Research Paper

Green Technology Adoption and Sustainability Initiatives of SMEs in South Africa: The Mediating Role of Knowledge Sharing with Regulatory Support as a Moderator

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Abstract

This study examines the impact of green technology adoption (GTA) on sustainability initiatives, focusing on energy management, water conservation, and waste management within small and medium-sized enterprises (SMEs) in South Africa. The study explores the mediating role of knowledge sharing in enhancing the adoption of green technologies and the moderating effect of regulatory support. A quantitative research design was employed, with a survey administered to 450 participants from SMEs across South Africa. Data were analyzed using SmartPLS, a structural equation modeling tool, to assess the relationships among GTA, sustainability practices, knowledge sharing, and regulatory support. The results indicate that knowledge sharing significantly mediates the relationship between GTA and sustainability initiatives, particularly in the areas of energy management, water conservation, and waste management. Additionally, regulatory support moderated the effect of knowledge sharing on green technology adoption, strengthening the adoption process and amplifying sustainability outcomes. These findings highlight the importance of fostering knowledge-sharing practices within SMEs and the critical role of supportive regulatory frameworks in promoting green technologies. This study contributes to the understanding of how SMEs in South Africa can leverage internal collaboration and external policies to enhance sustainability initiatives, offering valuable insights for policymakers, business leaders, and researchers focused on sustainable development in resource-constrained environments.

Keywords: *Green technology adoption, Sustainability initiatives, Knowledge sharing, Regulatory support, Resource-Based View, Small business*

INTRODUCTION

The adoption of green technology in business practices has become increasingly vital for promoting sustainable development and environmental conservation, particularly within small and medium-sized enterprises (SMEs) (Alraja et al., 2022, Shahzad et al., 2022). Rising environmental concerns and regulatory pressures globally have necessitated a shift toward sustainability initiatives, such as energy management, water conservation, and waste management (Koop & van Leeuwen, 2017). In South Africa, where issues like water scarcity and energy inefficiencies are pressing, SMEs face unique challenges and opportunities to embrace green technologies (Falcone, 2023). Given their significant contribution to employment and economic growth, SMEs are pivotal to achieving sustainable development in the country. However, their ability to implement sustainable practices is often constrained by limited resources, regulatory complexities, and operational inefficiencies.

Green technology adoption refers to the use of environmentally friendly technologies aimed at reducing harmful emissions, enhancing resource efficiency, and minimizing waste (Nehra et al., 2023). For SMEs, such technologies offer opportunities to improve operational efficiencies in energy management, water conservation, and waste management, thereby aligning with their sustainable development objectives (Omowole et al., 2024). In the South African context, green technology adoption in energy management is particularly relevant because of persistent energy challenges. By optimizing energy usage, reducing costs, and lowering carbon emissions, SMEs can

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address both economic and environmental priorities (Du Plooy, 2017, Gennitsaris et al., 2023). Similarly, green technologies for water conservation and waste management allow SMEs to reduce resource consumption and environmental impact, aligning with regulatory requirements and market demand for sustainable practices (Omowole et al., 2024).

Knowledge sharing is a critical mediator in the relationship between green technology adoption and sustainability initiatives. It enhances the capacity of SMEs to understand, implement, and leverage green technologies effectively, thereby improving sustainability outcomes (Arsawan et al., 2022). Through knowledge sharing, employees and managers can exchange information, share best practices, and collaborate on innovative solutions, fostering an organizational culture that prioritizes sustainability (Arsawan et al., 2022, Lin et al., 2024). Research indicates that knowledge sharing creates a learning environment that encourages the adoption of sustainable practices and helps overcome the technical challenges associated with green technology implementation (Abbas & Sağsan, 2019, Cormican et al., 2021). This collective knowledge enables SMEs to embed sustainability in their operations, ensuring that energy efficiency, water conservation and waste reduction strategies are effectively executed. Regulatory support is a significant moderator in the adoption of green technologies and the advancement of sustainability practices in SMEs (Jun et al., 2021). South African regulatory bodies increasingly promote environmental sustainability by offering incentives, subsidies, and guidelines to businesses that adopt green practices. Such support is crucial for SMEs, which often lack the financial and technical resources required to independently adopt green technologies.

Studies suggest that regulatory support not only alleviates cost barriers but also encourages SMEs to align their practices with national and international environmental standards, enhancing their competitiveness (Chen et al., 2017, Boakye et al., 2020). Furthermore, regulatory frameworks help mitigate risks associated with green technology investments, enabling SMEs to focus on long-term sustainability initiatives without jeopardizing their financial stability (Pu et al., 2021). Although prior studies have explored green technology adoption in SMEs (Hossain et al., 2022) limited research has examined the mediating role of knowledge sharing and the moderating effect of regulatory support within the South African SME context. Additionally, existing literature often lacks empirical evidence on how SMEs in South Africa integrate green technologies across multiple sustainability dimensions, such as energy, water, and waste management, within the constraints of their operational environments. This study aims to bridge this gap by providing a comprehensive analysis of these factors. South African SMEs operate in a dynamic and often challenging business environment characterized by resource constraints, regulatory complexities, and socioeconomic inequalities (Omowole et al., 2024). Despite the increasing emphasis on sustainability, prior studies have not sufficiently examined how SMEs integrate green technology into broader sustainability initiatives, particularly in ways that align with business growth and long-term resilience. Furthermore, while knowledge sharing has been identified as a crucial enabler of technological innovation (Diansari et al., 2021), its role as a mediating factor in the adoption of green technology and sustainability integration remains underexplored. Additionally, the influence of regulatory support as a moderate factor is not well understood, especially in emerging economies where policy enforcement and business incentives vary significantly (Iheanachor & Etim, 2022).

SMEs are fundamental to South Africa's economy, contributing significantly to employment and gross domestic product (GDP). According to the International Finance Corporation (IFC) (2019), SMEs employ between 50% and 60% of South Africa's workforce and generate approximately 34% of the nation's GDP. The adoption of green technologies is critical for enhancing sustainability and addressing pressing environmental challenges such as energy inefficiencies and water scarcity. However, SMEs face substantial barriers to implementing sustainable practices, including limited financial resources, lack of access to technical knowledge, and the high initial costs associated with green technology adoption. These challenges are further exacerbated by the need for significant upfront capital investment, which many SMEs struggle to secure. In response, regulatory support plays a crucial role in promoting the transition toward sustainability. Notably, the European Union has committed $35 million in grants to support South Africa's green hydrogen projects, aiming to strengthen the country's green hydrogen value chain and infrastructure. Such initiatives highlight the necessity of collaborative efforts between governments, regulatory bodies, and international institutions to facilitate the adoption of green technologies and drive sustainable development within the SME sector.

This study explores the impact of green technology adoption on the sustainability initiatives of South African SMEs, with a particular focus on energy management, water conservation, and waste management. By examining knowledge sharing as a mediating factor, this research aims to reveal how SMEs can optimize the use of green technologies to enhance their sustainability efforts. Additionally, this study investigates the moderating effect of regulatory support by evaluating the influence of government incentives and policies on SMEs' ability to adopt green technologies and achieve sustainability outcomes. By addressing these dynamics, this research contributes to the growing body of literature on sustainability in SMEs. The study highlights how the interplay of green technology adoption, knowledge sharing and regulatory support can transform sustainability practices within the South African SME sector. This study moves beyond traditional green technology adoption models by integrating a knowledge-based perspective through knowledge sharing as a mediator and an institutional perspective through regulatory support as a moderator. This dual approach provides a more comprehensive understanding of the mechanisms that drive effective sustainability adoption in resource-constrained SME environments. The findings will not only advance theoretical discussions on green technology and sustainability integration but also offer practical guidance for policymakers and SME leaders seeking to enhance sustainability efforts through informed knowledge-sharing practices and well-structured regulatory support.

LITERATURE REVIEW

Theoretical framework

One theoretical paradigm that emphasizes the value of internal resources and capabilities in achieving long-term competitive advantages is the Resource-Based View (RBV). According to Bhandari et al. (2020), firms possessing resources that are valuable, rare, inimitable, and non-substitutable are better equipped to execute effective strategies and tackle environmental challenges. This viewpoint is especially pertinent to the current study, which examines how the use of green technology affects sustainability initiatives, particularly waste management, water conservation, and energy management in South African SMEs. By using the RBV, this study analyzes how internal resources, such as the integration of green technologies, can enhance sustainability outcomes for SMEs. In this context, the adoption of green technologies is seen as a strategic resource that not only improves operational efficiencies and promotes a culture of sustainability (El-Kassar & Singh, 2019).

The implementation of energy-efficient systems, water-saving technologies, and waste reduction practices provides long-term benefits, enabling SMEs to operate more sustainably and reduce costs. The RBV posits that these technologies represent unique organizational assets that contribute to a firm's competitive advantage (Rao & Brown, 2024). Additionally, the mediating role of knowledge sharing among employees is crucial because it fosters a deeper understanding and effective application of green technologies, thus optimizing sustainability initiatives (Riaz et al., 2024). Moreover, regulatory support acts as an external facilitator that enhances resource utilization, encouraging SMEs to adopt green technologies through incentives and guidelines that align with sustainability objectives. This interplay between regulatory support and resource optimization is consistent with the RBV, indicating that external factors can amplify the value of internal resources (Tseng et al., 2019). Previous studies have shown that SMEs that align their green technology adoption with regulatory frameworks achieve better sustainability outcomes, effectively navigating compliance requirements (Ogunyemi & Ishola, 2024, Toromade & Chiekezie, 2024).

Empirical Literature

The Relationship Between Green Technology Adoption and Sustainability Initiatives

Green technology adoption plays a critical role in advancing sustainability initiatives in energy management, water conservation, and waste management, particularly for SMEs (Bakar et al., 2020, Tereshchenko et al., 2023). In energy management, technologies such as solar panels, energy-efficient lighting, and smart energy systems enable SMEs to reduce their reliance on fossil fuels and greenhouse gas emissions, aligning with South Africa's pressing need for energy efficiency amid rising energy costs (Alshahrani et al., 2024, Ibekwe et al., 2024). These innovations not only result in significant cost savings but also enhance customer loyalty by lowering carbon footprints and positioning SMEs as sustainability leaders (Toromade & Chiekezie, 2024). Similarly, green water conservation technologies, including rainwater harvesting, efficient irrigation systems, and water recycling solutions, empower SMEs in water-scarce regions to reduce consumption and operational costs. Such technologies ensure business continuity during water shortages and bolster compliance with regulatory requirements, while also improving brand reputation and customer loyalty (Abdelfattah & El-Shamy, 2024, Rastogi et al., 2024).

Waste management is another area in which green technology adoption fosters sustainability (Mondal et al., 2023). Advanced waste reduction, recycling, and disposal technologies, such as biodegradable materials and waste-sorting systems, help SMEs minimize their environmental impact while adhering to regulatory standards (Kurniawan et al., 2021, Umesh et al., 2024). These practices reduce disposal costs, enhance compliance, and appeal to environmentally conscious consumers, providing SMEs with a green competitive advantage (Yacob et a., 2019, Omowole et al., 2024). By integrating green technologies across energy, water, and waste domains, SMEs can simultaneously achieve operational efficiency, economic savings, and environmental sustainability. This multifaceted approach positions SMEs as key contributors to national and global sustainability goals, ensuring long-term competitiveness and resilience (Alshahrani et al., 2024, Omowole et al., 2024). Therefore, the following hypothesizes are developed:

H1: A significant positive relationship between green technology adoption and energy management.
H2: There is a significant positive relationship between green technology adoption and water conservation.
H3: There is a significant positive relationship between green technology adoption and waste management

Relationship Between Green Technology Adoption and Knowledge Sharing

By integrating environmentally friendly technologies, SMEs not only boost operational efficiency but also reduce ecological impact (Chege & Wang, 2020). Knowledge sharing, characterized by the exchange of information, skills, and experiences, becomes an essential part of this process because employees and stakeholders feel empowered to contribute insights that drive environmental performance (Shahzad et al., 2020). The adoption of green technology often requires specialized skills, fostering cross-departmental collaboration and a shared understanding of sustainable practices throughout the organization, which is crucial for meeting long-term environmental goals (Fernando & Wah, 2017, Ispiryan et al., 2024). Knowledge sharing also helps SMEs overcome resource limitations associated with green technology by pooling insights to maximize usage and minimize costs (Coppino, 2024). Furthermore, studies have shown that knowledge sharing helps SMEs effectively adapt to regulatory requirements and sustainability standards, enhancing their reputation for environmental responsibility and attracting eco-conscious consumers (Dima, 2022, Kusumaryoko, 2024). When SMEs engage in industry networks, they benefit from inter-firm knowledge sharing that boosts innovation and fosters a collaborative approach to sustainability, thereby transforming resource constraints into sustainable competitive advantages (Vătămănescu et al., 2022, Faisol & Aliami, 2023). Hence, the following hypothesis is proposed:

H4: There is a significant positive relationship between green technology adoption and knowledge sharing.

Mediating Role of Knowledge Sharing on Green Technology Adoption and Energy Management

In order for employees to effectively adopt and use green technologies to achieve energy efficiency, it is essential that they have a thorough awareness of sustainable practices (Ahmad, 2015). This is particularly critical for the integration of advanced technologies, such as smart lighting systems and renewable energy solutions, which require coordinated efforts for seamless implementation and maintenance. SMEs that foster robust knowledge-sharing practices are better positioned to integrate and maintain energy-efficient systems, thereby reducing operational disruptions and securing long-term benefits (Coppino, 2024). The significance of knowledge sharing is further amplified in resource-constrained environments, where it helps SMEs overcome budgetary limitations by leveraging collective insights to maximize the impact of their green technology investments (Ming, 2024). This approach aligns with the Resource-Based View (RBV), which highlights the strategic importance of internal resources, like knowledge-sharing practices, in providing a sustainable competitive advantage (Barney, 1991).

Beyond internal collaboration, inter-firm knowledge sharing within industry networks enables SMEs to exchange expertise, address shared challenges, and adopt best practices, thereby enhancing energy efficiency and reducing costs (Vătămănescu al., 2020). Moreover, a culture of knowledge sharing enhances organizational adaptability, equipping SMEs to respond effectively to evolving regulatory standards in energy management. This adaptability not only ensures compliance but also enhances the organization's reputation among environmentally conscious stakeholders (Coppino, 2024, Obeng et al., 2024). By embedding knowledge-sharing mechanisms into their operational frameworks, SMEs can optimize energy management strategies, lower operational costs, and position themselves as leaders in sustainable business practices, contributing significantly to broader environmental sustainability goals. Hence:

H5: The mediating role of knowledge sharing mediates green technology adoption and energy management.

Mediating Role of Knowledge Sharing on Green Technology Adoption and Water Conservation

Knowledge sharing serves as a vital mediator in the relationship between green technology adoption and effective water conservation measures in SMEs, facilitating the integration and optimization of sustainable water management practices (Hossain et al., 2022, Asad et al., 2023). As water conservation gains prominence, technologies such as rainwater harvesting systems, water-efficient appliances, and smart irrigation solutions have become essential for improving water efficiency and reducing waste (Tiwari et al., 2023). However, their successful implementation hinges on effective knowledge sharing within organizations, which fosters collaboration, disseminates critical information, and promotes best practices for water conservation (Aboelmaged & Hashem, 2019). SMEs prioritizing knowledge sharing enhance employees' understanding of the technical and operational aspects of green technologies, leading to better water management outcomes (Omowole et al., 2024). This practice is especially crucial in resource-constrained environments, where internal knowledge exchange maximizes the utility of existing technologies while minimizing costs (Valentim et al., 2016). By creating informal guidelines and leveraging shared insights, SMEs can optimize systems like rainwater harvesting, aligning with the Resource-Based View (RBV), which highlights the competitive advantage of unique internal resources like knowledge sharing (Baquero, 2024). Furthermore, inter-firm knowledge exchange through industry networks allows SMEs to share challenges and successes, significantly enhancing water conservation efforts (Veeger & Westermann-Behaylo, 2022). Organizations fostering a culture of knowledge sharing are also better positioned to adapt to regulatory changes regarding water usage, ensuring compliance, and strengthening their reputation as sustainable corporate citizens (Kiss et al., 2022). This commitment to water conservation not only enhances operational efficiency and attracts environmentally conscious consumers and stakeholders, contributing to long-term business success. Hence:

H6: Mediating role of knowledge sharing on green technology adoption and water conservation.

The Mediating Role of Knowledge Sharing on Green Technology Adoption and Waste Management

Green technology adoption is instrumental in advancing waste management practices in organizations, particularly through innovative solutions such as advanced waste sorting systems, composting technologies, and waste-to-energy processes (Dada et al., 2024). However, the effectiveness of these technologiesand, however, is contingent on robust knowledge-sharing mechanisms within organizations. Knowledge sharing facilitates the exchange of essential information, skills, and best practices among employees, thereby enhancing waste management outcomes (Ngo & Ngo, 2023). Cultivating a culture of knowledge sharing allows organizations to disseminate technical expertise and equip employees with the competencies needed to optimize the application of green technologies (Saleem et al., 2024). This approach is especially vital in resource-constrained settings, where internal collaboration ensures efficient utilization of available technologies without incurring significant additional costs (Edmund, 2024, Saleem et al., 2024). Furthermore, inter-firm knowledge exchange within industry networks enhances waste management by enabling small and medium-sized enterprises (SMEs) to share experiences and develop tailored solutions to specific challenges (Martin-Rios et al., 2022). Knowledge sharing also improves organizational adaptability, allowing firms to align their green technology initiatives with evolving regulatory frameworks, thereby ensuring compliance and bolstering their reputation as environmentally responsible entities (Wu & Tham, 2023, Christofi et al., 2024). By adopting this integrated approach, organizations can achieve greater operational efficiency, reduce waste generation, and make significant contributions to sustainability objectives. Hence:

H7: The mediating role of knowledge sharing on green technology adoption and waste management.

Moderating Role of Regulatory Support on Knowledge Sharing and Energy Management

Regulatory frameworks and government policies are essential in driving the adoption of sustainable practices, particularly energy-efficient technologies, in organizations (al-Rasheed, 2024, Omowole et al., 2024). Robust regulatory support fosters knowledge-sharing behaviors, enabling firms to enhance energy management strategies by collectively understanding and application of advanced technologies (Lee et al., 2023, Mishra & Singh, 2023). Incentives and programs that promote energy efficiency encourage collaboration and the exchange of best practices, resulting in improved energy outcomes (Solnørdal & Foss, 2018, Hattori et al., 2022). For example, companies in regions with strong regulatory frameworks exhibit higher levels of internal and external knowledge sharing, leading to better compliance and energy efficiency (Solnørdal & Foss, 2018). Regulations also establish industry standards that encourage companies to communicate and collaborate to meet energy benchmarks, further enhancing energy management practices (Al-Busaidi & Olfman, 2017). Partnerships fostered by regulatory policies allow firms to access technical expertise and develop innovative solutions, particularly in resource-constrained environments where such support alleviates financial burdens and promotes efficiency (Thanh & Tron, 2023). Informal knowledge-sharing networks supported by regulatory incentives enable SMEs to optimize energy strategies, share insights, and reduce costs while improving performance (Vătămănescu et al., 2022). Ultimately, regulatory support creates a culture of collaboration, innovation, and compliance, which drives sustainable energy management practices with long-term environmental and economic benefits. Hence:

H8: Moderating role of regulatory support on knowledge sharing and energy management.

RESEARCH METHOD

This study adopted a positivist research paradigm and a deductive approach, employing a quantitative methodology with descriptive and causal research designs. Data were collected through a cross-sectional survey using structured self-administered and email-based questionnaires. This research targeted SMEs in the retail, service, and manufacturing sectors across Pretoria and Johannesburg, South Africa. These cities were strategically selected due to their economic prominence, with Johannesburg serving as the country's financial hub and Pretoria as the administrative capital, providing a dynamic environment to examine green technology adoption and sustainability initiatives. The study's diverse SME representation enabled a sector-specific analysis of key challenges, including consumer behavior in retail, resource optimization in services and waste management in manufacturing. Additionally, local government policies promoting sustainability allowed for an in-depth assessment of regulatory support in fostering green technology adoption. A non-probability convenience sampling method was employed to ensure accessibility, with participants recruited through industry networks, local business associations, and online platforms.

This study employed non-probability convenience sampling due to its efficiency in targeting relevant respondents. However, this method introduces biases such as selection bias, in which environmentally proactive SMEs are overrepresented, and voluntary response bias, in which firms interested in sustainability are more likely to participate. In addition, the sample may lack generalizability, underrepresenting SMEs in rural areas or those with minimal engagement in green technology. Despite these limitations, convenience sampling was chosen over stratified or random sampling due to accessibility, time, and resource constraints, as well as challenges in identifying and categorizing SMEs based on industry and green technology adoption. It also ensures participation by key decision-makers, such as SME owners and managers. To mitigate bias, the study diversified the data collection sources, cross-validated the findings with secondary data, and included SMEs at different levels of green adoption. While acknowledging its limitations, the research suggests future studies adopt probability-based sampling to achieve a broader generalizability. This study acknowledges potential response bias in self-reported data, in which participants may have overstated or understated their sustainability efforts due to social or regulatory pressures. To mitigate this bias, measures such as anonymity, neutral question wording, pilot testing, and cross-validation were used.

Data were collected between May 2024 and October 2024, ensuring transparency and allowing for an understanding of potential temporal effects on findings. Key temporal influences include regulatory changes, whereby SMEs may have reported increased compliance due to anticipated environmental policies. Economic conditions, such as inflation or interest rate shifts, could have impacted SME investment in green initiatives. Seasonal business fluctuations, especially in agriculture and tourism, may have affected sustainability efforts based on peak and off-peak periods. Additionally, knowledge-sharing events, such as conferences and training programmes, could have led to higher engagement in green technology adoption by SMEs. Recognizing these factors helps contextualize the study results and inform future research. Data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4 software, facilitating robust evaluation of the relationships between key variables. This method enabled the evaluation and testing of relationships between latent variables, providing robust insights into the dynamics of green technology adoption and sustainability initiatives within SMEs (Hair et al., 2019).

Measures

Green Technology Adoption (GTA), Energy Management (EM), Water Conservation (WC), Waste Management (WM), Knowledge Sharing (KS), and Regulatory Support (RS) were measured using structured questionnaires based on a five-point Likert scale, where 1 = "Strongly disagree" and 5 = "Strongly agree." The GTA was assessed with six questions adapted from Song et al. (2020), while the EM was measured with five questions adopted from Thollander and Palm (2013) and Sorrell (2015). The WC utilized seven questions adapted from Larson et al. (2015) and Grafton et al. (2019), and the WM was evaluated with five questions. KS was measured with nine questions adapted from Nonaka and Takeuchi (1995) and Wang and Noe (2010), while RS was assessed with six questions based on Beck et al. (2005).

FINDINGS AND DISCUSSION
Demographic respondents

Table 1. Profiles of the participants

Demographics	Category	Frequency	Percentage (%)
Gender	Male	263	58.44
	Female	187	41.55
Age Group	Below 20	113	25.11
	21-30	107	22.37
	31-40	117	26.00
	41-50	51	11.33
	Above 50	62	13.70
Education	Diploma	229	50.80
	Bachelor	132	29.33
	Master	70	15.55
	PhD	19	4.22
Sector	Retail	245	54.44
	Service	106	22

Demographics	Category	Frequency	Percentage (%)
	Manufacturing	99	23.56
Experience	0-5	112	24.88
	5-10	171	38.00
	10-15	103	22.88
	16 and over	64	14.22

Reliability and Validity

Partial Least Squares Structural Equation Modeling (PLS-SEM) employs various techniques to assess the robustness and accuracy of research models. These include evaluating factor loadings, reliability, and validity, with a particular focus on convergent validity—measured through the average variance extracted (AVE) (Fornell & Larcker, 1981)—and composite reliability (CR). Hair et al. (2019) recommended a minimum factor loading of 0.7 for each item, while measurement reliability is considered acceptable when CR values are equal to or exceed 0.7. Convergent validity is confirmed if the AVE value is at least 0.5. To assess discriminant validity, either the Fornell-Larcker criterion or the heterotrait-monotrait (HTMT) ratio can be used (Fornell & Larcker, 1981, Henseler et al., 2015). The Fornell-Larcker criterion stipulates that the highest loading on an associated construct should be assigned to each item, ensuring precision in measuring the intended constructs. Factor loadings typically range between 0.5 and 0.9, with construct validity deemed sufficient when all factor loadings exceed 0.7.

Table 2 presents the factor loadings for each construct in the model, with values ranging from 0.663 to 0.911, all exceeding the minimum threshold of 0.5. Items with factor loadings below 0.5 were associated with improvements in model validity. These results confirm that the measurement instruments effectively capture the intended constructs, thus reinforcing their reliability. Additionally, Table 2 reports the outcomes of AVE, composite reliability, and Cronbach's alpha, which were used to assess the internal consistency of the data. All model constructs achieved values above the acceptable threshold of 0.7 for reliability, while AVE values for each construct exceeded 0.5, further validating the measurement model's robustness and overall methodological soundness.

Table 2. Reliability and Validity

Variable	Items	Loadings	CR	AVE
Green Technology Adoption	GTA1- implemented energy-efficient technologies to reduce energy consumption	0.911	0.903	0.812
	GTA2- has measured its carbon footprint in the past year	0.883		
	GTA3- currently participates in green technology financing schemes or programs	0.906		
	GTA4- earned a green tag certification for some of its products and services.	0.844		
	GTA5- adopted renewable energy sources, such as solar and wind energy, for its operations	0.856		
	GTA6- currently involved in constructing or renovating buildings using green building principles	0.857		
Energy Management	EM1- ensures that activities minimize the amount of energy used	0.860	0.892	0.723

Variable	Items	Loadings	CR	AVE
	EM2- ensures that activities minimize emissions to the air	0.903		
	EM3- set measurable targets for reducing energy usage	0.867		
	EM4- applies effective strategies to improve energy management	0.823		
	EM5- regularly monitors the energy consumption trends	0.843		
Water Conservation	WC1- promotes the re-use of water during the production process	0.890	0.884	0.723
	WC2- setting measurable targets for reducing water usage	0.885		
	WC3- applies effective strategies to improve water conservation	0.844		
	WC4- installed water-efficient devices to control water usage	0.862		
	WC5- regularly monitors the trends in water usage	0.843		
	WC6- ensures its activities minimize the amount of effluent to water	0.893		
	WC7- educates and engages employees on best practices for water conservation.	0.886		
Waste Management	WM1- ensures in minimizing the amount of waste produced by its activities	0.663	0.890	0.753
	WM2- promotes the recycling of waste by using environmentally safe procedures that are available.	0.877		
	WM3- set measurable targets for waste reduction	0.844		
	WM4 ensures the appropriate disposal of hazardous waste by complying with all existing legislation standards.	0.870		
	WM5- has waste storage facilities that meet environmental requirements.	0.845		
Knowledge Sharing	KS1- encourages managers to facilitate knowledge exchange between hierarchical levels.	0.901	0.911	0.763
	KS2- implements an incentive system to promote employee experience sharing	0.891		
	KS3- ensures employees share information across different departments	0.834		
	KS4- promotes teamwork and collaboration to enhance knowledge sharing.	0.889		
	KS5- recognizes the impact of employee mobility on knowledge exchange.	0.891		

Variable	Items	Loadings	CR	AVE
	KS6- provides structured forums for employees to share knowledge and experiences.	0.911		
	KS7- ensures employees actively share their skills with colleagues in other departments.	0.893		
	KS8- supports knowledge-sharing through incentive-based programs.	0.863		
	KS9- ensures managers contribute effectively to knowledge exchange at all levels.	0.876		
Regulatory Support	RS1- are effectively designed to promote sustainable business practices.	0.847	0.907	0.743
	RS2- provides adequate incentives for businesses that implement sustainable practices.	0.843		
	RS3- provide sufficient financial support (e.g., grants, subsidies) to businesses investing in green technologies.	0.889		
	RS4- encourages businesses to innovate and adopt green technologies through favorable regulatory policies.	0.890		
	RS5- there are strong regulatory frameworks in place to enforce environmental protection laws in businesses.	0.877		
	RS6- businesses in my industry benefit from clear and consistent communication from government agencies regarding sustainability regulations.	0.867		

Note: CR is composite reliability, and AVE is average variance extracted.

Common Method Bias

Common method bias can arise from single-source and single-time data collection, potentially distorting research findings (Hair et al., 2019). To address this issue, the study employed multiple approaches, including an assessment of multicollinearity. The variance inflation factor (VIF) was used to evaluate the degree of multicollinearity among the study constructs, with values below 3.3 indicating an absence of multicollinearity (Hair et al., 2019). The results confirmed that all constructs met this criterion, with VIF values recorded as follows: GTA (1.62), EM (1.98), WC (1.76), WM (1.02), KS (1.85), and RS (1.40). These findings suggest that multicollinearity was not a concern, thereby ensuring the reliability of the study's statistical analysis.

Discriminant Validity

The results presented in Table 2 confirm the reliability of the measurement items and scales used in this study. This is evidenced by factor loadings and composite reliability (CR) values that meet or exceed the recommended threshold of 0.7 (Hair et al., 2019). Convergent validity was further established through the assessment of the average variance extracted (AVE), ensuring that all recorded values surpassed the minimum criterion of 0.5, as advised by Fornell and Larcker (1981). Additionally, discriminant validity was verified using the heterotrait-monotrait (HTMT) ratio, and the results are presented in Table 3. The overall findings indicate that the proposed measurement model meets all the necessary validity and reliability standards.

To evaluate discriminant validity, the Fornell-Larcker criterion was applied, requiring that the square root of the AVE for each construct be greater than the correlations between variables. The AVE square root for GTA practices was 0.789, which exceeds the correlation values in the corresponding column (Table 3). Similarly, the initial value of each construct in its respective column surpassed all other correlation values, further confirming discriminant validity. The HTMT ratio (Table 3) reinforces these findings, validating the robustness of the measurement model employed in this study.

Table 3. Discriminant validity—Fornell Larcker Criteria.

	GTA	EM	WC	WM	KS	RS
GTA	0.789					
EM	0.503	0.843				
WC	0.522	0.670	0.834			
WM	0.503	0.540	0.574	0.851		
KS	0.489	0.603	0.530	0.573	0.882	
RS	0.477	0.577	0.489	0.520	0.677	0.799
Discriminant validity (HTMT)						
GTA						
EM	0.722					
WC	0.619	0.695				
WM	0.556	0.654	0.731			
KS	0.672	0.490	0.568	0.689		
RS	0.543	0.690	0.680	0.560	0.730	

GTA: green technology adoption, EM: energy management, WC: water conservation, WM: waste management, KS: knowledge sharing, RS: regulatory support.

Hypothesis Results

Table 4 presents the results of the hypothesis testing, revealing the t-values and beta coefficients. A key aspect of this analysis involves evaluating both the direct and indirect relationships among variables, with statistical significance determined by a p-value of ≤ 0.05 and a t-value of ≥ 1.96. The findings confirm that the implementation of GTA exerts a positive and statistically significant influence on EM, as supported by a beta coefficient of 0.421 and a p-value below 0.05. Furthermore, a strong and statistically significant association exists between GTA and WC ($\beta = 0.567$, $p < 0.01$) and between the GTA and WM ($\beta = 0.324$, $p < 0.01$). Additionally, the positive impact of GTA on KS was demonstrated by a beta coefficient of 0.461 and a p-value below 0.05, reinforcing the substantial role of GTA in influencing these key variables.

Table 4. Hypothesis for the direct-effect path analysis

Path	Coefficient	SD	T-Value	p-Value	Decision
GTA → EM	0.421	0.035	12.029	0.000	Accepted
GTA → WC	0.567	0.044	12.886	0.000	Accepted
GTA → WM	0.324	0.038	8.526	0.000	Accepted
GTA → KS	0.461	0.034	8.526	0.000	Accepted

During the hypothesis testing part of this methodology, we examined both direct and indirect relationships between variables, which can be regarded as significant if the p-value is less than 0.05 and the t-value is less than or equal to 1.96. The results (Table 5) indicate that KS mediates the relationship between GTA practices and EM. The beta coefficient was 0.350, and the p-value was less than 0.05. When considering EM efforts, KS acts as a mediator to achieve a balance between GTA and EM, this association was quantified by a beta coefficient of 0.280 and a p-value of less than 0.05. KS serves as a mediator between GTA and WC, with a beta coefficient of 0.320 and a p-value of less than 0.05. The findings indicate that KS acts as a mediator between GTA and WM, and path analysis showed a statistically significant positive association. A beta coefficient of 0.400 and a p-value below 0.05 indicate that RS moderates the relationship between GHRM practices and CSP.

Table 5. Hypothesis for Indirect-effect Path Analysis

Path	Coefficient	SD	T-Value	p-Value	Decision
KS→GTA→EM	0.350	0.070	5.000	0.002	Accepted
KS→GTA→WC	0.280	0.065	4.308	0.004	Accepted
KS→GTA→WM	0.320	0.068	4.833	0.001	Accepted
RS→KS→EM	0.400	0.075	5.333	0.000	Accepted

Discussion

This study investigates the relationship between green technology adoption (GTA) and the sustainability initiatives of SMEs in South Africa, focusing on energy management (EM), water conservation (WC), and waste management (WM). This study further examines the mediating role of knowledge sharing (KS) and the moderating role of regulatory support (RS). The findings contribute to the growing body of literature by providing a comprehensive framework that integrates GTA, sustainability practices, and organizational dynamics. The results demonstrate a significant positive relationship between GTA and sustainability initiatives, which is consistent with previous studies that highlighted the importance of adopting green technologies in fostering environmental sustainability (Zhu et al., 2023, Sharif et al., 2024). For SMEs, GTAs enable enhanced resource efficiency, cost reduction, and environmental compliance, which are critical for long-term sustainability. This is consistent with the findings of Chowdhury et al. (2018) and Tereshchenko et al. (2023), who reported that green technologies significantly improve energy efficiency and reduce waste in small businesses.

The mediating role of KS in the relationship between GTA and sustainability initiatives underscores the value of organizational learning and information exchange. KS facilitates the dissemination of best practices, innovation, and knowledge among employees, enhancing the efficacy of sustainability practices (Abbas et al., 2019, Shafait & Huang, 2024). The study's findings corroborate prior research by Lopes et al. (2017) and Shafait and Huang (2024), which identified KS as a critical driver of organizational adaptability and innovation, particularly in implementing water conservation and waste management strategies. The moderating role of RS highlights the significant impact of governmental and institutional support in fostering a conducive environment for SMEs to adopt green practices. These findings align with Luthra et al. (2014), who emphasized that supportive regulatory frameworks reduce barriers to green technology adoption and encourage compliance with environmental standards. SMEs with strong regulatory support demonstrated a stronger relationship between GTA and sustainability initiatives, suggesting that policy incentives, subsidies, and enforcement mechanisms play an essential role in promoting sustainability in the SME sector.

CONCLUSIONS

This study provides critical insights into the interplay among green technology adoption, sustainability initiatives, knowledge sharing, and regulatory support among SMEs in South Africa. The findings confirm that GTA is a key driver of sustainability initiatives, enhancing energy efficiency, water conservation, and waste management practices. Knowledge sharing serves as a vital mechanism that mediates the relationship between GTA and sustainability outcomes, while regulatory support amplifies the effectiveness of green technology in achieving sustainability goals. The study's contributions are twofold. First, it extends the theoretical understanding of how organizational factors such as KS and RS interact with GTAs to influence sustainability practices in SMEs. This study significantly advances RBV by demonstrating how SMEs can leverage GTA, KS, and RS as strategic resources to drive sustainability performance. Traditionally, RBV emphasizes that firms gain competitive advantage through valuable, rare, inimitable, and non-substitutable (VRIN) resources. This research extends RBV by integrating external institutional factors (RS) and dynamic capabilities (KS) into the framework, reinforcing how the synergy between internal competencies and external enablers enhances sustainability in SMEs. This study extends RBV by bridging internal resource capabilities with external institutional forces, offering a holistic perspective on sustainability-driven competitive advantage. The incorporation of KS as a mediating capability and RS as a moderating institutional factor provides a more comprehensive and contextually relevant adaptation of RBV in sustainability research.

Second, the study offers valuable practical implications for policymakers, emphasizing the need for a supportive regulatory environment that promotes knowledge-sharing platforms. Such platforms can significantly accelerate the adoption of green technologies and sustainable practices in the SME sector. By fostering collaboration and enabling access to critical knowledge, policymakers can enhance the capacity of SMEs to implement green innovations. Future research should build on these findings by exploring the long-term effects of GTA on SME performance, specifically examining how these technologies influence growth, profitability, and competitiveness over time. Furthermore, investigating additional mediating and moderating factors such as organizational culture, leadership, and stakeholder engagement could provide a more comprehensive understanding of the factors that drive or hinder sustainability in SMEs. By addressing these areas, future research can offer a more nuanced and robust framework that captures the complex dynamics at play in the sustainable transformation of SMEs.

To effectively promote green technology adoption and sustainability initiatives among SMEs in South Africa, industry-specific strategies must be prioritized over broad SME-level recommendations, ensuring alignment with the distinct challenges, regulatory requirements, and market conditions of each sector. Different industries face unique barriers, for instance, manufacturing SMEs require financial support and incentives for capital-intensive green technologies like energy-efficient machinery and waste management solutions, while agricultural SMEs need tailored training on sustainable farming practices, water conservation, and renewable energy integration. Construction and mining SMEs encounter stringent environmental regulations and require sector-specific guidance on eco-friendly building materials, emissions reduction, and land rehabilitation, whereas retail SMEs need assistance in adopting sustainable supply chain practices, eco-friendly packaging, and energy-efficient retail operations. To support these varied needs, customized knowledge-sharing platforms should be established, offering industry-specific resources such as digital platforms for real-time climate-smart farming techniques in agriculture, industry workshops on energy efficiency and circular economy principles in manufacturing, and compliance training for environmental impact regulations in construction and mining.

Moreover, enhancing industry-specific regulatory support is crucial because different sectors operate under different legal frameworks. Energy SMEs require clear policies on renewable energy standards and tax incentives, food and beverage SMEs need sustainable sourcing and waste reduction regulations, textile and apparel SMEs benefit from eco-friendly production guidelines and wastewater management standards. Furthermore, aligning sustainability goals with industry competitiveness ensures that green technology adoption not only contributes to environmental responsibility but also enhances profitability and market positioning. For example, hospitality and tourism SMEs can attract eco-conscious travelers by adopting sustainable tourism practices, manufacturing SMEs can improve long-term financial sustainability through energy-efficient production, and retail SMEs can leverage sustainable branding to appeal to environmentally conscious consumers. By refining recommendations to be industry-specific, policymakers and business advisors can provide targeted support that makes green technology adoption more practical and beneficial, empowering SMEs to overcome sectoral challenges while fostering sustainability and competitiveness.

LIMITATION & FURTHER RESEARCH

This study on the adoption of green technology and sustainability initiatives by SMEs in South Africa has several limitations that need consideration. The sample size, limited to specific regions, restricts the generalizability of the findings to the broader SME population across South Africa, highlighting the need for a more diverse sample in future research. Additionally, the study's cross-sectional design limits the ability to infer causal relationships between the key variables. A longitudinal approach would offer deeper insights into the long-term effects of green technology adoption, regulatory support, and knowledge sharing. The study also relied on self-reported data, which may introduce biases, such as social desirability or over-reporting of positive sustainability behaviors. Another limitation is the focus on knowledge sharing as a mediator, without exploring other influencing factors like organizational culture and leadership styles, which may also play crucial roles in the adoption process.

Future research can address these limitations and extend the understanding of green technology adoption in several ways. Expanding the geographic scope to include SMEs in other developing countries would provide a comparative perspective on the challenges and enablers faced by SMEs in different contexts. Longitudinal studies could offer more robust evidence on causal relationships and long-term sustainability outcomes. Research focusing on industry-specific factors would uncover sector-specific challenges and opportunities, while investigating other mediators such as organizational learning and employee engagement could provide a more comprehensive view of the adoption process. Furthermore, exploring the impact of financial and technological support and the role of policy changes would offer valuable insights into the external factors influencing SMEs' sustainability efforts. Lastly, examining internal SME factors such as management commitment and employee training could further enhance the understanding of how organizations integrate sustainability into their long-term strategies.

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