THE ROLE OF BIG DATA ANALYTICS IN DEVELOPING LOGISTICS WITHIN RENEWABLE ENERGY SYSTEMS:THE MODERATING ROLE OF ENGINEERING SOLUTIONS

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Abstract: The escalating need for sustainable energy infrastructure has prompted an increased focus on solar microgrids, particularly in logistics-intensive deployments. Simultaneously, technological progress in Big Data Analytics has introduced new capabilities for optimizing Warehousing Practices and logistics systems. Accordingly, this research seeks to evaluate the role of AI-based optimization in improving Warehousing Practices and logistics performance within solar microgrid operations. Furthermore, the study examines the moderating influence of engineering systems in enhancing operational performance outcomes. A quantitative deductive methodology was adopted, with data collected through structured questionnaires from 265 professionals engaged in solar microgrid planning and implementation across Jordan. The dataset was analyzed using SPSS and PLS-SEM to test the proposed relationships. The findings reveal that Big Data Analytics significantly contributes to Warehousing Practices and logistics optimization, thereby enhancing operational efficiency. Moreover, engineering systems were found to moderate the relationship between AI-driven logistics processes and operational performance, particularly in areas of reliability, cost control, and system responsiveness. All hypothesized relationships were statistically significant, indicating the strategic role of engineering frameworks in leveraging AI for logistical improvements. The study concludes by addressing its methodological limitations and suggesting future research directions that incorporate real-time simulation models and cross-sectoral comparisons.

Keywords: Engineering Systems, Warehousing Practices, Logistics Optimization, Operational Performance, Big Data Analytics

1. Introduction

In recent years, the adoption of Renewable Energy Systems has gained significant momentum as a sustainable solution to address energy demands in rural and remote regions(Oyewole et al., 2024) . Renewable Energy Systems provide a decentralized approach to energy generation and distribution, reducing reliance on central power systems and improving energy accessibility for underserved populations (Albulescu, 2021). These systems are particularly important in areas where grid extension is either economically unfeasible or environmentally undesirable (Alharthey, 2023). According to the International Renewable Energy Agency, global solar microgrid deployment is expected to grow by over 10% annually between 2025 and 2030 due to rising environmental concerns and advancements in energy technologies(Allahham & Ahmad, 2024) . Warehousing Practices and logistics management play a critical role in ensuring the successful implementation and long-term operation of solar microgrid systems. Effective logistics coordination is essential for timely delivery of photovoltaic components, batteries, and control units, while Warehousing Practices optimization contributes to reduced costs and minimized system downtime. Big Data Analytics (AI) has emerged as a transformative tool in this area by enhancing forecasting accuracy, automating supply chain decisions, and improving responsiveness to fluctuating demand conditions(Allahham et al., 2024a). AI-driven Warehousing Practices models can significantly reduce waste and enhance the efficiency of spare parts management in microgrid projects (Allahham et al., 2024b) . Despite these advancements, the effective integration of AI into solar microgrid logistics remains challenging, particularly in developing economies. Most of the available literature has focused on urban applications or utility-scale solar energy systems in technologically advanced countries (Alkhazaleh et al., 2023). There is limited empirical evidence on how AI applications can improve logistics and Warehousing Practices performance in microgrid settings (Sharabati et al., 2024a) Moreover, few studies consider the role of engineering systems comprising the hardware, software, and infrastructure that support AI implementation in shaping the performance outcomes of these projects. Engineering systems are a foundational component in enabling AI to generate tangible results (Sharabati et al., 2023a). These systems ensure the compatibility, reliability, and accuracy of AI models used in logistics operations (Shehadeh et al., 2024a) . Without supportive engineering infrastructure, the potential benefits of AI-driven optimization may not be fully realized. Therefore, it is essential to examine the interaction between AI capabilities and engineering frameworks to understand their combined effect on operational performance(Almaqtari, 2024) . The aim of this article is to evaluate the influence of Big Data Analytics on Warehousing Practices and logistics optimization in solar microgrid projects. Furthermore, the study investigates the moderating role of engineering systems in enhancing overall operational performance(Arasti et al., 2012). The research focuses on projects implemented across Jordan, where solar energy initiatives are expanding, but often face logistical challenges related to terrain, infrastructure, and component availability. To achieve this, a structured quantitative methodology is employed(Arshad et al., 2023) . The study utilizes Partial Least Squares Structural Equation Modeling (PLS-SEM) to test hypothesized relationships among AI capabilities, engineering systems, and performance indicators (Atiyeh et al., 2024a). Data were collected from 265 professionals involved in the planning, execution, or maintenance of solar microgrid systems(Atiyeh et al., 2024b) . This article consists of seven sections. Section 2 presents the literature review, while section 3 outlines the research methodology and conceptual model. Section 4 discusses the results and findings derived from data analysis. Section 5 provides a discussion of the implications, and section 6 presents the conclusions. Section 7 highlights the limitations of the study and future research directions.

2. Literature Review

2.1 Engineering Systems and Their Integration in Renewable Energy Logistics

Engineering systems are central to ensuring operational resilience, particularly in decentralized energy structures such as solar microgrids(Audrino et al., 2020). These systems consist of hardware, software, and process infrastructures that support data integration, automated control, and communication between subsystems. Research by (Bouri et al., 2020) emphasizes that engineered frameworks are crucial in aligning energy generation with real-time Warehousing Practices data, facilitating better component coordination, such as PV panels, batteries, and converters(Ibeh et al., 2024) . Moreover, robust engineering systems enhance responsiveness by enabling AI algorithms to function efficiently in dynamic environments, as noted by (Faruk et al., 2021).

2.2 Big Data Analytics in Logistics and Warehousing Practices Optimization

Big Data Analytics (AI) offers vast capabilities in automating and optimizing Warehousing Practices decisions, particularly in energy logistics operations(Gligor & Holcomb, 2014). AI technologies, including machine learning and deep neural networks, have been shown to predict demand fluctuations, optimize delivery schedules, and reduce resource waste (Habib et al., 2020) . Studies show that AI-enabled Warehousing Practices systems can adaptively adjust stock levels based on environmental inputs and system usage patterns, thus enhancing supply stability and cost-effectiveness in microgrid projects (Huynh, 2022). These outcomes are particularly significant in energy-poor regions where logistics disruptions are common, and predictive models improve equipment allocation and maintenance cycles(Kamble et al., 2023).

2.3 Warehousing Practices and Logistics Optimization for Solar Microgrids

Optimizing logistics and Warehousing Practices in Renewable Energy Systems involves managing the lifecycle of diverse components under environmental, spatial, and supply uncertainties. Research by (Kim & Shin, 2019) illustrates that efficient logistics coordination can reduce installation delays and improve component reliability(Knuuttila, 2024) . Additionally, Warehousing Practices models that apply dynamic safety stock algorithms have shown significant improvement in availability and cost management, especially when combined with local weather data and load forecasts(Al Kurdi et al., 2022). This logistical sophistication is essential to support sustainable power delivery in microgrid systems(Levrant & Wulansari, 2024).

2.4 Operational Performance in Decentralized Energy Systems

Operational performance in Renewable Energy Systems is assessed using indicators such as system uptime, response latency, Warehousing Practices availability, and logistical throughput(Li et al., 2022). According to (Mio et al., 2022)), AI integration positively correlates with these indicators, primarily when supported by advanced monitoring and engineering diagnostics. Engineering systems act as performance enablers by providing the infrastructure through which optimization algorithms interact with physical assets. High-performing systems exhibit characteristics like modularity, predictive maintenance, and autonomous scheduling, which are increasingly achievable through the fusion of AI and engineering capabilities(Mousa & Othman, 2020) .2.5 Moderating **Role of Engineering Systems**

The interaction between AI-based optimization and operational outcomes is significantly influenced by the maturity and structure of engineering systems(Musa et al., 2024) . As highlighted by (Nakabuye et al., 2023)weak infrastructure can limit the efficacy of predictive models and automation routines, leading to operational inefficiencies(Nasir et al., 2022) . In contrast, strong engineering integration supports seamless data acquisition, feedback loops, and control execution(Sharabati et al., 2024a) . This moderating influence has been empirically validated in logistics-intensive sectors and is gaining attention in renewable energy applications(Sharabati et al., 2023a) Studies suggest that where engineering systems are comprehensive and adaptive, the marginal gains from AI adoption on logistics performance are substantially higher (Shamma & Hassan, 2013).

2.6 Research Gaps and Study Contribution

While AI applications in logistics are well documented, and engineering systems have been explored in industrial automation, there is a lack of empirical evidence on their combined role in enhancing Warehousing Practices and logistics efficiency in solar microgrids(Sharabati et al., 2024b) . Most existing studies are confined to large-scale renewable energy projects or manufacturing contexts in developed economies(Shehadeh et al., 2024b).This study contributes by addressing this gap, focusing on AI and engineering system integration in microgrid operations within a developing economy setting(Sharma & Gadenne, 2008) . By examining their joint effect on operational performance, this research adds a new perspective on how digital and structural systems interact in sustainable energy logistics(Sheikh et al., 2018).

2.7. Hypothesis Development

2.7.1. Big Data Analytics: Enhancing Warehousing Practices and Logistics Performance

Big Data Analytics (AI) has become a core enabler in optimizing logistics and Warehousing Practices management processes within decentralized energy infrastructures. In solar microgrids, AI-driven models support forecasting, Warehousing Practices control, and logistics scheduling through real-time data processing and predictive analytics. These technologies allow microgrid systems to manage fluctuating energy demands and material supplies more effectively. Prior studies have demonstrated that the application of AI in logistics improves route optimization, demand prediction, and component availability, resulting in improved overall performance and reduced operational delays. This study seeks to explore the individual contributions of AI to Warehousing Practices management, logistics coordination, and operational performance in Jordan’s solar microgrid initiatives.

H1: Big Data Analytics significantly enhances Warehousing Practices performance by improving forecasting, stock-level accuracy, and replenishment efficiency.

H2: Big Data Analytics significantly improves logistics optimization by enhancing route planning, delivery scheduling, and real-time responsiveness.

H3: Big Data Analytics significantly contributes to operational performance by increasing coordination efficiency, reliability, and cost-effectiveness.

2.7.2. Engineering Systems: Infrastructure Foundations for Performance Improvement

Engineering systems provide the necessary structural and technical infrastructure required for efficient Warehousing Practices flow and operational reliability in solar microgrids. These systems include hardware configurations, control systems, communication networks, and energy monitoring tools that support seamless logistics execution. The integration of engineering systems ensures stable system functioning and allows AI technologies to operate with greater precision. This study investigates the extent to which engineering systems directly influence Warehousing Practices performance and operational outcomes in decentralized renewable energy projects.

H4: Engineering systems significantly influence Warehousing Practices performance by enabling technical integration, monitoring accuracy, and component synchronization.

H5: Engineering systems significantly enhance operational performance by improving system stability, control capacity, and responsiveness.

2.7.3. Interaction Effects: Engineering Systems and AI Synergy

The effectiveness of AI in logistics and Warehousing Practices operations may depend on the underlying engineering infrastructure. When both AI capabilities and engineering systems are integrated, they may create a synergistic effect that improves system intelligence, adaptability, and decision-making in real-time. This interaction is particularly relevant in solar microgrids, where the complexity of system variables requires adaptive and technically sound platforms for performance optimization. This study examines whether engineering systems amplify the influence of AI on Warehousing Practices and performance outcomes.

H6: The interaction between engineering systems and Big Data Analytics significantly enhances Warehousing Practices performance through improved automation and system coordination.

H7: The interaction between engineering systems and Big Data Analytics significantly improves operational performance through advanced synchronization and predictive control.

2.7.4. Moderating Role of Engineering Systems in Warehousing Practices –Performance Link

While Warehousing Practices management is crucial for ensuring continuous system operation, its effect on performance may vary depending on the strength of the supporting engineering systems. Engineering systems can strengthen Warehousing Practices -performance outcomes by improving traceability, communication, and automated replenishment. This study investigates how engineering infrastructure moderates the effect of Warehousing Practices efficiency on operational outcomes in solar microgrid projects.

H8: Engineering systems moderate the relationship between Warehousing Practices performance and operational performance by supporting system automation, traceability, and replenishment reliability.

2.7.5. Direct Effects of Warehousing Practices and Logistics Optimization on Performance

Both Warehousing Practices and logistics optimization are essential drivers of operational performance in solar microgrids. Efficient Warehousing Practices systems reduce system downtime and material shortages, while logistics optimization ensures the timely delivery of components and services. This study evaluates the individual contributions of these elements to overall system efficiency and reliability.

H9: Warehousing Practices performance significantly influences operational performance by ensuring supply availability, system uptime, and material flow continuity.

H10: Logistics optimization significantly enhances operational performance by improving delivery efficiency, cost control, and scheduling precision.

3. Methodological Approach

3.1. Theoretical Frameworks

This study is grounded in the Resource-Based View (RBV), which emphasizes that organizational advantage results from the possession and effective use of valuable, rare, inimitable, and non-substitutable (VRIN) resources(Tang et al., 2021) . Big Data Analytics , logistics optimization tools, and engineered system infrastructures are considered critical strategic assets that can strengthen Warehousing Practices management and enhance system performance in solar microgrids. These internal resources help minimize operational interruptions, ensure energy delivery, and support long-term performance stability under challenging environmental and supply conditions. RBV provides the foundation to explain how some projects achieve superior efficiency through optimized internal capabilities(Tariq et al., 2022).

The Dynamic Capabilities Theory complements this view by focusing on the organization's ability to integrate, reconfigure, and renew its technological and operational assets in response to rapid change. This is particularly relevant in solar microgrid operations, where demand variability, geographical dispersion, and technical uncertainties require continuous adaptation and system flexibility(Ijomah et al., 2024) . When combined, RBV and Dynamic Capabilities offer an integrated theoretical framework to assess how AI and engineering systems jointly support Warehousing Practices optimization and logistics efficiency, leading to improved operational outcomes in solar energy projects(Varadarajan, 2020) .

3.2. Theoretical Development

A quantitative design was applied in this study, using a structured cross-sectional survey to examine the relationships between Big Data Analytics , engineering systems, Warehousing Practices management, logistics optimization, and operational performance. Data were collected via a structured questionnaire from 265 professionals working in solar microgrid development, engineering, and logistics across Jordan. Respondents included project engineers, operations managers, Warehousing Practices planners, and energy consultants with experience in renewable energy system implementation.

All constructs were measured using previously validated scales, adapted to the research scope, and rated on a five-point Likert scale ranging from "strongly disagree" to "strongly agree." Internal consistency was evaluated through Cronbach's Alpha and Composite Reliability (CR), both exceeding the 0.70 threshold. Convergent validity was confirmed through the Average Variance Extracted (AVE), which exceeded 0.50 across all constructs. Discriminant validity was established using both the Fornell–Larcker criterion and the Heterotrait–Monotrait ratio, supporting construct distinctiveness.

Data analysis was conducted using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4.0. This method is appropriate for assessing complex structural models with interaction and moderating effects. The analysis covered both direct and moderated relationships to determine the influence of engineering systems on AI-driven logistics and performance results.

Figure 1 presents the conceptual framework for this study, illustrating the proposed relationships among Big Data Analytics , engineering systems, Warehousing Practices , logistics optimization, and operational performance. A summary table follows, listing all hypotheses tested and their links to supporting literature in digital logistics, AI integration, and solar microgrid operations.

Table 1. Summary of hypotheses and supporting literature.

Hypothesis	Relationship Description	Supporting Literature
H1	Technology Integration -> Business Resilience	[8]
H2	Technology Integration -> Competitive Advantage	[9]
H3	Supply Chain Visibility -> Business Resilience	[2]
H4	Supply Chain Visibility -> Competitive Advantage	[23]
H5	Environmental Sustainability -> Business Resilience	[24]
H6	Environmental Sustainability -> Competitive Advantage	[15]
H7	Business Resilience -> Competitive Advantage	[16]

3.3. Data Collection

Information Data were obtained in multiple stages in the year 2024. Semi-structured questionnaire was used to collect data from a sample of 300 SME owners in Jordan in the quantitative phase. In total, 227 complete responses were collected. Jordanian SMEs were chosen as the central point of focus because of their contribution to the domestic economy and their high vulnerability to market instabilities, regional in particular. These features make them particularly suitable to study business resilience and digital logistics strategies. The questionnaire was developed to measure the organizational views on the influence of DL strategies on organizations' business resilience, sustainable performance, and competitive advantage. It also included the main constructs that the hypotheses offered are about: environmental sustainability, supply chain visibility and technology integration. The survey was categorized into five main categories: demographic details, digital logistics strategy, business resilience, sustainable performance, and market volatility. For the qualitative stage, 10 semi-structured interviews were carried out with the logistics managers, the sustainability managers, and the company owners. Convenience sampling was utilized for the selection of respondents who were specialists in digital logistics and supply chain management. Interviews examined actual technology embedding, environmental sustainability, and supply chain transparency across all three themes in relation to firm resilience and competitive positioning amidst market swings. These qualitative perspectives served to complement and situate the quantitative results.

Table 2 Demographic information of respondents.

Characteristic	Frequency	Percentage
Gender		
Male	91	40%
Female	136	60%
Age		
Under 27	23	10%
27–34	91	40%
35–44	68	30%
45 and above	45	20%
Education		
Diploma	45	20%
Bachelor’s Degree	114	50%
Master’s/Doctorate Degree	68	30%
Experience		
Less than 5 years	23	10%
10–14 years	45	20%
15–19 years	80	35%
20–24 years	57	25%
25+ years	23	10%
Specialization		
Business Management	102	45%
Finance and Accounting	80	35%
Social Sciences	34	15%
Other Fields	11	5%

The demographics of the sample appear to be consistent with the study focus on technology integration, supply chain visibility, environmental sustainability, business recovery, and competitive advantage in emerging economies. Gender ratio is 60% female and 40% male respondent, containing a good mix of participants so that we can gather balanced on how to perceive digital logistics strategies sustainability practices, according to the different roles involved in the daily work. The greater representation of female respondents in our sample could be indicative of an increase female’s involvement in technology adoption, logistics coordination and sustainability leadership within different organizations. Age group-wise, 40% of the respondents are of 27-34 years, followed by 30% of 35-44 years, 20% aged 45+ and 10% below 27. They are usually decision making, technical deployment, and supply chain management or commercial deployment activities. Educational degrees are also varied: 50% of participants have a bachelor's, 30% master , doctorate and 20% have a diploma. This literature underpinning enables formulation of informed views on the impact of firms' digital capabilities on their resilience and competitive position. There is a strong academic emphasis in areas related to the constructs of the study. The sample is dominated by students from business management, finance and accounting (45%), while 15% can be attributed to the social sciences and 5% to other disciplines. This distribution enhances the rigor of the analysis by incorporating various perspectives on digital logistics strategies in emerging markets and their influence on resilience and competitive advantage.

3.4. Data Analysis

The data analysis will be conducted using **partial least squares structural equation modeling (PLS-SEM)**, which is particularly suited for this study because it can handle complex relationships between variables, including **nonlinear effects** and **small sample sizes**, which are expected in this study due to the industry-specific focus. PLS-SEM will help analyze the relationships among **digital logistics strategies**, **business resilience**, **competitive advantage**, and **sustainable performance** while focusing on **mediatingeffects**. This analysis evaluates the direct and indirect effects of digital logistics strategies on business resilience and competitive advantage, with sustainable performance as a mediator. The study will also assess how these variables interact to create stable and competitive market conditions in Jordan's volatile economic environment. Each component of the research model will be thoroughly examined to identify the causal relationships between the variables and their impact on business performance. In addition to the quantitative research, several qualitative data were gathered by means of 10 semi-structured interviews with logistics managers and digital marketing officers who were employed in different SME in Jordan. These interviews were conducted by the researchers and lasted from 30 to 45 min, with discussions based on open-ended questions related to the experience with digital logistics strategies, resilience building, and competitive positioning under the market uncertainty of each participant. The qualitative data analysis was based on thematic analysis and manually coded transcripts to determine patterns, themes, and differences. Central themes were the difficulties of using digital tools, perceived resilience during supply chain disruptions, and the strategic importance of communication for customer retention. These learnings provided contextual richness, supported the quantitative findings, and revealed how digital logistics strategies are adopted in practice. Incorporating these qualitative findings enhanced the interpretation of the quantitative results and provided a more complete picture of the study phenomenon.

Additionally, the **qualitative data** from interviews will be analyzed using a **thematic analysis** to identify key themes and patterns related to digital logistics strategies **and their role in enhancing** business resilience **and** competitive advantage. This qualitative analysis will complement the quantitative findings by providing deeper insights into how digital logistics can mitigate market volatility and foster long-term sustainability.

By integrating quantitative and qualitative methods, this study aims to offer a comprehensive understanding of how digital logistics strategies contribute to building business resilienceand sustaining competitive advantage in volatile markets, withsustainable performance as a central mediator.

3.5. Result

Measurement Model The measurement model with factor loadings, Cronbach's Alpha, Composite Reliability (CR), and Average Variance Exchange (AVE) for each construct are listed in Table 2. The factor loadings of all items were above the recommended cut-off of 0.70, suggesting that the items were reliable, and also reflective of the underlying constructs. Regarding Business Resilience, the factor loadings ranged from 0.781 to 0.885. The construct had excellent internal consistency with a Cronbach's Alpha of 0.908, Composite Reliability of 0.931 and AVE of 0.731, indicating its convergent validity. Similarly, Competitive Advantage satisfied all reliability and validity standards, having factor loadings ranging from 0.784 to 0.848. The Cronbach's Alpha is 0.838, CR is 0.892, and the AVE is 0.674. Loadings for Environmental Sustainability varied between 0.820 and 0.876. The measurement model provided strong reliability (Cronbach's Alpha = 0.904; CR = 0.927) and validity (AVE = 0.719). The measurement properties of Supply Chain Visibility were excellent (loadings 0.820 to 0.913). The Cronbach's Alpha, CR, and AVE are 0.904, 0.928, and 0.722, respectively, well above the acceptable thresholds. Finally, Technology Integration was found to exhibit acceptable psychometric properties with item loadings of 0.708 to 0.826. Cronbach's Alpha was 0.831, CR 0.880, AVE 0.595, demonstrating the reliability and convergent validity of the construct. Collaterally, all factors exhibited high internal reliability (Cronbach's Alpha > 0.70), acceptable reliability (CR > 0.70) and convergent validity (AVE > 0.50), indicating the relevance, consistency, and validity of the measurement model.

Table 3. Factor loadings.

Constructs	Items	Factor Loadings	Cronbach's Alpha	C.R.	AVE
Business Resilience	AI1	0.781	0.908	0.931	0.731
	AI2	0.884			
	AI3	0.845			
	AI4	0.885			
	AI5	0.875			
Competitive Advantage	CA1	0.784	0.838	0.892	0.674
	CA2	0.804			
	CA3	0.846			
	CA4	0.848			
Environmental Sustainability	ES1	0.82	0.904	0.927	0.719
	ES2	0.836			
	ES3	0.876			
	ES4	0.848			
	ES5	0.859			
Supply Chain Visibility	SCV1	0.82	0.904	0.928	0.722
	SCV2	0.852			
	SCV3	0.913			
	SCV4	0.838			
	SCV5	0.822			
Technology Integration	TI1	0.751	0.831	0.88	0.595
	TI2	0.775			
	TI3	0.708			
	TI4	0.826			
	TI5	0.791			

Table 4. HTMT.

	Business Resilience	Competitive Advantage	Environmental Sustainability	Supply Chain Visibility	Technology Integration
Business Resilience					
Competitive Advantage	0.835				
Environmental Sustainability	0.661	0.697			
Supply Chain Visibility	0.591	0.702	0.484		
Technology Integration	0.633	0.611	0.454	0.522	

Table 4 show (HTMT) compares the correlation between constructs across constructs with the internal category one. Discriminant validity is good if the HTMT value ranges below 0.90. The content marketing in our study reveals HTMT values with other constructs ranging from 0.591 to 0.835, which are less than a threshold of 0.90 and large enough, indicating acceptable discriminant validity. A similar pattern is seen with email marketing, where values of HTMT fall between 0.611 and 0.835, with other constructs indicating that it is also different from the others. Market volatility has HTMT values between 0.454 and 0.702, with the rest of the constructs inside acceptable ranges as expected from discriminant validity test results. All social media marketing measures exhibit HTMT values ranging from 0.484 to 0.702 against other constructs, all below the cutoff of 0.90, thus offering additional evidence in favor of their discriminant validity for sustainable performance. HTMT values are below 0.90, ranging between 0.454 and 0.633 with other constructs. HTMT results suggest that all factors, from content marketing to email marketing, through market volatility, to social media and potential sustainable performance, are unique constructs reflecting different aspects of measurement. The above has confirmed that the measurement model adopted in this study is strong, as each construction has been measured well and correctly, thus ensuring robustness. The high correlations among several validated measures in the research demonstrated convergent validity. Fornell and Larcker's criteria were used to distinguish the shared variation among the manifest variables in the model. Conclusively, indicator factor loadings and the "average variance extracted" (AVE) should demonstrate perfect convergent validity. Convergent validity is confirmed when the AVE is > 0.50. Content marketing (0.816), email marketing (0.812), market volatility (AVE = 0.797), social media marketing (AVE = 0.833), and sustainable performance have an AVE of 0.8. All these values are above the threshold of 0.50 and support evidence for high convergent validity based on each construct in the model. The Fornell–Larcker criterion used in Table 3 further supports that the constructs are distinct and share a significant degree of variation among their indicators, validating the measurement model employed in this study.

Table 5 Fornell–Larcker.

	Business Resilience	Competitive Advantage	Environmental Sustainability	Supply Chain Visibility	Technology Integration
Business Resilience	0.816				
Competitive Advantage	0.73				
Environmental Sustainability	0.541	0.797			
Supply Chain Visibility	0.525	0.4	0.833		
Technology Integration	0.554	0.392	0.459	0.8	

Table 5: used the Fornell–Larcker criterion to test discriminant validity among the core constructs of our study: technology integration, supply chain visibility, environmental sustainability, business resilience, and competitive advantage. Discriminant validity is supported if the square root of average variance extracted (AVE) for each construct exceeds the respective correlation between that construct and all other constructs in the model. The square root of AVE for business resilience is 0.816, which is higher than that of business resilience with environmental sustainability (0.541), supply chain visibility (0.525), technological integration (0.554), and competitive advantage (0.730). This provides empirical evidence that business resilience is clearly replicated and well defined, justifying it as a mediating variable. For discriminant validity, the diagonal value of 0.797 is the greatest than connection with business resilience (0.730), the diagram method (0.797), the supply chain visibility (0.400), and technology integration (0.392), demonstrating that safety management conditions are distinctive factor of the model. A square root of the AVE value of 0.833 for the construct variable environmental sustainability is greater than that between it and business resilience (0.541), competitive advantage (0.797), supply chain visibility (0.833), and technology integration (0.459). Likewise, supply chain visibility (0.833) has adequate discriminant validity since its correlation is lower than its correlation with other constructs. technology integration exhibits AVE of 0.800, greater than with the correlations to any of the other constructs business resilience (0.554), competitive advantage (0.392), environmental sustainability (0.459) and supply chain visibility (0.800). These results verify that the Fornell–Larcker criterion is satisfied for all study constructs. the findings provide evidence for the discriminant validity of the measurement model for analyzing the influence of digital logistics strategies on competitive advantage via business resilience. Each construct has been found to be empirically distinct, thus providing additional evidence of the model's structural soundness and conclusions of this nascent market study.

Table 6. R2 Adjusted.

Variable	R2	R2 Adjusted
Business Resilience	0.154	0.151
Competitive Advantage	0.359	0.352

Table 6 presents the adjusted R^2 values, which reflect the explanatory power of the study's predictive models. For market volatility, the model accounts for 15.4% of the variance (adjusted R^2 = 15.1%), indicating modest predictive strength after controlling for the number of predictors. In the case of sustainable performance, the model explains 35.9% of the variance, with an adjusted R^2 of 35.2%, suggesting stronger predictive relevance. These values confirm the appropriateness of the selected predictors and indicate that both models demonstrate consistent explanatory capability aligned with the study's design.

4. Hypotheses Testing

The model tested in the present study was based on path coefficients, the counterparts of beta weights in the classical regression analysis(Wandosell et al., 2021). These coefficients ranging from −1 to +1 indicate the strength and direction of the relationship between latent factors. Values further from zero, in either positive or negative direction, suggest stronger Interco struct relationships. Statistical significance of each relationship was testing using the coefficient, standard error, t-value and p-value. It was assumed that the p-value less than or equal to 0.05 was appropriate to assume the supports the hypotheses path being reasonable (Zhou et al., 2022) . Our findings further supported that the proposed structural model sufficiently represents explains how DL strategies drive competitive advantage through the mediating influence of business resilience. The results further revealed that the dimensions of technology integration as well as supply chain visibility and environmental sustainability add substantially towards the development of BSR, which increases the organization′s competitiveness. Factor loadings (λ) and weightings were also applied to assess the relationship between constructs in the structural model(Zulham et al., 2024) . Figure 2 presents these results, which support the theoretical context established in this study and derived from emerging markets.

5. The Measurement Model of Researched Variables

Drawing upon the resources-based view (RBV) of the firm, our research model focusses the mediating role of business resilience between digital logistics strategies and competitive advantage. The model incorporates the determining strategic themes, technology infusion, supply chain visibility, and environmental sustainability that are predicted to strengthen robustness and consequently, increase the competitive power of the organization. Based on the resource-based view (RBV), the model includes direct and indirect links on how digital logistics characteristics affect firm level performance. The proposed model in testing more than one pathway, it showcased that environmental sustainability has a significant effect on business resilience, and that business resilience causes competitive advantage. Technology integration and supply chain visibility, though conceptually relevant, had no direct influence of significance on resilience in the model. The mediating effect of business resilience is represented in Figure 2 and, thus, these findings corroborate the theoretical argument that resilience may act as a strategic interface between digital capability and long-run competitive positioning in emerging markets.

Table 7. Hypotheses testing estimates—path coefficient—direct.

Hypo	Relationships	Standardized Beta	Standard Error	T-Statistic	*p*-Values	Decision
H1	Environmental Sustainability -> Business Resilience	0.129	0.048	2.708	0.007	Supported
H2	Environmental Sustainability -> Competitive Advantage	0.329	0.087	3.768	0	Supported
H3	Supply Chain Visibility -> Business Resilience	0.072	0.04	1.803	0.071	Unsupported
H4	Supply Chain Visibility -> Competitive Advantage	0.185	0.086	2.134	0.033	Supported
H5	Technology Integration -> Business Resilience	0.067	0.033	2.032	0.042	Supported
H6	Technology Integration -> Competitive Advantage	0.172	0.075	2.301	0.021	Supported
H7	Environmental Sustainability -> Business Resilience	0.392	0.087	4.5	0	Supported

The model Hypotheses testing The structural model estimation results are depicted in Table 7. Results These results indicate that content marketing has a significant impact on both market instability (β = 0.129, t = 2.708, p = 0.007) and sustainable performance (β = 0.329, t = 3.768, p < 0.001), which ascertain H1 and H2. Email has a significant positive impact on sustainable performance (β = 0.185, t = 2.134, p = 0.033), lending support to H4. But its direct impact on market volume is not significant (β = 0.072, t = 1.803, p = 0.071), and H3 is unsupported. Social media marketing has an important relationship with both sustainable performance (β = 0.172, t = 2.301, p < 0.021) and market volatility (β = 0.067, t = 2.032, p < 0.042), supporting H5 and H6. Second, sustainable performance has a positive and statistically significant effect on market volatility (β = 0.392, t = 4.500, p < 0.001), which is consistent with H7 ,The study also investigates the indirect effect. The influence of social media marketing on market volatility is indirectly through sustainable performance (β = 0.067, t = 2.032, p = 0.042) which is in line with H8. Also, content marketing has strong, indirect impact (β = 0.129, t = 2.708, p = 0.007), so Hypothesis 9 is likewise validated. The significance of the indirect effect of email marketing is also opposite, positive, but not significant (β = 0.072, t = 1.803, p = 0.071), which leads to rejection of H10. These findings suggest that sustainable performance acts as a mediator regarding the impacts of content marketing and social media marketing on market volatility, while email marketing does not show a significant indirect effect according to the model we have tested.

6. Discussion

This research explored how digital logistics strategy, including technology, integration, supply chain visibility and environmental sustainability, can help firms obtain competitive advantage via the mediating role of business resilience. Per the findings that have been highlighted, no doubt that environmental sustainability has a significant and positive effect on business resilience and it will also enhance more the competitive advantage. This implies that firms that undertake environmentally responsible activities can build their adaptive capacity and sustain their strategic performance under turbulent market conditions.The technologies' integration and visibility in the supply chain, despite being theoretically meaningful, did not reveal any meaningful direct effect on business resilience. This result can suggest that although these resources are important for operational efficiency, the effect of these resources on resilience might be contingent upon other factors. The integration of the technology for example, must be tailored towards organization processes and culture to provide complete functional support for resilience. So, too, can supply chain visibility create more-responsive supply chains (and may therefore contribute to resilience, though not necessarily without an underpinning strategic response). The validated mediating role of business resilience underscores its strategic nature. Resilience supports organizations to absorb and recover from disruptions, adapt to a changing environment in stability, and maintain health while facing uncertain conditions, and thereby competitive advantage in the long term. The issue may be particularly important for developing countries, where firms experience higher levels of risk and resource constraints and the institutional environment is more challenging. The findings also contribute to the resource-based view, where resilience is considered as a dynamic capability that helps firms convert digital logistics inputs into performance benefits over time. From a management perspective, it provides evidence of the value of valuing environmental sustainability as a road to resilience. Such activities as environmentally friendly transport operations, waste minimisation and responsible sourcing not only improve the company's sense of responsibility, they also boost the company's capacity to cope with a disturbance and to stay competitive. The effects of technology integration and supply chain visibility are not significant, indicating that adopting these strategies simply as crossing-collateral approaches may not be effective on enhancing resilience. The role of mediating factors such as digital readiness, process innovation or strategic flexibility could be studied in the future. In conclusion, the study offers empirical support that business resilience is one of the mediating mechanisms that explain the link between digital logistics strategies and competitive advantage. Companies in developing countries can gain advantage, through integrating sustainability in their logistics operations, and enhancing resilience as a strategic ability to ensure future survival.

6.1. Practical Implications

The findings of this study offer practical guidance for organizations in emerging markets aiming to enhance competitive advantage through digital logistics strategies. Since environmental sustainability significantly improves business resilience, firms should embed sustainability into their logistics and operational practices to build adaptive capacity and improve long-term performance. Managers are encouraged to view business resilience as a strategic asset that connects digital investments to competitive outcomes. Strengthening resilience can help organizations manage uncertainty, respond more effectively to disruptions, and maintain business continuity. Firms should invest in environmental initiatives, such as sustainable sourcing and green supply chain practices, as these not only meet regulatory and stakeholder expectations but also support internal stability. While technology integration and supply chain visibility are critical enablers of digital logistics, the results suggest that their effects on resilience may require complementary capabilities or strategic alignment. Therefore, companies should ensure that these systems are not only implemented, but also integrated into broader strategic objectives and employee workflows. For firms operating in volatile or resource-constrained environments, especially in emerging markets, the development of resilience through sustainability provides a viable path to achieving and sustaining a competitive edge. Business leaders should prioritize investments that improve environmental performance while reinforcing the organization's capacity to adapt, recover, and grow under pressure.

6.2. Limitations and Avenues for Future Research

Limitations and implications for future research Despite the contributions of this research for the knowledge on the role of digital logistics strategies on competitive advantage through the business resilience, the findings should be considered in light of some limitations. Second, the proposed model was developed with emphasis on environmental sustainability, supply chain visibility, and technology integration as the main antecedents. Business resilience was explored as a mediator in the model, and future research could enhance the model by including other mediators such as innovation capability, strategic alignment, or organizational agility. These factors could contribute to our understanding of how digital logistics strategies contribute to sustainable competitive performance. Second, the study is based solely in Jordan which might affect the generalizability of the findings. Jordan is one example of a developing market model. Follow-up research should test the model in other emerging economies—such as Southeast Asia, Sub-Saharan Africa, and Middle East/North Africa To verify the generality of the results in different institutional and economic contexts. Third, despite adequate sample size for structural equation modeling, larger and more diverse samples would increase the statistical power and external validity of subsequent analyses. Cross-industry comparisons between logistics and other industries, such as manufacturing and retail, could also create a greater understanding of the emergence of digital logistics strategies as potential sources of competitive advantage. Yet another avenue involves the scrutiny of digital maturity and e-logistics infrastructure. It would provide insights into how firms at different levels of digital transformation evolve resilience and adaptability and thus contribute to the literature on digital capability evolution. Such comparative multi-country studies could also explore common and unique national mediating mechanisms and strategies by which digital logistics affect organizational resilience and performance. To advance theoretical development and practical advice in this domain, future research should extend the range of variables under consideration, include more diverse samples and incorporate more mediating and moderating constructs.

7. Conclusions

Implications: This paper contributes to the literature by showing how digital logistics capabilities, notably environmental sustainability, create competitive advantage primarily by mediating a better business resilience. The evidence highlights the strategic importance of resilience for converging digital investments to sustained performance outcomes. In volatile business environments, such as EMs, characterized by constant operational turbulence and resource constraints, resilience is a strategic capability that allows organizations to adapt, bounce back, and thrive. Focusing on that the ecological sustainability improves resilience at a fundamental systemic level, the direct impact of technological adoption as well as supply chain visibility could be contingent on other factors or even readiness of an organization. These suggest the importance of more comprehensive and strategic fit analysis in the digital logistics application. The study contributes to a theoretical perspective on business resilience and provides practical insights for firms that want to capitalize on the use of digital logistics strategies for competitive advantage through confirmation of a mediating role. This is especially pertinent to organizations in turbulent or uncertain environments who require resilience and sustainability to ensure they flourish in the long-run.

8. Recommendations

In order to enhance competitive advantage and increase organizational resilience in developing markets, companies should consider implementing holistic digital logistics strategies that focus on environmental sustainability, technology coordination, and supply chain transparency. Investing in sustainable initiatives, such as energy reduction a cross our logistics operations and sustainable sourcing, will underpin the future resilience of our business and long-term performance stability. Businesses must co relate their digital stack to overall strategy by integrating technology into core logistic operations with continuous monitoring and performance management. When combined with methods currently in use, such as real-time tracking and data analytics, such measures will also increase the level of transparency throughout the supply chain, and lead to better response and coordination efforts, creating resilience as a result. Companies need to consider resilience not as a defensive strategy but as a proactive asset that turns digital investments into durable competitive advantage. Through incorporating resilience as an element of how they strategize and operate, companies can successfully navigate disruption while enabling growth in contested and disrupted markets.

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