Asian Development Policy Review
ISSN(e): 2313-8343
ISSN(p): 2518-2544
DOI: 10.55493/5008.v14i2.5989
Vol. 14, No. 2, 40-53

URL: www.aessweb.com

Revitalizing green economy based MSMEs: The interplay of quadruple helix collaboration, digital transformation, and financial innovation in enhancing business sustainability

St Salmah Sharon[1+]
Muchtar[2]
Mustika Kusuma Basir[3]
Kasmir Syariati[4]
Muh Arif[5]

[1,2,3]*Sekolah Tinggi Ilmu Ekonomi Ciputra Makassar, Indonesia.*
[1]*Email: salmah.sharon@ciputra.ac.id*
[2]*Email: muchtar@ciputra.ac.id*
[3]*Email: mustika.kusuma@ciputra.ac.id*
[4]*Universitas Ciputra Surabaya, Indonesia.*
[4]*Email: kasmir.syariati@ciputra.ac.id*
[5]*Faculty of Economics and Business, Universitas Muslim, Indonesia.*
[5]*Email: muh.arif@umi.ac.id*

(+ Corresponding author)

Article History
Received: 1 December 2025
Revised: 18 February 2026
Accepted: 12 March 2026
Published: 27 April 2026

Keywords
Business resilience
Digital transformation
Financial innovation
Green economy
MSME sustainability
Quadruple helix.

ABSTRACT

This study examines the roles of the Quadruple Helix, digital transformation, and financial innovation in enhancing the sustainability of green-economy–based MSMEs in South Sulawesi Province, Indonesia. Using a quantitative approach, survey data were collected from 280 MSMEs in Maros, Bulukumba, and the Selayar Islands and analyzed with Partial Least Squares–Structural Equation Modeling (PLS-SEM) using SmartPLS 4. The results show that the Quadruple Helix significantly promotes digital transformation but does not directly influence MSME sustainability. Digital transformation has a strong positive effect on sustainability and acts as a key mediating variable linking both the Quadruple Helix and financial innovation to sustainable business performance. Financial innovation also exerts a significant positive direct effect on MSME sustainability. This study contributes to the literature by empirically validating an integrative model that combines Quadruple Helix collaboration, digital transformation, and financial innovation within a green economy framework. From a policy perspective, the findings highlight the importance of strengthening digital capabilities and inclusive financial innovation through multi-actor collaboration to support regional MSME sustainability strategies.

Contribution/ Originality: This study introduces an integrative framework demonstrating that digital transformation is the key mechanism linking Quadruple Helix collaboration and financial innovation to sustainable MSME performance in green-economy contexts.

1. INTRODUCTION

Green economy-based revitalization of MSMEs is increasingly seen as an important pillar of sustainable development (D'Amato & Korhonen, 2021; Mehmood, Kautish, Mangla, Ali, & Kazancoglu, 2024). MSMEs play a significant role in economic growth but face barriers such as high transition costs, limited access to technology, and limited financing (Adamowicz, 2022; Majali, Alkaraki, Asad, Aladwan, & Aledeinat, 2022). Government regulatory support, strategic partnerships, and co-creation processes can encourage MSMEs to participate in sustainable business practices, with multisectoral collaboration as a key factor toward a green economy (Yusfiarto, 2023). Digital transformation and financial innovation expand opportunities for MSMEs through operational efficiency, wider market reach, and access to green financing (Furr, Ozcan, & Eisenhardt, 2022; Mattila, Yrjölä, & Hautamäki, 2021;

Mudmainna & Sanapang, 2025; Owoseni, 2023; Schneider & Kokshagina, 2021). Furthermore, the application of green accounting improves financial performance as well as environmental sustainability (Octavia et al., 2020; Prahara, Kurnawan, Muhammad, & Syahrial, 2023; Sriayudha, Octavia, & Indrawijaya, 2020).

The quadruple helix framework, involving government, academia, industry players, and civil society, is a strategic approach to encouraging collaboration-based innovation (Aggarwal & Sindakis, 2022; Okfalisa et al., 2022; Yun & Liu, 2019). This approach can be explained through a combination of theories, namely Stakeholder Theory (Freeman, Dmytriyev, & Phillips, 2021; Freeman, Phillips, & Sisodia, 2020), Resource-Based View (RBV), and Triple Bottom Line (Elkington, 1998). In this perspective, business sustainability is achieved through stakeholder engagement, resource optimization, and the achievement of economic, social, and environmental performance. Digital transformation and financial innovation play roles not only in improving efficiency but also as catalysts for adopting inclusive and sustainable green business models (Afonso, Monteiro, & Thompson, 2012; Carayannis & Campbell, 2009).

The novelty of this research lies in integrating the quadruple helix framework, digital transformation, and financial innovation within the context of MSMEs. Previous studies tend to examine these factors separately, such as the impact of digitalization on financial performance or the relationship between financial innovation and environmental practices (Sharma, Shahbaz, Singh, Chopra, & Cifuentes-Faura, 2023; von Böhlen & Simberova, 2025). The lack of empirical evidence regarding the implementation of the quadruple helix model in promoting MSMEs' green economy adoption is a research gap (Melany et al., 2024). This study aims to address this by presenting an integrated framework that contextualizes green accounting, innovation systems, and financial inclusiveness as drivers of MSME sustainability (Fidanoski et al., 2022; Zheng & Zhang, 2023).

Practically, this research is expected to provide strategic insights for policymakers, academics, and industry players in building a supporting ecosystem that enhances the resilience and environmental responsibility of MSMEs. Previous research indicates that innovation capacity and digital adoption are key determinants of MSMEs' resilience (Fidanoski et al., 2022; Mudmainna & Sanapang, 2025; Zhang & Li, 2023), while the quadruple helix model has been shown to foster innovation ecosystems (Leydesdorff & Smith, 2022; Morawska-Jancelewicz, 2022; Yun & Liu, 2019). Thus, this study seeks to bridge the gap between the macro goals of sustainable development and the micro practices of accounting and business in MSMEs (Yusfiarto, 2023).

The local context of this research focuses on MSMEs in three strategic regions in South Sulawesi: Maros Regency, Bulukumba Regency, and Selayar Islands Regency, which have high agricultural and tourism potential but are vulnerable to ecological pressures and limited access to digitalization and innovative financing. The selection of these locations allows for mapping challenges and opportunities for MSMEs within strong local economic ecosystems, yet exposed to environmental risks. Therefore, the main objective of the research is to analyze the role of quadruple helix integration, digital transformation, and financial innovation as enablers in revitalizing green economy-based MSMEs, while providing policy recommendations and theoretical implications relevant to the sustainability of Indonesia's MSME sector (Angreyani, Akbar, Haeruddin, Mustafa, & Mustafa, 2023; Gunawan, Jufrizen, & Pulungan, 2023; Leščinská, Šebo, & Badidová, 2025; Yusfiarto, 2023).

2. LITERATURE REVIEW

2.1. Quadruple Helix (QH) and Digital Transformation (H1)

The Quadruple Helix (QH) model is an innovation framework emphasizing collaboration among four main actors: government, academia, industry, and civil society, to create a sustainable, knowledge-based ecosystem (Afonso et al., 2012; Aggarwal & Sindakis, 2022; Bhattacharjya, Bhaduri, & Kakoty, 2023; Cai, 2022; Cai & Lattu, 2022; Shin, Rask, & Kahma, 2023). The synergy between these actors is believed to accelerate the innovation process, drive economic growth, and strengthen social development (Bhattacharjya et al., 2023; Nordberg, Mariussen, & Virkkala, 2020; Yun & Liu, 2019).

In the context of MSMEs, the government acts as a regulator, academia produces knowledge and research, industry acts as an implementer, while civil society becomes a user as well as a feedback provider (Li & Pang, 2023b; Octavia et al., 2020; Okfalisa et al., 2022). Previous research has shown that QH support through strategic collaboration accelerates technology adoption and digital transformation of MSMEs (Cahyani, Hidayat, & Marcelino, 2023; Okfalisa et al., 2022; Roman & Fellnhofer, 2022; Shin et al., 2023). Therefore, a hypothesis can be proposed.

H_1: Quadruple Helix has a significant positive effect on Digital Transformation.

2.2. Financial Innovation and Digital Transformation (H2)

Digital transformation involves adopting digital technologies to change business models, enhance operational efficiency, and strengthen customer interactions (Garzoni, De Turi, Secundo, & Del Vecchio, 2020; Škare, Gavurova, & Porada-Rochon, 2024). One of the important drivers of digital transformation is financial innovation. Financial innovation includes developing financial products, services, and business models utilizing digital technologies (Leščinská et al., 2025; Mekinjić, Grujić, & Vujičić, 2020; von Böhlen & Simberova, 2025).

In MSMEs, financial innovations such as digital payments, platform-based financing, and cloud-based record-keeping help expand access to finance, improve cash flow efficiency, and speed up the transaction process. Studies show that digitalization of financial services accelerates technology adoption and business efficiency (Ključnikov, Civelek, Červinka, Vozňáková, & Vincúrová, 2022; Li & Pang, 2023a). Thus, the proposed hypothesis is:

H_2: Financial innovation has a significant positive effect on Digital Transformation.

2.3. Digital Transformation and MSME Sustainability (H3)

The implementation of digital transformation is believed to directly contribute to the sustainability of MSMEs. Digital technologies not only improve operational efficiency but also expand market access and strengthen customer relationships (Mudmainna & Sanapang, 2025; Nguyen, Nguyen, Nguyen, Nguyen, & Ta, 2023). This supports long-term business resilience.

Research by Octavia et al. (2020), Puri, Kaur, Kalra, and Gill (2025), and Sriayudha et al. (2020) shows that digitalization plays an important role in improving the competitiveness and sustainability of MSMEs. Therefore, a hypothesis can be formulated.

H_3: Digital Transformation has a significant positive effect on MSME Sustainability.

2.4. Quadruple Helix and MSME Sustainability (H4)

Besides influencing digital transformation, the Quadruple Helix also directly contributes to MSMEs' sustainability. Collaboration among QH actors enables MSMEs to access capital, technology, and strategic partnership networks, supporting their growth and resilience in competitive markets (Anifa, Ramakrishnan, Joghee, Kabiraj, & Bishnoi, 2022; Carayannis, Campbell, & Grigoroudis, 2022; Leydesdorff & Smith, 2022; Okfalisa et al., 2022; Yun & Liu, 2019). Such support strengthens business resilience and creates sustainable competitiveness (Irungu, Liu, Liu, & Wanjiru, 2023). Thus, the following hypothesis is proposed:

H_4: The role of the Quadruple Helix has a significant positive effect on MSME Sustainability.

2.5. Financial Innovation and MSME Sustainability (H5)

Financial innovation plays a strategic role in enhancing the sustainability of MSMEs. Digital financial technologies enable greater access to finance, improve cash flow management efficiency, and expand marketing networks (Angreyani et al., 2023; Anifa et al., 2022; Gunawan et al., 2023; Mekinjić et al., 2020). Therefore, financial innovation contributes to the competitiveness and sustainability of MSMEs. The proposed hypotheses are:

H_5: Financial Innovation has a significant positive effect on MSME Sustainability.

2.6. The Mediating Role of Digital Transformation (H6)

Recent literature emphasizes that the role of the Quadruple Helix in MSME sustainability is often mediated by digital transformation (Agostino, Saliterer, & Steccolini, 2022; Cahyani et al., 2023; Carayannis & Campbell, 2009; Mekinjić et al., 2020; Puri et al., 2025; Yang, Zhang, & Zhang, 2024). QH creates a conducive environment for digitalization through regulation, academic support, industry implementation, and community acceptance. It is this digital transformation that ultimately strengthens business sustainability. Therefore, the following hypothesis is proposed.

H_6: Digital Transformation mediates the influence of Quadruple Helix on MSME Sustainability.

2.7. The Role of Financial Innovation Mediated by Digital Transformation on MSME Sustainability (H7)

Financial innovation plays a crucial role in supporting MSME sustainability, but its influence is often indirect, primarily through digital transformation. Digital technology enables MSMEs to access and optimize innovative financial services such as fintech, e-wallets, crowdfunding, and cloud-based record-keeping. Digital transformation acts as an enabler connecting financial innovation with sustainability through operational efficiency, financial transparency, and market expansion (Babina, Fedyk, He, & Hodson, 2024; Benetyte, Gonenc, & Krusinskas, 2021; Li & Pang, 2023a; Purwoko, Judijanto, Abidin, & Antesty, 2023; Rachmawati, Wijaya, & Pambreni, 2023; Yulistiawan, Wirawan, Dewi, & Hananto, 2023). Thus, the synergy between the two strengthens business resilience while encouraging environmentally friendly business practices (Ohajionu, Gyamfi, Haseki, & Bekun, 2022; Sandberg, Alnoor, & Tiberius, 2023).

H_7: Digital Transformation Mediates the Effect of Financial Innovation on MSME Sustainability.

Based on the description of the literature review and hypothesis development above, the research model developed is shown in Figure 1:

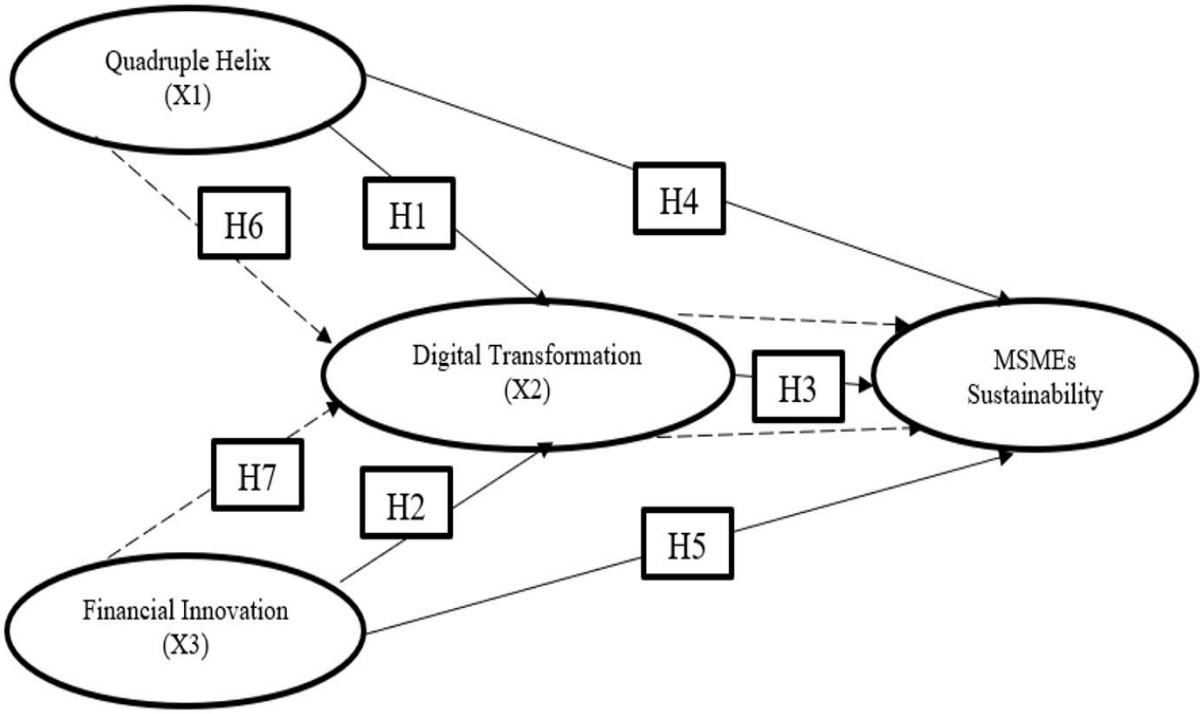

Figure 1. Empirical model research.

3. RESEARCH METHOD

This study employs a quantitative approach using a survey method to analyze the relationship between the Quadruple Helix, digital transformation, financial innovation, and the sustainability of green economy-based MSMEs.

The research population includes all active MSMEs registered with the Office of Cooperatives and SMEs in three districts in South Sulawesi: Maros, Bulukumba, and Selayar Islands. The sample was purposively selected based on the following criteria: MSMEs operating for at least two years, engaging with external parties such as government, academics, communities, or financial institutions, and willing to complete the questionnaire. The total sample size was 280 respondents.

The research instrument was a questionnaire based on variable indicators, with measurement using a 5-point Likert scale. Quadruple Helix variables are measured by the intensity of MSME collaboration with academia, government, industry, and community; digital transformation is seen from the use of information technology in production, distribution, and marketing (Owoseni, 2023); financial innovation is measured through the use of technology-based services such as fintech, e-wallet, and crowdfunding (Anifa et al., 2022; Xiong, Zhang, & Mo, 2023); while MSME sustainability is measured through energy efficiency, waste management, environmental awareness, and business continuity (Darmayanti, Milshteyn, & Kashap, 2023).

Prior to widespread distribution of the questionnaire, the instrument was tested for validity and reliability. The validity test was conducted using Pearson correlation analysis, while reliability was assessed with Cronbach's Alpha to ensure consistency between items (Hair, Matthews, Matthews, & Sarstedt, 2017; Sarstedt, Ringle, & Hair, 2021). The data analysis technique employed was Partial Least Squares Structural Equation Modeling (PLS-SEM) using SmartPLS software version 4.

The analysis was performed in three stages: first, testing the measurement model (outer model) to evaluate the validity and reliability of indicators; second, testing the structural model (inner model) to examine relationships between latent variables; and third, testing hypotheses through t-statistic and path coefficient values (Memon et al., 2021).

4. RESULTS

4.1. Respondent Characteristics

This study involved 280 MSME actors in three strategic coastal areas of South Sulawesi: Maros District (35.7%), Bulukumba District (32.1%), and Selayar District (32.1%). The location selection considered the region's economic potential, tourism sector, and MSMEs' active involvement in green economy initiatives. Regarding gender, respondents were relatively evenly distributed, with 50.7% men and 49.3% women, indicating that MSMEs' role in business sustainability involves equal contributions from both genders, emphasizing the need for inclusive policies (Angreyani et al., 2023). Based on position, most respondents were business owners (60.0%), followed by managers (25.0%) and employees (15.0%).

This shows that most respondents are key decision-makers involved in sustainability strategies, digital investment, and quadruple helix partnerships (Leydesdorff & Smith, 2022; Morawska-Jancelewicz, 2022; Yun & Liu, 2019). The business type is dominated by the culinary sector (42.9%), followed by trade (27.9%), services (18.6%), and others (10.7%), aligning with the economic characteristics of coastal areas related to tourism and environment-based branding opportunities (Xiong et al., 2023).

In terms of business duration, 40.0% of MSMEs have been operating for 3-5 years, 31.4% for 6-10 years, 16.1% for ≤ 2 years, and 12.5% for more than 10 years. This variation highlights the differing readiness of new and established MSMEs to adopt digital transformation, financial innovation, and green practices as sustainability strategies (Owoseni, 2023). A full breakdown of respondent characteristics can be seen in Table 1.

Table 1. Characteristics of research respondents.

Characteristics	Category	Number (n=280)	Percentage (%)
Gender	Male	142	50.7%
	Female	138	49.3%
Position	Business Owner	168	60.0%
	Manager	70	25.0%
	Employee	42	15.0%
Business type	Culinary	120	42.9%
	Trade	78	27.9%
	Services	52	18.6%
	Other	30	10.7%
Length of employment/Business	≤ 2 years	45	16.1%
	3 - 5 years	112	40.0%
	6 - 10 years	88	31.4%
	> 10 years	35	12.5%
Respondent location	Maros Regency	100	35.7%
	Bulukumba Regency	90	32.1%
	Selayar Regency	90	32.1%

Source: Researcher, data processed, 2025.

4.2. Evaluation of the Measurement Model (Outer Model)

To assess the quality of the measurement model, an evaluation of indicator reliability, internal consistency, and convergent validity was conducted. This stage ensures that each indicator accurately reflects its underlying latent construct and that the constructs themselves demonstrate sufficient reliability for further structural analysis. The results of the outer loading values, Cronbach's Alpha, Composite Reliability, and Average Variance Extracted (AVE) for all constructs are summarized in Table 2.

Table 2. Result of outer loading, Cronbach's alpha, CR, and AVE.

Construct/Item	Outer Loading	Cronbach's alpha	Composite Reliability (rho_c)	AVE	Result
X1: Quadruple Helix		0.925	0.947	0.817	Valid & Reliable
X1.1. Supporting policies. incentives. training. pro-MSME regulations	0.901				
X1.2. Business partnerships. technology transfer. market access	0.934				
X1.3. Research and development support. HR training. business incubation	0.866				
X1.4. Public literacy. MSME advocacy. digital promotion	0.913				
X2: Financial Innovation		0.860	0.905	0.704	Valid & Reliable
X2.1. Financing source information	0.843				
X2.2. Ease of financing application	0.858				
X2.3. Ease of financing requirements	0.791				
X2.4. Digital financial system integration	0.861				
X3: Digital Transformation (Mediation)		0.861	0.905	0.705	Valid & Reliable
X3.1. Digitalization of operational processes	0.857				
X3.2. Utilization of digital media and applications	0.852				
X3.3. Digital competence of human resources	0.808				
X3.4. Integration of digital information systems	0.841				

Construct/Item	Outer Loading	Cronbach's alpha	Composite Reliability (rho_c)	AVE	Result
Y: Sustainability		0.825	0.884	0.655	Valid & Reliable
Y1: Increased business revenue	0.836				
Y2: Increased customers	0.814				
Y3: Market and technology adaptation	0.761				
Y4: Business development and environmental Sustainability	0.824				

Source: Researchers, Data Processed, 2025.

Table 2 presents the results of the validity and reliability evaluation of the constructs through the outer model analysis show that all indicators exhibit outer loading values above 0.70, meeting the criteria for convergent validity. The outer loading value of each indicator is above 0.70, indicating a strong contribution to the construct (Hair et al., 2017; Sarstedt et al., 2021). For example, the Quadruple Helix indicator (X1.1-X1.4) has a loading value between 0.866 and 0.934, reflecting high validity and consistency in the collaboration of academics, government, businesses, and communities.

The Cronbach's Alpha and Composite Reliability (CR) values also exceed the 0.70 threshold, namely Quadruple Helix (0.925; 0.947), Financial Innovation (0.860; 0.905), Digital Transformation (0.861; 0.905), and Sustainability (0.825; 0.884) (Memon et al., 2021; Sarstedt et al., 2021). Similarly, the AVE values are >0.50, confirming adequate convergent validity. Overall, these results prove that the research instruments are reliable and valid, conforming to PLS-SEM standards in recent quantitative studies (Hair et al., 2017; Sarstedt et al., 2021).

4.3. Structural Model (Inner Model Analysis)

To examine the relationships among the latent constructs and test the proposed hypotheses, the structural model was evaluated using the bootstrapping procedure in PLS-SEM. This assessment provides information regarding the significance, direction, and strength of each causal path within the model. The analysis also determines whether the theoretical framework developed in this study is empirically supported. The detailed path coefficients, along with their corresponding t-statistics and p-values, are presented in Table 3.

Table 3. Path coefficients.

Items	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
H1. Quadruple helix →Digital transformation	0.354	0.353	0.081	4.348	0.000
H2. Quadruple helix →MSMEs sustainability	0.103	0.101	0.084	1.228	0.220
H.3. Digital transformation → Financial innovation	0.291	0.296	0.075	3.892	0.000
H.4. Digital transformation → MSMEs sustainability	0.371	0.373	0.079	4.671	0.000
H.5. Financial innovation → MSMEs sustainability	0.187	0.191	0.076	2.459	0.014
H.6. Quadruple helix →Digital transformation→ MSMEs sustainability	0.066	0.068	0.032	2.068	0.039
H.7. Financial innovation →Digital transformation→ MSMEs sustainability	0.054	0.056	0.027	2.053	0.040

Source: Researchers, Data Processed, 2025.

The results of path coefficient analysis show that the Quadruple Helix significantly affects MSMEs' digital transformation ($\beta = 0.354$; $t = 4.348$; $p < 0.001$), emphasizing academia, government, business, and community roles.

This finding is in line with Afonso et al. (2012); Aggarwal and Sindakis (2022); Bhattacharjya et al. (2023); Cai (2022); Cai and Lattu (2022), and Shin et al. (2023), who emphasise that the Quadruple Helix accelerates digital transformation through collaborative innovative environments and the Quadruple Helix Innovation theory (Carayannis & Campbell, 2009), which emphasizes the dynamics of knowledge-based innovation. However, the direct effect of the Quadruple Helix on MSME sustainability was not significant ($\beta = 0.103$; $p = 0.220$), supporting the view that multi-actor collaboration's contribution is more effective when mediated by digital transformation and financial innovation (Bhattacharjya et al., 2023; Hu, Guo, & Zhai, 2023; Nordberg et al., 2020; Yun & Liu, 2019).

Digital transformation is found to be significant to financial innovation ($\beta = 0.291$; $p < 0.001$), which supports MSMEs' access to fintech, e-wallet, and digital financing services (Garzoni et al., 2020; Škare et al., 2024). Additionally, digital transformation also positively affects sustainability ($\beta = 0.371$; $p < 0.001$) in line with (Majali et al., 2022), who emphasised its role in driving green entrepreneurial orientation. Financial innovation is also significant for sustainability ($\beta = 0.187$; $p = 0.014$), reinforcing studies by Mekinjić et al. (2020) that innovative financing instruments support the growth of green MSMEs. The path analysis shows that the Quadruple Helix's role in MSME sustainability is significant only through digital transformation mediation ($\beta = 0.066$; $t = 2.068$; $p < 0.05$). This means that collaboration across actors, government, academics, business actors, and communities does not automatically improve sustainability but must be internalized through the adoption of digital technology. Digital transformation is a crucial mechanism that converts external support into tangible capabilities for MSMEs to achieve efficiency, expand markets, and increase sustainable competitiveness. Similarly, financial innovation also significantly influences MSME sustainability through digital transformation ($\beta = 0.054$; $t = 2.053$; $p < 0.05$). This confirms that innovative financial services such as fintech, e-wallets, and crowdfunding will have an optimal impact on sustainability when integrated with the digitalization process. Thus, both the Quadruple Helix and financial innovation require digital transformation as the main bridge to contribute to MSME sustainability within a green economy framework. Therefore, the sustainability of green economy-based MSMEs is mainly determined by digital transformation and financial innovation as key mediators (Mudmainna & Sanapang, 2025).

5. DISCUSSION

To provide a more comprehensive overview of the hypothesis testing results, Table 4 presents a summary of the overall findings based on path analysis in the structural model. This table summarizes the acceptance or rejection status of each hypothesis, accompanied by the t-statistic and p-value values that form the basis for the determination. This presentation facilitates the interpretation of the consistency of empirical findings with the theoretical framework constructed in the study and serves as the main basis for developing a more in-depth discussion.

Table 4. Results.

Items	T statistics (|O/STDEV|)	P values	Results
H1. Quadruple helix →Digital transformation	4.348	0.000	Accepted
H2. Quadruple helix → MSMEs sustainability	1.228	0.220	Rejected
H3. Digital transformation → Financial innovation	3.892	0.000	Accepted
H4. Digital transformation → MSMEs sustainability	4.671	0.000	Accepted
H5. Financial innovation → MSMEs sustainability	2.459	0.014	Accepted
H6. Quadruple helix →Digital transformation → MSMEs sustainability	*2.068*	*0.039*	Accepted
H7. Financial innovation →Digital transformation→ MSMEs sustainability	2.053	0.040	Accepted

Source: Researchers, Data Processed, 2025.

5.1. Discussion Based on Hypothesis Testing Results

H_1: Quadruple Helix → Digital Transformation (Accepted).

The results indicate that the Quadruple Helix (QH) has a positive and significant effect on digital transformation. This finding confirms that collaboration among government, industry, academia, and society plays a crucial role in fostering digital adoption among MSMEs. QH provides institutional support, knowledge transfer, and legitimacy that encourage MSMEs to adopt digital technologies. This result is consistent with prior studies emphasizing QH as a catalyst for innovation ecosystems rather than a direct driver of performance outcomes (Aggarwal & Sindakis, 2022; Okfalisa et al., 2022).

H_2: Quadruple Helix → MSMEs Sustainability (Rejected).

The analysis shows that QH does not have a direct effect on MSME sustainability. This suggests that multi-actor collaboration alone is insufficient to generate sustainable outcomes without being translated into internal capabilities. From a Stakeholder Theory perspective, QH enhances engagement and policy alignment, but sustainability outcomes require internal strategic resources. This finding supports the argument that external support must be operationalized through organizational capabilities to influence sustainability performance (Yusfiarto, 2023).

H_3: Digital Transformation → Financial Innovation (Accepted).

The findings demonstrate that digital transformation significantly influences financial innovation. Digital adoption enables MSMEs to access and utilize digital financial services, including fintech platforms, e-wallets, and digital payment systems. This result confirms that digital readiness is a prerequisite for financial innovation and supports previous studies highlighting the role of digital infrastructure in accelerating financial inclusion and innovation (Anifa et al., 2022; Leščinská et al., 2025).

H_4: Digital Transformation → MSMEs Sustainability (Accepted).

Digital transformation has a strong and significant effect on MSME sustainability. This finding aligns with the literature suggesting that digital technologies improve operational efficiency, market access, and customer engagement, which collectively enhance economic, social, and environmental performance. The result reinforces the Triple Bottom Line perspective, where digitalization contributes simultaneously to economic resilience, social inclusion, and environmental awareness (Adomako & Nguyen, 2023; Baiyere, Salmela, Nieminen, & Kankainen, 2025; Elkington, 1998; Slavković, Pavlović, Mamula Nikolić, Vučenović, & Bugarčić, 2023).

H_5: Financial Innovation → MSMEs Sustainability (Accepted).

The results confirm that financial innovation positively affects MSME sustainability. Innovative financial mechanisms improve access to capital, enhance resilience, and support long-term business continuity. In the context of the green economy, financial innovation enables MSMEs to invest in environmentally friendly practices and sustainable technologies, supporting previous empirical evidence (Angreyani et al., 2023; Anifa et al., 2022; Permatasari & Gunawan, 2023).

H_6: Quadruple Helix → Digital Transformation → MSMEs Sustainability (Accepted).

The mediating effect of digital transformation in the relationship between QH and sustainability is statistically significant. This indicates that QH contributes to MSME sustainability indirectly through digital transformation. Digitalization acts as the mechanism that converts external collaboration and policy support into sustainable business practices. This finding addresses the research gap by empirically confirming the mediating role of digital transformation.

H_7: Financial Innovation → Digital Transformation → MSMEs Sustainability (Accepted).

Digital transformation significantly mediates the relationship between financial innovation and MSME sustainability. Financial resources alone do not guarantee sustainability unless MSMEs possess the digital capabilities to utilize them effectively. This supports the Resource-Based View, emphasizing digital capability as a strategic internal resource that enables MSMEs to leverage financial innovation for sustainable outcomes (Oneshko, Ostropolska, Pomazun, Hrynchyshyn, & Rak, 2022; Zhou, Zhang, & Li, 2023).

6. CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH DIRECTIONS

This study provides empirical evidence that MSME sustainability in the green economy context is not driven by isolated factors but by the interaction between external collaboration, internal capabilities, and financial support mechanisms. The results demonstrate that the Quadruple Helix significantly promotes digital transformation, confirming its role as an ecosystem builder that facilitates knowledge exchange, stakeholder engagement, and institutional support. However, the Quadruple Helix does not directly influence MSME sustainability, indicating that collaborative governance alone is insufficient without effective internal adoption of digital capabilities.

Digital transformation is a proven critical mediating mechanism that translates both Quadruple Helix collaboration and financial innovation into sustainable outcomes. It significantly enhances MSME sustainability by improving operational efficiency, market reach, and adaptive capacity, aligning with the Resource-Based View and Triple Bottom Line perspectives. Financial innovation also plays a dual role, directly strengthening sustainability and indirectly accelerating it through digital transformation. Overall, this study confirms that digital transformation functions as the central pathway through which external support and financial resources are converted into long-term MSME sustainability within the green economy framework.

Despite its contributions, this study has several limitations. First, the cross-sectional design restricts the ability to capture dynamic changes in digital transformation and sustainability over time. Longitudinal studies are recommended to examine causal evolution and long-term impacts. Second, the research focuses on MSMEs within a specific regional and sectoral context, which may limit generalizability to other industries or geographic settings. Future studies could expand the scope by incorporating cross-country or multi-sector comparisons.

Third, the measurement of sustainability primarily relies on perceptual indicators, which may be subject to respondent bias. Future research could integrate objective performance data or environmental metrics to enhance robustness. Additionally, exploring mediating or moderating variables, such as green leadership, organizational culture, or regulatory quality, may enrich the model's explanatory power and deepen understanding of sustainable MSME development in the green economy era.

Funding: This research was funded by the Ministry of Higher Education, Science, and Technology of the Republic of Indonesia through the Directorate of Research and Development under the Fundamental Research Grant 2025 (No. 130/C3/DT.05.00/PL/2025.
Institutional Review Board Statement: The Ethics Committee Ciputra School of Business Makassar approved this research based on research permit letter No. 001/UCM-LPPM/SKel/VI/2025 on June 25, 2025.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Data Availability Statement: Upon a reasonable request, the supporting data of this study can be provided by the corresponding author.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Disclosure of AI Use: The author(s) employed OpenAI's ChatGPT to assist in improving the clarity and coherence of the Introduction. All generated content was carefully reviewed, validated, and approved by the authors.

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