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Enhancing Agricultural Supply Chain Sustainability through Digitalization: Insights from Agricultural Waste Recycling Companies in Aswan, Egypt

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Abstract: The research aims to investigate the effect of digitalization on sustainable supply chains, particularly in recycling agricultural wastes in Egypt. The research pursues to assess current collection processes within circular supply chains, look for the opportunities of implementing digital technologies in facilitating the collection of agricultural waste, and analyze the effects of digitalization on the performance of supply chains.

Design/methodology/approach: The research utilized an inductive approach and gathered data from recycling company employees through a survey. Correlation and regression analysis was carried out to test the relationship between research variables by using SPSS.

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The study's findings that there is a significant effect of digitalization on agricultural supply chain sustainability. Also, have shown that the incorporation of applications, information and communication technology, transportation management systems, and cloud computing has a noteworthy effect on the sustainability of the supply chain. This influence is particularly pronounced in the agricultural supply chain. Based on these findings, decision-makers in the agricultural waste industry must follow the following recommendations to reach a more sustainable supply chain., including investing in digital technologies, promoting a culture of improvement and digital literacy, and forming partnerships with technology providers. These measures can enhance operations, minimize waste, and contribute to more sustainable practices, ensuring competitiveness and meeting environmental obligations.

The originality value of the Digitalization studies is a subject which has not been reviewed its effect on Agricultural Supply Chain Sustainability in Aswan, Egypt in the literature previously.

Keywords: *Digitalization, Supply chain sustainability, Agriculture wastes, Sustainability, circular supply chain.*

Introduction

Improving agricultural products depends on securing a sustainable future, which requires using Information Technology tools and methods (Riemma, et al., 2023). Digital technologies have improved control, visibility, and resource utilisation, reduced costs, and enhanced customer satisfaction in agriculture. (Lalitvamsi, et al., 2023). Also, digital technology improves supply chain sustainability by increasing efficiency and reducing energy use, transportation time and resource waste (Lalitvamsi, et al., 2023). In contrast, traditional food supply chains lack efficiency, sustainability, and coordination due to challenges in production, transportation, storage, handling, and contamination (Vukmirović, et al., 2023). However, digitalization offers the potential to enhance the efficiency of information flow and processes. Key players within the agri-food supply chain have recognized the necessity of embracing sustainable strategies and technologies to enhance performance, thus highlighting the overall importance of a sustainability and efficiency management model (Kontopanou & Tsoulfas, 2022).

So, today digital supply chains are essential to Industry development, emphasizing transparency and benefiting from improved information availability, enhanced logistics, real-time data collection, and improved inventory management (Bigliardi, et al., 2022). The above promotes an increase, in sustainability is increasingly important, encompassing environmental, social, and economic aspects. Supply chain managers make key decisions that effect the organization's environmental and social performance, focusing on ecological quality, worker treatment, and other environmental issues (Chauhan, 2022). Discussions ongoing around business sustainability emphasize the creation of resilient organizations through integrated economic, social, and environmental systems. Which had led to companies focus on the lifecycle effects of their decisions and the sustainability of their supply chains. Digital supply chains promote transparency and centralization, while sustainable supply chain management incorporates automation and digital technology to improve coordination and overall sustainable performance. (Ahi, et al., 2023). In Aswan, the main problem is the inefficient collection of agricultural waste, leading to unsustainable practices such as burning and dumping. The challenges include centralized waste collection, lack of infrastructure, and geographical barriers. Traditional waste management methods create additional issues, such as a lack of proper timing between waste collectors and farmers, leading to a lack of trust and awareness among farmers. To address these challenges, authorities need to improve communication, efficiency, and processing systems to meet international environmental standards. Therefore, this research explores agricultural waste recycling companies in Egypt, identifying significant associations between

variables. Using an inductive approach, the research reveals the challenges in agribusiness that hinder supply chain sustainability. The study highlights the role of digitalization in reducing waste, increasing economic value, and enhancing sustainability awareness. Based on what was mentioned in the previously mentioned literature, the study aims to: -

1. To examine the relationship between the use of applications and Agricultural Supply Chain Sustainability.
2. To examine the relationship between the use of information &communication technology (ICT) and Agricultural Supply Chain Sustainability.
3. To examine the relationship between the use of transport management systems (TMS) and Agricultural Supply Chain Sustainability.
4. To examine the relationship between the use of cloud computing (CC) and Agricultural Supply Chain Sustainability.

Literature Review & Hypothesis Development

Digitalization

Transportation Management System (TMS)

Transportation in logistics provides a flow of materials, products, and persons between production facilities, warehouses, centres of distribution, terminals, and clients (Kenyon, et al., 2011). It serves as the only activity providing time and place utilities through both inbound and outbound logistics processes. Efficient scheduling and organization of transportation are essential for optimizing the physical flow of products within the supply chain. Transportation Management Systems (TMS) have emerged as essential digital technologies in enhancing transportation efficiency within the circular supply chain. Transportation Management Systems imply the use of technology to achieve the objective of transportation such as low costs, delivery on time, and increase in velocity of transportation and at the same time optimizing the use of resources of the organization (Stock and Lambert, 2010).

TMS has a significant effect on promoting sustainable practices throughout the Agricultural supply chain. By enabling controlled shipping operations, TMS promotes environmentally responsible transportation practices while minimizing environmental effect. This aligns with the increasing focus on sustainability in supply chain management. Furthermore, Trade compliance procedures are simplified by TMS by providing relevant information and documentation. This facilitates smoother transportation operations across different modes of transportation such as land, air, or sea, and ensures compliance with regulatory requirements. TMS will make it easier to collect agricultural waste. Allowing more efficient and organized transportation of these materials. By using the TMS system, we will be able to improve agricultural waste collection, ensuring timely and sustainable

collection from farmers. This technology promotes sustainable practices by controlling the shipment of agricultural waste and addressing typical transportation-related issues, such as pollution and poor road scheduling. Moreover, TMS can improve the collection process by providing transparency in daily transportation operations, simplifying shipping operations, and improving the efficiency of agricultural waste collection from farmers (Muhalia, et al., 2021). Based on the information provided, the researcher has formulated the research hypothesis in the following manner:

H.1 There is a positive statistical relationship between the use of transport management systems (TMS) and agricultural supply chain sustainability.

TMS is a sustainability champion for your Agricultural supply chain. It optimizes routes, consolidates shipments, and tracks goods in real-time, leading to less fuel use and emissions. This data allows for smarter decisions and improved efficiency. Beyond environmental benefits, TMS saves money on fuel, labour, and operations, giving you more resources for sustainability efforts. In short, TMS is a powerful tool for building a greener and more cost-effective supply chain (Akshee, et al., 2019; Rosário, et al., 2022).

Application

The sustainability of the agricultural supply chain can be improved by application software that enhances efficiency, transparency, and resource management. Here are a few crucial elements of this influence data management and traceability utilizing application software like blockchain technologies enhances the visibility and tracking of the agricultural supply chain by securely storing and exchanging information on the source, handling, and standards of products throughout the entire production process. Efficiently managing resources like water and fertilizers with IoT-based smart agriculture systems can optimize crop growth by providing just the right amount needed, reducing waste and environmental impact. The importance of application software in the agricultural industry has increased significantly in recent years (Vandana, et al., 2018). As an indispensable tool for agronomists, application software provides versatility, accuracy, and ease of use. Agricultural mobile applications have proven to be an effective solution to farmers' problems. By providing farmers with essential information such as soil properties, agricultural waste collection, weather updates, and government blueprints, these apps are changing the agricultural landscape. Moreover, specialized applications in the field of agriculture have enabled agricultural waste collection companies to obtain vital information about crop management and harvest time, insect. The integration of Android-based mobile apps with external device groups such as Arduino for sensor integration is also gaining

popularity. This combination allows farmers and businesses to access and analyze real-time data, enabling precision farming and improving crop productivity and quality as well as for agricultural waste companies. In conclusion, the integration of application software into the agricultural industry has transformed the way farmers and businesses approach their work. Farmers and businesses can now access valuable information, make informed decisions, and improve their farming practices with the help of various applications. These applications have led to increased productivity, improved efficiency, and overall growth in the agricultural sector. In today's rapidly changing world, accurate weather forecasts are of paramount importance. Accessing real-time weather information is crucial (Vandana, et al., 2018). Based on the information provided, the researcher has formulated the research hypothesis in the following manner:

H.2 There is a positive statistical relationship between the use of applications and agricultural supply chain sustainability.

Using applications in Supply chain management is key to sustainability. They provide real-time data for optimizing logistics, reducing waste, and tracking responsible practices. This data empowers collaboration and goal-setting, leading to a greener and more cost-effective supply chain (Weronika et al., 2023).

Information & Communication Technologies (ICTs)

Information and communication technology (ICT) is a field of work and study that includes technologies such as desktop and laptop computers, software, peripherals, and connections to the Internet that are intended to fulfil information processing and communications functions (Ali, et al., 2011).

(ICT) improves resource efficiency, decision-making procedures, and overall clarity, all of which are critical components of the sustainability of agricultural supply chains (Samadder, et al., 2023). The use of ICT in agriculture has revolutionized many aspects of agricultural practices by bringing about breakthroughs in positioning, production, and marketing strategies (Brintha, et al., 2022). These technologies enable data-driven decision-making that maximizes resource use and minimizes environmental impact, providing farmers with fast and accurate information on crop management practices, climate patterns, and market prices. ICTs have the potential to transform agriculture and move it toward a more efficient and sustainable future by bridging the digital divide and providing personalized solutions (Brintha, et al., 2022). Based on the information provided, the researcher has formulated the research hypothesis in the following manner:

H.3 There is a positive statistical relationship between the use of information & communication technology (ICT) and agricultural supply chain sustainability.

Supply chain sustainability gets a major boost from ICT applications. These tools track goods for responsible sourcing, optimize logistics for lower emissions, and manage resources efficiently. Real-time data empowers collaboration and goal-setting, leading to a greener, cost-effective supply chain with a strong environmental reputation. Simply put, ICT isn't a fad, it's a must-have for building a sustainable future in your supply chain (Siano, et al., 2021; Weronika, et al., 2023).

Cloud Computing (CC)

Cloud computing refers to the development of an information system that enables businesses and individuals to access on-demand networking, which is shared by a group of managed IT resources such as applications, storage, and servers. Today, as the industry develops, teachers and researchers are increasingly drawn to cloud computing. Cloud computing has become an integral part of our lives without this service and we rely on it for data, storage, and gaming to business management we depend even on document writing on cloud platforms. The infrastructure provided by cloud computing encompasses all key digital trends such as artificial intelligence, mobile computing, and industry dynamics. Although cloud computing has many advantages, it also poses significant challenges, especially regarding the protection of customers' data (Shashi and Shashi, 2022). Improving sustainability in the Agricultural supply chain sector is made possible in large part by cloud computing. Through the use of cloud technology, establishments can attain intelligent automation, scalability, agility, and real-time visibility, resulting in more sustainable and effective operations. Furthermore, by boosting transparency, cutting operating expenses, and improving monitoring across the product lifecycle, the using of blockchain technology in cloud architecture can further enhance sustainability. Also, a promising topic for sustainable supply chains is green computing, which emphasizes eco-friendly methods and lowering energy use. This is especially true when paired with cloud services like AI and IoT. With the help of cloud-based technologies, supply chains can lower their carbon footprint. For example, smart shelves can optimize logistics and cut down on pointless trips, which lowers the carbon footprint of the supermarket supply chain (Ahmad, et al., 2023). Based on the information provided, the researcher has formulated the research hypothesis in the following manner:

H.4 There is a positive statistical relationship between the use of cloud computing (CC) and agricultural supply chain sustainability.

Cloud computing (CC) is a game-changer for sustainable supply chains. Energy-efficient data centres and scalable resources minimize your environmental effects. But CC goes further: collaboration platforms connect partners for sustainable practices, while applications optimize inventory and reduce waste. Even better, CC unlocks advanced tools for innovation, driving

future breakthroughs in sustainable supply chains. In short, CC is the key to a greener, more collaborative, and innovative future (Paitoon, et al., 2019; Muhammad, et al., 2022).

Digitalization and Agricultural Supply Chain Sustainability

Sustainable SCM uses automation and digital technologies to coordinate material, information, and financial flows. Future supply chains should prioritize incorporating technologies to increase sustainability performance. Furthermore, digitalization effects supply chain practices and sustainability in a variety of areas, including economic growth, energy reduction, and pollution reduction (Romagnoli, et al., 2023). Digitization has allowed organizations to optimize procedures and achieve higher levels of profitability and sustainability in supply chain management. The trend of digitalization in agriculture is expanding rapidly. Digital agriculture, also known as 'Smart Farming' utilizes precision and data-driven technologies to assist farmers with real-time and site-specific decision-making (Dong, et al., 2023). The sustainability of the supply chain will be significantly improved by digitalization, which will aid in collecting agricultural waste from farmers. By optimizing procedures and decreasing inefficiencies, digitalization reduces the environmental impact and time required to collect garbage, improving the overall sustainability of the supply chain. Real-time monitoring and data-driven decision-making improve resource utilization while reducing wasteful transportation, resulting in decreased energy consumption and emissions. Furthermore, comprehensive traceability given by digital platforms promotes responsibility and adherence to sustainability requirements throughout the garbage collection process. Digitalization develops a culture of sustainability among stakeholders by encouraging collaboration and motivating involvement, eventually contributing to the resilience and longevity of the entire supply chain (Dong, et al., 2023; Akbari & Hopkins, 2022; Sarkis, et al., 2021).

The Significant Effect of Digitization on Agricultural Supply Chain Sustainability

The Literature emphasizes the importance of interconnected digital technologies such as cloud computing, ICT, application software, and TMS in the sustainability of the agricultural supply chain. The research presents a strategy for improving sustainability by showing how these technologies are interdependent and mutually beneficial. A unified approach is formed by combining TMS for efficient transportation, application software for resource management, ICT for communications, and cloud computing for real-time visibility. The following approach enhances the effect of supply chain management by bringing its processes to the highest level while achieving measurable goals concerning resources. These technologies are all interrelated as the paper has explained, and used to lay the foundations of an effective agri-

food supply chain system that is sustainable. Hereafter, some case studies of how these digital technologies have been successfully used in the farming supply chain. Firstly, the agri-food industry's literature on digital technology emphasizes how developments like blockchain, artificial intelligence, and the Internet of Things have the potential to revolutionize farming supply chains (Hassou, et al., 2023). Secondly, Case studies show how these technologies might improve efficiency and sustainability in concrete ways, but critical analysis is still needed to solve the problems and constraints that now exist (Ashoka, et al., 2023). Third, Another research highlights that to fully exploit the promise of digital solutions in agriculture, hurdles to mainstream acceptance, such as those related to the economic, social, and ethical domains, must be overcome (Finger, 2023). Fourth, furthermore, research indicates that emphasizing IoT, Blockchain, and machine learning can support diversity, equity, and inclusion in agricultural supply chains. This emphasizes the necessity for additional assessment and development to accommodate local settings and ecosystem dynamics (Mwangakala, et al., 2023). Finally, in general, the assessment of digital technologies in the farming supply chain can be made better and more practically relevant by identifying research gaps and incorporating crucial insights (Melesseet al., 2023).

Research Framework

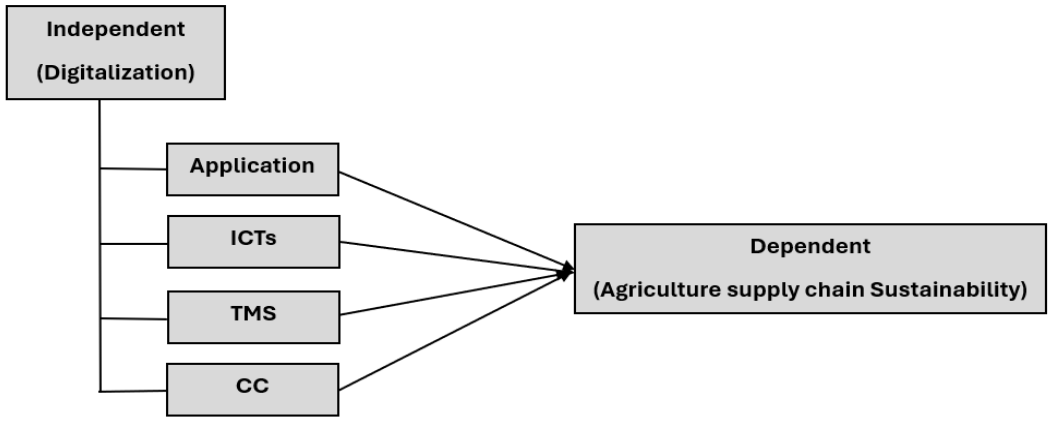

Fig 1: Research Model

(Source: Created by the researcher)

Methodology

Using an inductive approach, the research reveals the challenges in agribusiness that hinder supply chain sustainability. The researcher conducted a correlation and regression analysis to test the hypotheses and explain the different aspects of digitalization and their influence on enhancing agricultural

supply chain sustainability. To do this, the researcher designed a questionnaire, data was collected from employees of recycling companies by using a survey,

and analyzed output data to conclude the effect of digitalization and agricultural supply chain sustainability.

Data and sample

The data relating to digitalization and agricultural supply chain sustainability was collected from primary sources about insights from agricultural waste recycling companies in Aswan, Egypt on enhancing agricultural supply chain sustainability through digitalization: using the survey method. Also, the study targeted Employees of recycling companies who will adopt digitalization. As the society is infinite, it is impossible to accurately determine the total number of individuals in it. So, to select the sample, 271 respondents were chosen from the overall population of companies employees in the area, using the following equation:

$$n_o = \frac{Z^2 pq}{e^2} \qquad \frac{z^2 * 50\% * 50\%}{(5\%^2)} = 271$$

The Employees of recycling companies in the Aswan Governorate were given a questionnaire, which was circulated based on their geographical location. The target sample specified in the table below was considered when distributing the questionnaire.

Table (1) *Sample Distribution*

Aswan governorate centres	Sample
Aswan	40
Kom Ombo	70
Drao	70
Edfu	80
Nasr al-Nub	11
Total	271

Source: Created by the researcher

Statistical analysis

Introduction

This section's material focuses on statistical analysis processes and strategies for answering hypothesis testing. Below is a list of these procedures:

Questionnaire structure

The questions in the questionnaire were developed by examining previous research on the study variables and using the same measurement tool for evaluation. This method enabled the questionnaire to be pre-tested, eliminating the need for a Questionnaire Pilot Study. The allocation of questions for each category was as follows:

Part 1: Independent variable: “Digitalization” consists of 4 dimensions:

1- Transport management system: it consists of (5) Statements

2- Application: it consists of (6) Statements

3- Information & communication technology: it consists of (5) Statements

4- Cloud computing: it consists of (4) Statements

Part 2: Dependent variable: "agricultural supply chain sustainability” consists of 4 Statements.

Procedures and methods of statistical analysis

The researcher checked the data to confirm the completeness and quality of data input and statistical analysis before releasing it using the computerized Statistical Package for Social Sciences (SPSS) Statistical Package for Social Sciences V26. Questionnaires that were incomplete or did not contain credible responses were excluded by carefully reviewing each questionnaire that was filled out to guarantee the accuracy of the data before carrying out the analysis.

An answer to the research hypotheses

The study in this chapter of statistical analysis procedures and methods that were used to answer the questions and hypotheses.

The survey list was sent and generated from the entities under investigation, and the table below indicates the response rate and the proper lists that are acceptable for statistical tests.

Table (2):A statement of the number of survey lists distributed and received for the study sample

Lists	The number
Number of distributed questionnaires	**271**
The obtained lists are valid for analysis	**265**
The percentage of incorrect listings	**6**
Correct roll response rate	**97.7%**
non-response rate	**2.3%**
Total	**100%**

Source: Created by the researcher

The previous table shows that 265 survey lists were input and statistically evaluated, with a proportion of correct replies of around 97.7%, indicating a very good response rate.

Reliability & Validity

To determine the reliability of the instrument used to evaluate sample answers, the Cronbach Alpha coefficient is employed to assess the stability of the questionnaire's paragraphs and dimensions. The researcher used the Cronbach Alpha reliability coefficient to assess the stability of the study's content variables, It was found that the coefficient checked the total of the axes "The effect of digitalization on the Agricultural Supply Chain Sustainability".

Table (3) shows the results of the stability test (Cronbach Alpha coefficient values) for all questionnaire paragraphs. The accepted values for Cronbach Alpha coefficient are about 70%.

Table (3) : *Reliability of Variables (Enhancing Agricultural Supply Chain Sustainability through Digitalization: Insights*

Ser	Dimensions	Reliability	Validity
Digitalization			
D1	Transport management system	0.813	0.901
D2	Application	0.786	0.886
D3	Information &communication technology	0.788	0.877
D4	Cloud computing	0.764	0.874
Total Dimensions: Digitalization		0.914	0.956
Total Dimensions: Agricultural Supply Chain Sustainability		0.701	0.837
Total Dimensions: Enhancing Agricultural Supply Chain Sustainability through Digitalization: Insights From Agricultural Waste Recycling Companies in Aswan, Egypt		0.928	0.963

Source: Created by the researcher

The previous table shows that the Cronbach Alpha coefficient values for all dimensions are more than 70%, indicating a good level of internal stability for all questionnaire paragraphs. As a consequence, the metrics used in the study to measure questionnaire paragraphs have internal consistency, allowing us to depend on their responses to meet the study's aims and analyze its outcomes.

The researcher used the Pearson Correlation coefficient to evaluate the survey's validity, measuring the internal consistency of dimensions and the effect of digitalization on the overall dimensions of sustainable supply chain in agriculture. A correlation close to one indicates a strong relationship. The value of the correlation coefficient less than 0.30 is generally considered weak, while a value between 0.30 and 0.70 is considered moderate, and a value greater than 0.70 is considered strong. As indicated in Table 3, all values exceed 0.70, indicating strong internal consistency for dimensions.

Pearson Correlation for Independent Variable & Dependent Variable

The researcher used Pearson correlation to measure the relationship between independent and dependent variables. A significance level less than 0.05 indicates a significant relationship, while a level greater than 0.05 indicates no statistically significant relationship.

Table 4: Correlation between Dimensions the " Enhancing Agricultural Supply Chain Sustainability through Digitalization: Insights From Agricultural Waste Recycling Companies "by using Pearson correlation

Dimensions	y	x	X1	X2	X3	X4
y- Agricultural Supply Chain Sustainability	-					
x- Digitalization	0.942**	-				
x1- Transport management system	0.854**	0.753**	-			
x2- Application	0.636**	0.622**	0.519**	-		
x3- Information & communication technology	0.579**	0.564**	0.647**	0.684**	-	
x4- Cloud computing	0.594**	0.562**	0.610**	0.768**	0.583**	

** Correlation is significant at the Significance level 0.01 (2-tailed).
*. Correlation is significant at the Significance 0.05 level (2-tailed).

The previous table shows, There is a strong significant positive relationship between Dimensions "Effect of Digitalization on Agricultural Supply Chain Sustainability ", The value of Pearson correlation coefficient ranges between (.519: .924), with a highly significant ($p < 0.01$). The relationship between the independent variable and the dependent variable shows a positive relationship, suggesting that enhancing digitalization is crucial to improving Agricultural Supply Chain Sustainability.

Regression

Coefficient of Regression Multiple (Model Stepwise) to find the effect of independent (Digitalization) X, including Transport management system (X1), Application (X2), Information & communication technology (X3), and Cloud computing (X4) on the dependent variable (Agricultural Supply Chain Sustainability in Egyptian Recycling Agriculture Waste Company). Y multiple regression coefficients show to measure the effect of the most dimensions independent variables on the dependent variable.

Table (5): Enhancing (Agricultural Supply Chain Sustainability) through (Digitalization): Insights From Agricultural Waste Recycling Companies by using Model multiple regression

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
Constant	.651	4.834	0.01**	202.335	.001**	75.8%
x1- Transport management system	.616	16.786	0.01**			
x2- Application	.097	2.128	0.01**			
x3- Information & communication technology	.055	1.356	Insig			
x4- Cloud computing	.096	2.573	0.01**			

The study finds that the independent variable (Digitalization) x explains (75.8%) of the total change in the dependent variable (Agricultural Supply Chain Sustainability in Egyptian Recycling Agriculture Waste Company) y, which has a significant significance. Using selection (T. Test), we find that the independent variable (Transport management system) x1, (Cloud computing) x4, and (Application) x2, had a significant effect on the (Agricultural Supply Chain Sustainability in Egyptian Recycling Agriculture Waste Company) y, which value of "t" (16.786), (2.573), (2.128), at a level less than (0.01). To test the quality of the conciliation model as a whole was used for the test (F-test), where the value of the test is (202.335), which is significant at a level less than (0.01), which indicates the quality of the effect significance of the regression model on (Agricultural Supply Chain Sustainability in Egyptian Recycling Agriculture Waste Company).

Prove the hypothesis research

We accept the statistical alternative hypothesis there is an Effect of " Digitalization" on "Agricultural Supply Chain Sustainability in Egyptian Recycling Agriculture Waste Company".

Equation of the form

1. (Agricultural supply chain sustainability in egyptian recycling agriculture waste company) y = . 651+ 0.616 transport management system x1+ 0.097 application x2 + 0.096 cloud computing x4

6. results

2. The results of the previous table confirmed the existence of a statistically significant effect on all dimensions of digitalization (transport management system, application, and cloud computing), and are significant effect on the dependent, (sustainable supply chain) based on the test (t(equal (16.786), (2.128), (2.573), response where we find that the level of indication is less than 0.05. on agricultural supply chain sustainability.

3. The results show a highly meaningful strong positive relationship between the adoption of the transport management system and the improvement of agricultural supply chain sustainability, with a correlation coefficient of 0.854, signifying a highly meaningful relationship at a regression level of .000. this confirms the validation of the third hypothesis, which proposes a statistical relationship between the utilization of tms and the sustainability of the supply chain. furthermore, the results also revealed a moderately to strong positive relationship between the implementation of mobile applications and the enhancement of agricultural supply chain sustainability. the correlation coefficient obtained was 0.636, signifying a statistically significant relationship at a regression level of .034. this supports the validity of the first hypothesis, which proposes a statistical relationship between the use of applications and agricultural supply chain sustainability. finally, the results indicated a moderately strong to strong positive relationship between the implementation of cloud computing and the enhancement of agricultural supply chain sustainability. the correlation coefficient was calculated to be 0.594, showing a statistically significant relationship at a regression level of .011. this confirms the validity of the fourth hypothesis, which suggests a statistical relationship between the use of cloud computing and agricultural supply chain sustainability.

4. Dimension (information & communication technology) does not significant effect on the dependent, (agricultural supply chain sustainability), and the dimension (information & communication technology) is not statistically significant. it can be said to have a weak effect on the variable adopted because the study sample, located in the south of the level, lacks sufficient knowledge of ict and its sustainability use.

5. The study's findings shed light on the significant role of digitization and sustainable performance in the supply chain, notably in industries like agricultural waste recycling. organizations may strengthen their supply chain capabilities by utilizing digital technology, resulting in higher long-term competitive performance. the use of digital technologies may also boost environmental and social sustainability by reducing energy usage, improving logistics, and encouraging collaboration among supply chain partners. furthermore, investing in a tailored digital supply chain model may help businesses reduce risks, improve performance, and contribute to societal stability and progress. as a result, incorporating digitization into supply chain

operations may assist agricultural waste recycling companies in achieving greater sustainability, operational efficiency, and overall success.

Discussion

Transportation Management System (TMS)

6. The adoption of transportation management systems (TMS) by companies has been widely confirmed, as evidenced by the study conducted by (Romagnoli, et al. 2023). their research highlights that, out of 157 usable observations, 88 companies have implemented tms, whereas 69 companies have not shown interest. this sample represents approximately 12% of the targeted company population of 1200. the adoption rate indicated by this study is a positive indicator, underscoring tms as one of the highest-performing technologies in the field of logistics. tms integrates multiple protocols within the supply chain to optimize the physical movement of products, enhancing sustainable practices through controlled shipments and mitigating common transportation issues such as pollution and inefficient route planning (Romagnoli, et al., 2023).

7. TMS significantly improves product flows and logistics through several key mechanisms: centralized visibility, route optimization, and effective carrier relationship management. these enhancements result in increased efficiency, cost reductions, and improved customer service. the sustainability aspect of tms is particularly noteworthy. by optimizing routes and consolidating shipments, tms effectively lowers fuel consumption and co2 emissions. furthermore, the automated processes and centralized oversight provided by tms reduce errors and inefficiencies, which in turn decreases waste. the ability of tms to track and optimize packaging materials further minimizes waste and reduces environmental impact (Ragunathan, 2024).

8. Contrary to the positive effects of tms on the agriculture supply chain the study by (Drljača, et al.,2023), suggests that disruptions or interruptions in the transportation process can occur at any time and anywhere in the supply chain due to various factors such as pandemics, war conflicts, natural disasters, terrorism, and bad management. it also emphasizes the vulnerability of the transportation process, as evidenced by recent events such as the covid-19 pandemic, the blockade of the suez canal, and the war in ukraine. these disruptions can have far-reaching consequences for trade and supply chain reliability, leading to delays, loss of revenue, and increased pressure on seaports.

Information and Communications Technology (ICT)

9. Mandicak's study opposes our approach to integrating information and communications technology (ict) into supply chain management. while their findings suggest that ict can aid in reducing materials,

improving logistics services, optimizing resource allocation, and enhancing waste management, this opposition could be attributed to the fact that our study sample is mainly situated in regions with a limited grasp of ict and its sustainable uses (Mandičák, et al.,2021; Maria, et al.,2023).

Cloud Computing

10. Our research aligns with a prior study conducted by yenugula et al., which examines the utilisation of cloud computing in supply chain management. their findings indicate that the cloud contributes significantly to various aspects of supply chain management, including offering real-time visibility into operations, enhancing cooperation and communication among companies, accelerating supply chain responsiveness, monitoring inventory levels, implementing improvement methods via cloud-based solutions, and aiding in disaster recovery. this synchronization between our study and theirs underscores the beneficial effect of cloud technology on supply chain management practices (yenugula, et al.,2023). within the agricultural supply chain, digital technologies can significantly increase productivity and collaboration. for example, cloud computing allows farms to remotely store massive amounts of data and access sophisticated analytics. based on real-time data, farmers can adapt their methods to use resources more effectively. in addition, cloud services facilitate the integration of data from different chain partners, thereby facilitating collaboration and decision-making (king, et al. 2014). also suggest that cloud computing allows farms to remotely store massive amounts of data and access sophisticated analytics, facilitating collaboration and decision-making, which aligns with our findings. and also emphasizes the benefits of cloud-based solutions in providing real-time visibility, enhancing collaboration and communication, and improving supply chain responsiveness. it also highlights the advantages of cloud-based solutions in offering advanced data analytics capabilities, enabling real-time tracking of inventory and shipments, and providing a collaborative platform for supply chain partners to share information and coordinate efforts (wang, et al.,2023).

Application

11. The integration of digital applications in agriculture enhances the efficiency and sustainability of the agricultural supply chain and improves cooperation among supply chain partners. the use of yield monitors and gps mapping in row crop farming has contributed to a significant increase in productivity and profitability, with corn farmers in the u.s. experiencing a 10% higher yield in 2001 and a 23% increase in yield by 2005. the use of variable rate technology (vrt) in fertilizer application improves resource management by utilizing inputs more efficiently and reducing waste and environmental effect. by optimizing machining paths, automated guidance systems reduce energy consumption and greenhouse gas emissions, leading to

cost savings and a reduction in carbon footprint. by using digital tools, data sharing and real-time communication can be improved, leading to more informed decision-making and supply chain optimization. the sustainability and market value of livestock products are enhanced by traceability systems that meet consumer demand for information on food origin and production methods. the benefits of digital applications in agriculture include reduced energy use, better resource management, and improved supply chain cooperation, which are good for both the environment and the economy. according to (ali, et al., 2022), investigate the social and economic effects of digital agriculture, highlighting concerns about potential inequities. the study emphasizes that smallholder farmers, who often lack access to technology and infrastructure, may be further marginalized by the digital divide. the researchers call for efforts to ensure equitable access to digital tools and to build the capacity of smallholder farmers to benefit from digital agriculture.

Conclusion, Recommendations, and Future Research

The study focused on the relationship between digitization and various supply chain components, as well as how they affected the profitability and sustainability of farm waste firms. the study validated various hypotheses and demonstrated, the study found that digitalization improves supply chain integration, operations, and distribution. furthermore, the study demonstrated that increased degrees of supply chain integration might lead to more sustainable practices. the study's data was acquired through staff questionnaires at farm waste recycling companies. the findings highlight the relevance of digitization in improving supply chain efficiency and its beneficial effect on sustainability, giving significant information for agriculture waste industry managers looking to increase business profitability and sustainability.

The study offers several applicable visions and recommendations, for decision-makers in the agricultural waste industry. First, spending on digital technologies such as AI, IoT, blockchain, and applications can facilitate operations, minimize waste, and enhance tracking and transparency through the supply chain. Second, promoting a culture of continuing improvement and digital literacy among staff can improve the effective application of these technologies. Still, decision-makers should contemplate rising partnerships with technology providers to be always updated with the latest evolutions and make sure the firm’s systems are elastic and adaptable to future needs. With categorized digitization and supply chain integration, Managers can also contribute to more sustainable practices not only maximizing their business profitability. This exhaustive approach is crucial for remaining competitive and meeting the growing demands for environmental obligations and responsibility in the industry. The research and the results are derived from Aswan`s society through agriculture waste collection companies. This study is not generalized,

due to that, this gives space for researchers to apply the study to the whole country internally or apply it to countries that have the same characteristics and features externally, and this allows researchers to use different tools to collect data such as Interview, Observation, and Real life data This gives them a chance to check the results.

Research limitations

The research is centered on enhancing the sustainability of the agricultural supply chain by implementing various digitalization aspects in the context of agricultural waste collection firms in Aswan, Egypt. The research concluded in July 2024.

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APPENDIX

No	words	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)
	Independent: digitalization					
Dimension 1: transport management system (TMS)						
1	Transportation Management System Helps Agricultural Waste Collection Companies Reduce their Activity Time.					
2	Transportation management systems help in the transfer of information and goods more efficiently.					
3	Transportation management systems help to confirm the shipment at the correct time for transportation and tracking.					
4	Transport management systems help reduce CO2 emissions.					
5	A transport management system dedicated to shippers helps improve delivery methods automatically. Algorithms identify the most fuel-efficient methods.					
	Dimension 2: application					
6	The use of smartphones and their applications is one of the most important means of modern technology provided to serve sustainability.					
7	Agricultural waste collection companies must understand the determinants of the adoption of mobile technologies and integrate them into their					

	collection channels.					
8	Using smartphone apps helps companies improve their services and access new markets in agrarian waste collection.					
9	The use of smartphone applications helps agricultural waste collection companies reduce the cost of production.					
10	The use of smartphone applications raises the competitiveness of agricultural waste collection companies, earns their competitive advantage, and effectively implements sustainability.					
11	Smartphone technology and applications are good marketing and advertising tools to reach farmers anytime.					
	Dimension 3: information& communication technology (ICT)					
12	Agricultural waste collection companies rely on Information communication technology to keep abreast of recent developments.					
13	Agricultural waste collection companies use software for distribution and assembly work.					
14	Information communication technology helps determine waste collection sites through geographical analysis.					

15	Using information and communication technology helps improve the agricultural waste collection process and reduce collection time.					
16	Information communication Technology reduces the costs of agro-waste collection.					
	Dimension 4: cloud computing					
17	Cloud computing helps in the use of renewable energy from different sources such as industries resulting from agricultural waste.					
18	Cloud services offer different technologies and processes leading to more green data centers that help to apply sustainability effectively.					
19	The transition to cloud computing helps agro-waste aggregators reduce their energy requirements and achieve sustainable growth.					
20	Green computing fosters a culture of teleworking and hybrid, allowing businesses to use smaller office space and reducing employees' infrastructural requirements.					
	Dependent: supply chain sustainability					
21	agriculture supply chain sustainability reduces					

	the number of agriculture waste returns.					
22	agriculture supply chain sustainability reduces the number of transportation and cost					
3	Sustainable supply chain management helps reduce climate pollution, recycle materials again, and conserve non-renewable resources.					
4	Sustainable supply chain management reduces production costs and stabilizes the level of production.					
25	Using agricultural waste in the supply chain helps achieve environmental and economic benefits.					