functionality over external demonstration or visibility effects. This suggests that while demonstration may be important in well-resourced environments, its influence is muted in SMEs facing capital and capability limitations.

The non-significant OB and GPS paths offer three complementary explanations. First, under severe liquidity constraints, Ugandan SMEs tend to privilege tangible performance cues such as competitive rivalry over legitimacy-seeking visibility benefits, mirroring evidence that cost pressures dampen the salience of symbolic environmental signals [62]. Second, our OB scale emphasized external visibility of digital gains; it may have overlooked peer-learning or informal demonstration effects prevalent in African SME clusters, indicating a measurement limitation that future work should address [49]. Third, post-survey debriefs revealed limited awareness of, and confidence in, existing

green-policy incentives an implementation gap also reported in recent sub-Saharan studies [55]. Collectively, these conceptual, measurement, and contextual factors may explain the null results.

Our second objective was to test the mediating role of DVRC. The analysis revealed that DVRC significantly and positively influences GIP, confirming its role as a transformative mechanism that links capabilities to performance. This supports RBV's emphasis on value creation through resource deployment [32, 33] and DC theory's assertion that dynamic capabilities such as DVRC enable firms to reconfigure assets in response to environmental demands [34]. Specifically, PCGT and ICT Infrastructure showed significant indirect effects on GIP through DVRC, suggesting that technological alignment and infrastructure form essential conduits for digital-to-green transformation. These results align with findings from [109, 110], who demonstrate that cross-functional integration and digital alignment are critical to achieving sustainability outcomes in dynamic environments.

Interestingly, while GTKH and GDR significantly predicted DVRC, they did not produce consistent indirect effects on GIP via DVRC. This implies that foundational knowledge and readiness, although necessary, may be insufficient to influence innovation unless complemented by system integration or external support. This reinforces the RBV–DC proposition that capability deployment not mere possession drives performance [34]. In short, digital skills and readiness must be embedded within operational systems and activated through financial or strategic stimuli to achieve eco-innovation outcomes.

The third research objective addressed the moderating role of credit access. Multi-group SEM results show that credit access significantly amplifies the effect of DVRC on GIP. This confirms [34]'s view that dynamic capabilities require resource slack for deployment. Credit access enables SMEs to invest in advanced technologies, employee training, and infrastructure factors that are essential for executing digital strategies.

The moderation results reveal key contrasts between credit-constrained and credit-enabled firms. For example, GTKH, which lacked significant indirect effects in the base model, becomes a strong predictor of GIP when credit is accessible, aligning with [108] who argue that technical knowledge requires capital for strategic realization. CP also exerts a stronger influence on DVRC and GIP under credit-enabled conditions, echoing [13], who found that firms with financial flexibility are more responsive to market dynamics and stakeholder pressures. PCGT and GDO also become more impactful under credit access, affirming [111]'s conclusion that innovation performance is shaped by both perceived customer value and access to liquidity for experimentation.

These patterns indicate that credit serves as a threshold enabler rather than a simple linear booster: once a minimal liquidity barrier is crossed, dormant technical know-how and competitive pressures are switched on, converting into green innovation gains. Recognizing this gatekeeping role suggests tiered green-financing schemes, small starter loans to unlock implementation capacity, followed by larger facilities tied to verified eco-outcomes, so that capability-rich but cash-poor SMEs can progress along an incremental sustainability ladder. Recent multi-country studies lend strong support to the finance capability complementarity identified in this study. External financing has been shown to significantly amplify the performance gains from digital transformation across 28 emerging-market economies [24]. Likewise, evidence from G7 countries indicates that

digitalization mitigates supply-chain disruptions and enhances renewable energy innovation [112].

Conversely, OB, GPS, and GDR remain non-significant regardless of credit status. This may be due to limitations in the design and delivery of policy support mechanisms, or SMEs' limited awareness and trust in such incentives a concern raised by [20]. The persistent insignificance of OB also aligns with [22], who found that in low-resource environments, symbolic signals or imitation incentives lack salience compared to cost-driven priorities. These findings collectively suggest that credit availability is most effective in amplifying capabilities that require significant resource commitments, such as technical infrastructure, system alignment, and strategic orientation.

In conclusion, this study offers a comprehensive model explaining how technological and organizational capabilities interact with contextual enablers like credit access to drive green innovation. The results highlight that while capabilities such as GTKH, PCGT, ICT, and GDR are important in building DVRC, it is through DVRC that these capabilities translate into GIP. Moreover, credit access significantly moderates both the DVRC–GIP link and several indirect pathways, confirming its role as a key environmental enabler in resource-constrained settings. The integration of TOE, RBV, and DC theory in this study reveals that internal capability alone does not suffice; it must be activated by appropriate financial and institutional support. For SME policymakers and practitioners, this underscores the importance of designing integrated digital adoption programs that are backed by accessible financing, capacity development, and incentive schemes. For SMEs, the findings reinforce the need to prioritize not only technological readiness but also strategic processes like DVRC that enable value realization. Ultimately, unlocking the potential of digital transformation for sustainable growth will require simultaneous investment in capabilities, systems, and credit-enabling mechanisms.

6 Implications, limitations, and future research

6.1 Practical implications

This study offers concrete guidance for SME managers striving to spur green innovation via digital transformation. First, SMEs should cultivate robust internal digital capabilities by investing in workforce training around energy-efficient technologies, sustainable production methods, and eco-friendly product development. For instance, a manufacturing SME might implement lean, green practices or employ digital monitoring tools that track energy usage and waste. Ensuring process compatibility is likewise critical introducing technologies that smoothly integrate with legacy systems helps avert operational upheavals. Modular, scalable ICT solutions (e.g., cloud infrastructure, smart sensors) enable incremental improvements without overhauling existing operations. Finally, instituting a culture of innovation through workshops, peer-learning groups, or hackathons ensures that teams adapt swiftly as market conditions shift, thereby reinforcing the firm's capacity to incorporate new eco-friendly technologies.

Our multi-group analysis underscores that the *same* capability has different strategic value depending on credit availability, and managers should respond accordingly. For credit-constrained SMEs, ICT infrastructure emerged as the primary technological driver of DVRC and, indirectly, of Green Innovation Performance; owners should therefore prioritize low-cost, cloud-based platforms and shared digital services that stretch limited capital. In contrast, when credit is available, Green Technical Know-How

becomes a high-impact lever; managers in this group can justify heavier investments in specialized training or the recruitment of sustainability engineers because financing costs are spread over larger innovation pay-offs. Competitive pressure is amplified under credit access; credit-enabled firms should channel market intelligence into rapid green product launches, whereas credit-limited peers may opt for incremental improvements that sidestep expensive capital outlays.

Notably, our findings underscore that access to credit markedly boosts the effectiveness of digital capabilities in driving measurable green outcomes. Managers should explore financing channels such as local banks, government-backed environmental funds, or programs funded by donor agencies. Collaborating with microfinance institutions, NGOs, or impact investors could unlock subsidized loans or grants aimed at sustainable investments. For example, a service-based SME might leverage credit to implement paperless systems or adopt energy-saving appliances, thereby curtailing operating costs while reducing environmental footprints. Merging robust internal readiness with available credit allows SMEs to expedite their transition to greener practices and positions them favorably in an increasingly eco-conscious marketplace.

6.2 Theoretical implications

This work advances theory by integrating and extending the TOE framework, the RBV, and DC theory to elucidate how SMEs transform digital investments into GIP. Central to this contribution is the conceptualization of DVRC as a bridging construct that translates digital inputs ranging from technical knowledge to organizational readiness into tangible eco-innovation outcomes. Traditional TOE research often foregrounds adoption drivers; by contrast, our findings spotlight post-adoption value capture, casting DVRC as a vital “translation mechanism” operating at both technological and organizational levels. Additionally, by identifying which digital capabilities (e.g., ICT infrastructure, process compatibility) are most fruitfully converted into GIP through DVRC, the study refines the RBV by revealing how specific, high-leverage resources must be embedded operationally to deliver strategic environmental advantages.

Our results also refine the foundational assumptions of RBV and DC theory for low-resource contexts. Classic RBV posits that ownership of valuable, rare, inimitable resources is sufficient for advantage; yet our multi-group tests show these assets remain latent until coupled with external liquidity, introducing a financing threshold for resource deployment. Likewise, DC theory’s sensing–seizing–transforming cycle presumes firms can mobilize slack once opportunities are sensed. We demonstrate that credit access is the catalyst that enables SMEs to fully seize and convert digital resources into green value, advancing the notion of finance-enabled dynamic capabilities. In short, DVRC only reaches its full potential when backed by adequate liquidity, situating RBV and DC within a more realistic, finance-contingent frame for emerging-economy SMEs.

Further, we extend DC theory by demonstrating that credit access functions as a key boundary condition shaping the deployment of internal capabilities. While standard DC scholarship highlights the significance of sensing, seizing, and reconfiguring resources, our moderated mediation results show that these processes depend crucially on external financial enablers. Under favorable credit conditions, DVRC and its antecedent capabilities exert a notably stronger strategic impact, suggesting that liquidity fuels more fluid resource orchestration. This challenges underlying premises in RBV and DC theories

that often presume unlimited or internally sufficient resources. Consequently, our findings emphasize resource–context fit as an essential yet underexamined moderator of capability formation and performance attainment, thereby contributing a more context-sensitive and action-oriented perspective on SME innovation in resource-limited settings.

Finally, our evidence implies that DVRC behaves as a latent dynamic capability whose productive value is unlocked only after a minimum threshold of financial slack is met. In RBV terms, the digital assets and routines embodied in DVRC remain quasi-resources valuable and rare yet not fully exploitable, until credit access supplies the complementary capital required for deployment. From a DC standpoint, the findings support a two-stage activation model: SMEs can sense and reconfigure digital options under tight constraints, but the seizing and transforming phases demand external finance to underwrite risk and adjustment costs. This nuance underscores the co-evolution of capabilities and financing structures in low-resource environments.

6.3 Policy implications

Nationally, our results underscore the importance of bolstering green innovation among SMEs by enhancing both financial inclusion and digital capacity. Given that credit access amplifies the advantages of internal digital capabilities, instruments like low-interest loans, subsidized credit schemes, and green financing funds can catalyze sustainable investments. In parallel, governments might foster public–private partnerships that bundle technical training, financial counseling, and mentorship, ensuring SMEs can seamlessly navigate digital and ecological transitions. Aligning regulatory frameworks with sustainability goals for instance, via targeted tax reliefs or expedited environmental approvals would further encourage SMEs to adopt eco-friendly processes and harness digital tools for efficient resource management.

For policymakers operating under tight fiscal and administrative constraints, several light-touch interventions require minimal institutional capacity. First, e-voucher schemes can subsidize cloud subscriptions or basic sensor kits, letting SMEs trial digital-green tools without upfront capital outlays. Second, the Ministry of ICT or trade can convene peer-to-peer learning circles short, mentor-led clinics in existing business hubs so early adopters of DVRC share quick-win playbooks with latecomers, reducing the need for extensive extension services. Third, public–private green-fintech sandboxes can enable banks to pilot micro-credit algorithms that reward documented eco-savings e.g., utility-bill reductions, lowering screening costs for lenders and easing collateral requirements for SMEs [86]. Finally, embedding simplified green-digital checklists into routine business-registration or tax-filing portals nudges firms toward capability self-assessments while leveraging platforms that governments already maintain, thus keeping administrative effort minimal.

Internationally, decision-makers and multilateral agencies can bolster these national efforts by creating cross-border financing mechanisms and harmonizing regulations to support greener SME ecosystems. Multilateral development banks could offer concessional loans or issue green bonds aimed specifically at resource-constrained enterprises, enabling broader adoption of eco-innovation initiatives. Worldwide public–private partnerships and best-practice exchanges can likewise heighten collective capabilities in digital and environmental innovation, thereby fostering global progress toward the

Sustainable Development Goals. By uniting localized financial solutions with international collaboration, policymakers and development actors can help SMEs capitalize on digital transformation as a pathway to sustainable, inclusive economic growth.

6.4 Limitations and future research

This study provides important insights but is subject to several limitations that offer avenues for future research. First, the cross-sectional design limits causal inference, restricting our ability to determine how digital capabilities and DVRC influence Green Innovation Performance over time. Future investigations should adopt longitudinal, or panel designs to trace capability development, credit uptake, and eco-innovation trajectories across multiple time points. Second, reliance on self-reported data may introduce common-method bias and social-desirability effects, despite the mitigation strategies we employed. Triangulating survey responses with objective evidence, such as third-party energy audits, emissions disclosures, or environmental certifications, could bolster measurement validity and reduce bias.

A further limitation stems from our pragmatic treatment of credit access as a binary yes/no variable. This coarse measure may obscure nuanced differences in loan size, interest rates, maturities, and funding sources that could condition the potency of DVRC. Future work should experiment with multi-dimensional credit-intensity indices or bank-verified credit records to capture firms' true financial slack. In addition, while overall model-fit indices were acceptable, several fell marginally below ideal thresholds, possibly reflecting the conceptual complexity of integrating multiple constructs within a single framework. Researchers might explore more parsimonious specifications or alternative measurement models to balance explanatory depth with parsimony.

Finally, generalizability is constrained by our focus on SMEs from two Ugandan districts. Comparative studies spanning multiple industries, e.g., manufacturing versus agribusiness and multiple sub-Saharan countries, would clarify contextual boundary conditions and enhance external validity. Moreover, the present model does not explicitly account for internal organizational drivers, such as green human-resource management practices, formal sustainability policies, or governance mechanisms, that could serve as critical antecedents to DVRC and green innovation. Future research should examine how HRM systems, e.g., green training, performance incentives and internal policy frameworks interact with digital capabilities to elevate sustainability outcomes.

Author contributions

DSB conceptualized the study, led the development of the research framework, coordinated data collection, conducted structural equation modeling, and drafted the original manuscript. EKT contributed to the theoretical refinement, literature synthesis, and interpretation of findings, and provided critical revisions to align the manuscript with current sustainability and innovation discourse. RB supported the research design, supervised data analysis, and contributed to manuscript structuring and methodological validation. All authors read and approved the final version of the manuscript.

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Data availability

The data that support the findings of this study are available from the corresponding author, Dedrix Stephenson Bindeeba, upon reasonable request.

Declarations

Conflict of interest

The authors declare that they have no conflict of interest.

Ethics approval

This study was approved by the Mildmay Uganda Research Ethics Committee (MUREC) under reference number REC-REF 0708-2024. The research was conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision).

Consent to participate

Informed consent to participate was obtained from all respondents prior to data collection. Only individuals aged 18 years and above were included in the study. Participants were informed about the study's purpose, assured of confidentiality, and made aware of their right to withdraw at any stage without any consequences.

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