The Effect of Green Hydrogen Technological Innovation on Sustainable Supply Chains (A Suez Canal Economic Zone SCZONE Case Study)

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Abstract:

The Purpose: The study aims to evaluate the effect of technological innovation in green hydrogen on sustainable supply chains in the Suez Canal Economic Zone. The primary objective is to determine whether there is a statistically significant effect of technological innovation in green hydrogen on various aspects of supply chains, such as sustainable purchasing, sustainable production, sustainable distribution, and investment recovery, while providing practical recommendations based on the results to achieve performance improvements.

Design/methodology/approach: A descriptive study was used for the current research. Two types of data were used to achieve this approach from the following sources: - Secondary Data: It is the data obtained to build theoretical framework of the research. - Primary Data: By obtaining these data from Employees in the Suez Canal Economic Zone. These data were collected in the field study through questionnaire. Correlation and regression analysis were carried out to test the relationship between research variables by using SPSS.

The Findings: The overall results showed that all reliability coefficients exceeded 70%, indicating high reliability in the responses. Statistical analyses confirm a strong relationship between technological innovation in green hydrogen and sustainable supply chains, with an R^2 coefficient of 54%, indicating a significant positive impact on various dimensions of purchasing, production, distribution, and investment recovery.

The originality value: Regarding technological innovation in green hydrogen, is a subject which has not been reviewed its impact on sustainable supply chains in Egypt in the literature previously.

Keywords: Green Hydrogen, Green Innovation, Suez Canal Economic Zone (SCzone), Sustainable supply chain.

1. Introduction:

Green innovation encompasses all innovations contributing to creating key products, services, or processes that reduce environmental damage while enhancing natural resource usage (Albort-Morant et al., 2018). It plays a pivotal role in guiding the proper utilization of resources for human well-being, with increasing demands from consumers for companies to reconcile production with environmental sustainability.

In this context, hydrogen technologies have gained significant political and industry attention. These technologies offer a cleaner alternative that reduces emissions, especially in fossil fuel-dependent sectors like transportation and industry (Albrecht et al., 2020). Hydrogen’s use as an energy carrier is key to a carbon-neutral future, with electrolysis-produced hydrogen offering large-scale energy storage capabilities. This transition from fossil fuels to hydrogen will shape industries and determine national competitiveness in the future (Kovač & Paranos, 2021).

As hydrogen technologies evolve, their role in sustainable supply chains becomes clearer. Green hydrogen contributes to mitigating climate change by enabling cleaner energy solutions. Egypt, with its vast renewable energy potential from wind and solar, is strategically positioned to be a major producer of clean energy, bolstering environmental efforts across the region (Oxford Analytica, 2022). The Egyptian government's push for sustainable development has positioned the country as a leader in the green economy, with projects in the Suez Canal Economic Zone leading the charge.

Egypt has embarked on several initiatives to localize green hydrogen production, with plans for up to 15 green hydrogen projects in the Suez Canal economic zone alone. These projects aim to produce green hydrogen and ammonia, strengthening Egypt’s status as a clean energy hub. The government’s commitment is evident with the signing of various MoUs, highlighting international collaboration and investment in renewable energy. During COP27, Egypt elevated nine of these MoUs to more detailed framework agreements, boosting investor confidence in the potential of Egypt’s hydrogen sector (Oxford Analytica, 2022).

Additionally, Egypt's national hydrogen plan, valued at over $40 billion, and the launch of its green hydrogen production plant in Ain Sukhna underscore the country’s commitment to a sustainable, carbon-neutral energy future. The Egyptian Ministry of Electricity and Energy has also updated its "Energy Strategy 2035" to incorporate hydrogen as a key energy source. Moreover, the government has signed agreements with international entities, including the European Bank for Reconstruction and Development, to finance hydrogen-related advisory projects, further solidifying its role as a green energy leader.

2. Literature Review:

Below are the most important previous studies related to the issue of the effect of the Green Hydrogen Technological Innovation on Sustainable Supply Chains and the relationship between them to identify the most important topics presented, define the objectives and the most important results, comment on these studies and clarify the extent of their use, as well as when identifying the research gap, they are divided into the following axes:

2.1. Independent Variable: Green Hydrogen Technological Innovation.

The concept of **green innovation** is the development of other synonyms or related constructs (eg eco-innovation, eco-efficiency), which are often used loosely in the literature.

Environmental innovation involves creating, absorbing, or exploiting a product, service, process, or organizational method that brings modernity to the company and results in the reduction of environmental risks, pollution, and other negative impacts. Besides, environmental innovation includes a set of innovative technologies, systems, products, and/or processes aimed at preventing or minimizing environmental damage (Albort-Morant, et al, 2018).

The term sustainable innovation was coined to define “the integration of conservation and development to ensure that modifications to the planet truly ensure the survival and well-being of all people.”

Green technological innovation is an important way to reduce carbon emissions and achieve sustainable development (Li, & Li, 2022).

Green hydrogen is mainly hydrogen produced from the electrolysis of water based on renewable energy. The resulting energy carrier can be used in many power applications (Walwyn, et al, 2019).

2.2. Studies in Green Hydrogen Technological Innovation:

Below are the most important studies related to the Green Hydrogen Technological Innovation variable:

Shen et al. (2023) aim to address the modern challenge of efficiently utilizing energy resources to achieve economic growth while minimizing environmental impacts. The research focuses on sectors such as transportation, aviation, and refining, which face the pressing need to reduce reliance on fossil fuels. It explores hydrogen energy as an often-overlooked solution in environmental strategies and assesses the environmental impacts of green hydrogen in the top seven hydrogen-consuming countries between 1995 and 2019.The findings reveal key insights into the role of green hydrogen. The study demonstrates that the adoption of green hydrogen, in conjunction with green finance, environmentally related technologies, energy efficiency measures, digitalization, and structural changes, positively contributes to environmental sustainability in these countries. However, it also highlights that CO2 emissions are exacerbated by factors such as dependence on natural resources and urbanization, further complicating environmental challenges.

Ashari et al. (2023) aims to explore the global hydrogen technology innovation system (TIS) by examining three key knowledge and technology transfer channels: publications, patents, and standards. Given that the adoption of hydrogen technologies requires confidence in their safety, the study places a special focus on hydrogen safety, analyzing how these channels contribute to the development and diffusion of hydrogen technologies. The findings reveal that while public safety and hydrogen research have significantly increased, patent activity has stagnated. The analysis of safety-related patents shows a limited connection between patents and scientific publications, with little recognition of research in non-patent literature. Similarly, publications are underrepresented in the 75 international standards for hydrogen and fuel cells reviewed. This limited transfer of knowledge from academic papers to standards highlights the need for greater researcher involvement in standardization processes. The study also presents recommendations for improving the alignment of the three channels to strengthen the TIS for hydrogen technology.

2.3. Dependent Variable: Sustainable Supply Chains.

Supply chains are defined as a sequence of organizations—the facilities, functions, activities of those organizations—that are involved in the production and delivery of a product or service, beginning with the major suppliers of raw materials and extending all the way down to the end customer (Dubey, et al, 2021).

Sustainable Supply Chain: refers to companies' efforts to consider the environmental and human impact of their products' journey through the supply chain, from raw material sourcing to production, storage, delivery, and every transportation link in between (Khan, et al, 2021).

2.4. Studies In Sustainable Supply Chains:

Below are the most important studies related to the Sustainable Supply Chains variable:

Hohn and Durach (2023) address the growing public and academic interest in firms' social sustainability practices, particularly focusing on why only a few companies take responsibility for social issues within their supply chains. The research aims to enhance the theoretical understanding of why some firms adopt this responsibility while others do not. The findings divide the existing literature into seven application areas, offering detailed insights. The study highlights that research on social sustainability, which covers issues like health and safety, labor rights, and discrimination, remains limited. It also emphasizes the promising potential for future research in integrating Industry 4.0 technologies—such as blockchain, big data analytics, and the Internet of Things (IoT)—with sustainable and green supply chains (GSC). Rana and Jani (2023) aim to define Industry 4.0-SLSS (Sustainable Lean and Green Supply Chain) practices and performance measures that promote sustainability in supply chains. The researchers sought to develop a practical framework that decision-makers and managers can use to enhance sustainability in their supply chain operations. The findings reveal that "Product Development Competencies (PDC)" ranked first in the Key Criteria category, highlighting its critical impact on supply chain sustainability. "Advanced Technology Competencies (ATC)" followed in second place, with "Organizational Management Competencies (OMC)" ranking third. Additionally, "People and Sustainable Competencies (PSC)" and "Soft Computing Competencies (SCC)" were identified as important factors contributing to achieving sustainable supply chains. Khanam and Ghosh (2022) aimed to explore the relationship between sustainable supply chain management practices and the cost performance of manufacturing firms in Bangladesh. The research also sought to identify environmentally friendly approaches and evaluate their impact on the financial performance of these firms. The findings revealed a positive relationship between sustainable purchasing and investment recovery practices and improved cost performance in manufacturing firms. However, sustainable distribution was found to have a negative relationship with cost performance, suggesting that certain eco-friendly distribution practices may be more costly for these firms. Interestingly, sustainable production practices showed no significant effect on cost performance within the studied context. Li and Li (2022) aimed to analyze the impact of green technology innovation on the development of transportation companies, with a particular focus on the transportation sector in China. Using the LL-FE model, the researchers sought to determine how green innovations influence both the industry and broader cooperation efforts, especially in the context of South-South cooperation. The findings indicate that green technology innovations positively affect the development of South-South cooperation in the transportation sector. Specifically, a 1% increase in green technology innovation reduces carbon emissions by approximately 0.23%. These innovations not only have direct effects on emission reduction but also promote cooperation through indirect mechanisms such as technological diffusion, increased market competition, and social network effects. This research provides valuable insights into the role of green technologies in advancing sustainable practices and fostering collaboration within the transportation industry. Dubey et al. (2021) aimed to provide a comprehensive overview of the drivers behind sustainable and frugal global supply chains, particularly in light of emerging countries' responses to the COVID-19 pandemic. The authors employed a focus group approach to identify key motivations, drawing on existing literature from peer-reviewed international journals and reports. They utilized comprehensive explanatory structural modeling to analyze the intricate relationships between various drivers. The findings indicated that government financial support, along with policies and regulations, significantly impacts technology adoption and initiatives, mediated by leadership and influenced by national culture and international rules. Moreover, the research highlighted that emerging technologies, voluntary initiatives, and ethical values significantly affect supply chain talent and the implementation of frugal engineering practices. This underscores the crucial role of governmental and cultural factors in shaping sustainable supply chain practices in the context of emerging economies.

2.5. Studies related to the relationship between Hydrogen and Supply Chains:

Below are the most important studies related to the relationship between Hydrogen and Supply Chains:

Yang et al. (2022) aimed to identify promising hydrogen fuel cell transport technologies to support the formulation of research and development (R&D) policies and guide investment decisions. The research sought to provide insights to researchers regarding technologies likely to dominate the field of hydrogen fuel cell transportation in the future. The findings from the analysis of the patent database revealed two promising technologies, while the examination of the thesis database identified five additional promising technologies related to hydrogen fuel cell transportation. This comprehensive approach offers valuable guidance for stakeholders in making informed decisions regarding R&D investments and policy formulation in the hydrogen fuel cell transport sector. Elvira et al. (2022) aimed to investigate the potential of hydrogen technology in transportation, particularly focusing on how it could contribute to the sustainability goals of societies, with a specific emphasis on Mexico. The research explored the adoption of hydrogen as a complementary energy source for maritime transport, aiming to enhance both economic and environmental performance, particularly in the areas of packaging and distribution. The findings indicated that environmental and economic performance within the transportation sector is intricately linked to key supply chain management (SCM) processes, especially those related to packaging and distribution. By implementing reusable packaging and adopting fuel-saving distribution methods, the research suggested opportunities for optimizing transportation and upstream/downstream operations within the supply chain. This optimization could lead to reduced costs and improved environmental performance, highlighting hydrogen technology's potential to advance sustainable logistics and transportation objectives in Mexico. Kim et al. (2021) conducted a case study focused on optimizing the hydrogen supply chain for South Korea, which is expected to become a significant hydrogen importer. The research aimed to evaluate various feasibility scenarios, spanning from international supply sources to domestic consumption, with an emphasis on meeting the decarbonized hydrogen needs of South Korea while considering the production capacities of exporting countries over a twenty-year horizon. Using mixed-integer linear programming, the research optimized South Korea's hydrogen supply chain. The findings indicated that the most feasible approach for hydrogen imports involves predominantly sourcing blue hydrogen from Qatar and Russia, alongside green hydrogen from the UAE and India. Additionally, the study recommended utilizing liquefied hydrogen in the near term due to the cost-effectiveness of resource prices in the selected exporting countries. This research provides critical insights into the strategic planning required for South Korea's transition to a hydrogen economy.

2.6. Commentary on Previous Studies:

The current studies on green hydrogen technological innovation and sustainable supply chains exhibit strong compatibility with previous research. Earlier studies emphasized the environmental benefits and technical challenges of hydrogen production, along with the integration of sustainability into supply chain practices. Recent works, such as those by Islam (2023) and Shen et al. (2023), align with past findings on the necessity of innovative technologies and economic potential in reducing fossil fuel dependency. Furthermore, research by Hohn and Durach (2023) and Nirmal et al. (2023) reflects earlier insights into the limited adoption of social sustainability practices, while Khanam and Ghosh (2022) reinforce the link between sustainable practices and financial performance. Additionally, Frankowska et al. (2022) contribute to the discourse by addressing logistical challenges and advocating for improved energy management systems in hydrogen integration, showcasing an ongoing dialogue that supports and builds upon established knowledge in these fields while identifying new avenues for future research.

3. Study Problem:

The problem of the research is to examine the relationship between technological innovation for green hydrogen on sustainable supply chains SCZone. Therefore, this study seeks to answer the following questions:

- What is the extent of interest in Sustainable Supply Chain for SCZone?
- What are the most important challenges facing the Sustainable Supply Chain in SCZone?

- How is interested SCZone in using Green Hydrogen Technological Innovation in Sustainable Supply Chain?
- How the Green Hydrogen Technological Innovation affect the Sustainable Supply Chain at SCZone?

4. Study Objectives:

The study aims to achieve the following objectives:

- To recognize the extent of interest in Sustainable Supply Chain in SCZone.
- To determine the extent of interest in Green Hydrogen Technological Innovation in SCZone.
- To investigate the extent of the impact of Green Hydrogen Technological Innovation on Sustainable Supply Chain in SCZone.
- To present a number of recommendations and proposals to officials and leaders in SCZone based on the Findings of the research, which can be generalized and used in practical application.

5. Study Hypotheses:

The main hypothesis: "There is a Statistically Significant impact of Green Hydrogen Technological Innovation on Sustainable Supply Chains in SCZone". Several hypotheses emerge from this main hypothesis:

-There is a Statistically Significant impact of Green Hydrogen Technological Innovation in Sustainable Procurement.

- There is a Statistically Significant impact of Green Hydrogen Technological Innovation on Sustainable Production.
- There is a Statistically Significant impact of Green Hydrogen Technological Innovation on Sustainable Distribution.
- There is a Statistically Significant impact of Green Hydrogen Technological Innovation on Investment Recovery.

6. Study Model:

The study employed the following variables to achieve its objective:

- **Independent Variable: Green Hydrogen Technological Innovation**.
- **Dependent Variable: Sustainable Supply Chains**

The following diagram illustrates the theoretical relationship model between the key variables of the study, represented by the independent variable (Green Hydrogen Technological Innovation) and the dependent variable (Sustainable Supply Chains):

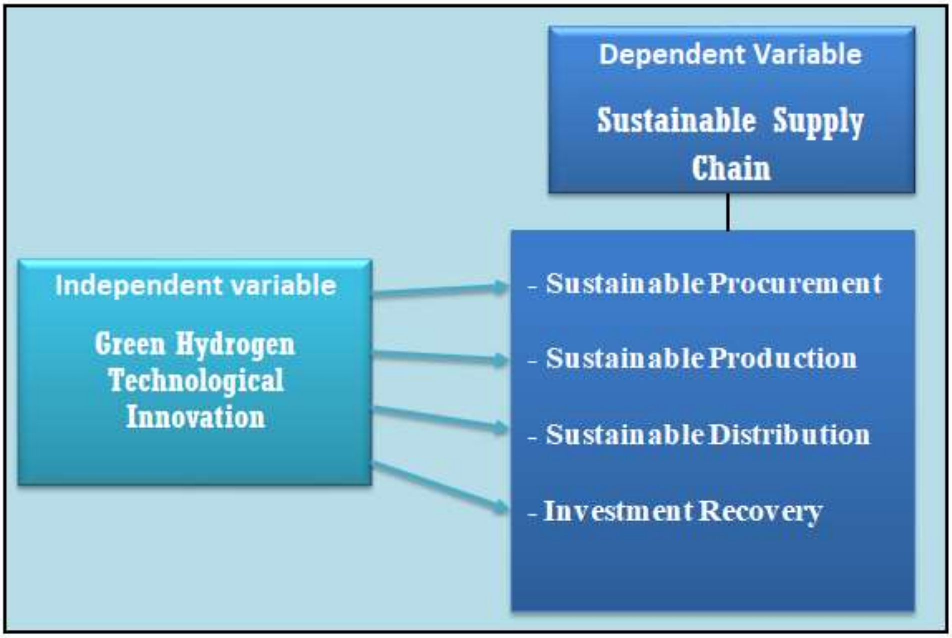

Figure (1): Model framework of the study.

7. Study Importance:

The importance of the current research is due to its scientific and practical additions as follows:

The importance of this research lies in an attempt to contribute to bridging the research gap in studies and research on the efficiency of Green Hydrogen Technological Innovation and supply chain practices, the research is also in response to what many previous studies called for conducting more studies and research on these topics, their great importance in enriching the academic library and scientific research centers, especially those interested in administrative studies. This research can also provide a database to help researchers and scientists to conduct more research in this field.

The importance of the research is related to the field of application, as the SCZone in Egypt played a pivotal role in Egypt. The importance of the research also lies in the fact that it deals with a vital administrative topic that touches the core of the work of the SCZone in Egypt, which operates in an environment characterized by development, change and renewal. Need to highlight the importance of research and the global challenge in supply chain and especially SCZone.

8. Study Methodology:

A descriptive study was used for the current research. According to (Sekaran, & Bougie, 2010), the descriptive study design is not experimental in that it deals with relationships between variables in a natural rather than a laboratory setting. Circumstances and events have already occurred and the researcher can identify the variables that are most relevant to the analysis of existing relationships.

In descriptive design, the hypothesis is also formulated and tested and generalizations of the results are reached through inductive reasoning. Descriptive design also uses randomization methods so that error can be estimated when population characteristics are inferred from sample observations and variables and procedures are described (Cooper, Schindler, 2013).

Although Green Hydrogen Technological and Innovation Sustainable Supply Chains have already been established in many companies, no study has been conducted to assess the impact of Sustainable Supply Chains on Green Hydrogen Technological Innovation in Suez Canal Economic Zone. The researcher who used this research sought to investigate discrepancies and come up with recommendations that would improve overall performance and bridge the research gap in this area.

Two types of data were used to achieve this approach from the following sources: **- Secondary Data:** It is the data obtained to build theoretical framework of the research, where it was relied on to identify theoretical background of the research, on the various references of books and articles and previous studies of academic theses of the relevant and published research, which dealt with the topics of Green Hydrogen Technological Innovation and Sustainable Supply Chains.

- Primary Data: These data were collected in the field study through questionnaire to test the validity of the assumptions on which the research was based. By obtaining these data from Employees in the Suez Canal Economic Zone.

9. Research Sample:

The research population consists of stakeholders involved in the supply chain and hydrogen technology sectors within the Suez Canal Economic Zone (SCZone), including industry professionals, policymakers, and academics, estimated at approximately 42 individuals. A stratified sampling design was employed, categorizing the population into distinct strata based on sector and role within their organizations to ensure a representative sample. The targeted sample size is 37 respondents, achieving an 88% return ratio from distributed questionnaires. Data was collected through a structured electronic questionnaire, facilitating ease of response and improving overall participation.

10. Descriptive statistics:

10.1. Green Hydrogen Technological Innovation variable:

The strength of the dimensions of the independent variable (Green Hydrogen Technological Innovation) was measured to assess their availability, and these dimensions were ranked in order to importance from the perspective of the study participants, as follows:

Table (1): Internal consistency by used the coefficient of correlation Pearson for Dimension independent variable Green Hydrogen Technological Innovation (x)

N	Statements	Pearson Correlation	Sig.
1	Introduce hydrogen technologies as a modern option to enhance economic development in the Suez Canal Economic Zone.	0.832**	Less than 0.01
2	The industrial sector in the region is engaging in research and development to implement hydrogen technology in its operations.	0.644**	Less than 0.01
3	Identifying of the challenges that may confront the adoption of hydrogen technology within the region.	0.825**	Less than 0.01

4	Exploring investment opportunities in research and development to boost hydrogen technology in the area.	0.611**	Less than 0.01
5	Encouraging companies to integrate hydrogen technologies into their operations within the region.	0.548*	Less than 0.05
6	Studying the impact of hydrogen technology on achieving sustainable development in the area.	0.728**	Less than 0.01
7	Evaluating local policies and regulations to support the application and adoption of hydrogen technology in the region.	0.719**	Less than 0.01
8	Developing skills and organizing training for workers in the area to transfer to hydrogen technology.	0.746**	Less than 0.01
9	Assessing the ability of workers in the region to adopt hydrogen technology and develop their skills.	0.651**	Less than 0.01
10	The local government is promoting collaboration between the public and private sectors to enhance hydrogen technology in the region.	0.620**	Less than 0.01
11	The environmental benefits of hydrogen technology are being explored in the Suez Canal Economic Zone, with a focus on carbon reduction and environmentally friendly practices.	0.537*	Less than 0.05
12	Collaboration between education and local industries is being considered to promote hydrogen technology research, skills development and regional innovation.	0.601**	Less than 0.01

****Correlation is significant at the less 0.01 level.**
***Correlation is significant at the less 0.5 level.**

The results presented in the table demonstrate a strong internal consistency among the various independent variable, Green Hydrogen Technological Innovation (x), as measured by Pearson correlation coefficients. Most statements reveal statistically significant correlations at the less than 0.01 level, indicating a robust relationship between the promotion and implementation of hydrogen technologies and various aspects such as economic development, research and development engagement, and the environmental benefits of hydrogen technology. For instance, the highest correlation (0.832**) emphasizes the introduction of hydrogen technologies as a pivotal option for enhancing economic development in the Suez Canal Economic Zone. Meanwhile, correlations like 0.548* for encouraging companies to integrate hydrogen technologies indicate that while still significant, these dimensions may require further attention to strengthen their connection. Overall, the data underscores the importance of fostering an integrated approach to advance hydrogen technology adoption and its sustainable impact in the region

10.2 Sustainable Supply Chains variables:

Table (2): Internal consistency by used the coefficient of correlation Pearson for Dimensions independent variables Sustainable Supply Chains (y)

N	Statements	Pearson Correlation	Sig.
Y1- Sustainable Procurement			
1	Institutions in the region are studying the inclusion of sustainability standards in their procurement processes.	0.812**	Less than 0.01
2	Sustainable procurement processes in the region face specific challenges, and an investigation is underway to understand and overcome them.	0.510*	Less than 0.٠٥
3	The local government is taking specific measures to promote sustainability in procurement processes within the region.	0.705**	Less than 0.01
4	Employees' understanding of concepts and practices related to sustainable procurement is verified through appropriate training.	0.694*	Less than 0.01

y2- Sustainable Production			
1	Companies in the region adopt principles of sustainable production to preserve natural resources and reduce waste.	0.695**	Less than 0.01
2	Companies encourage the use of clean and sustainable production technologies within the region.	0.863**	Less than 0.01
3	The impact of sustainable production on the overall performance of companies within the region is evaluated and analyzed.	0.578*	Less than 0.05
4	Collaboration between companies and the government is encouraged to promote sustainable practices in production processes.	0.710**	Less than 0.01
Y3- Sustainable Distribution			
1	Institutions in the region integrate sustainability standards into their distribution processes.	0.695**	Less than 0.01
2	Companies are encouraged to use environmentally friendly transportation and sustainable technologies in distribution operations within the region.	0.547*	Less than 0.05
3	The impact of sustainable distribution on the overall performance of companies within the region is evaluated and analyzed.	0.739**	Less than 0.01
4	Collaboration between companies and the government is encouraged to promote sustainable distribution within the region.	0.833**	Less than 0.01
Y4- Investment Recovery			
1	Companies in the region assess how they can analyze and gain value from unused or obsolete assets.	0.735**	Less than 0.01
2	Encouragement is given for the reuse of equipment and materials in investment operations to enhance sustainability.	0.592*	Less than 0.05
3	The environmental impact of investment recovery operations is estimated and analyzed within companies in the region.	0.616**	Less than 0.01
4	Initiatives are in place to promote collaboration among companies to jointly improve investment recovery operations.	0.521*	Less than 0.05

****Correlation is significant at the less 0.01 level.**
***Correlation is significant at the less 0.5 level.**

The table illustrates the internal consistency of the independent variable dimensions related to Sustainable Supply Chains (y) through Pearson correlation coefficients. The results indicate strong correlations across various dimensions, with most statements achieving statistical significance at the less than 0.01 level, highlighting the critical role of sustainable practices in procurement, production, distribution, and investment recovery. For instance, a notable correlation of 0.863** reflects the strong commitment of companies in the region to encourage clean and sustainable production technologies, while a significant correlation of 0.812** points to institutions actively studying the integration of sustainability standards in procurement processes. However, some statements, such as those concerning specific challenges in sustainable procurement (0.510*) and the reuse of equipment in investment operations (0.592*), suggest that while they are significant, they may require further investigation and support to enhance their impact. Overall, these findings emphasize the interconnectedness of sustainable supply chain practices and thier potential to improve the environmental and economic performance of companies in the region

11.Test the Hypotheses of the Study:

<u>H1. The (Green Hydrogen Technological Innovation) x has a statistically significant positive impact on the dimensions of (Sustainable Supply Chains). Y</u>

- Simple liner regression was used to examine the impact of the effect of Green Hydrogen Technological Innovation (independent variable) on the Sustainable Supply Chains (dependent variable), as following

Table (3): Simple Liner Regression to the impact of (Green Hydrogen Technological Innovation) on (Sustainable Supply Chains)

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
constant	0.591	1.210	0.01**	41.351	.01*	54.2%
Green Hydrogen Technological Innovation x	0.736	6.430	0.01**			

**** Significant level 0.01**

From the above table it is clear that:

<u>1 - (R^2): coefficient of determination</u>

We find that the independent variable (Green Hydrogen Technological Innovation) x explains (54.2%) of the total change in the dependent variable (Sustainable Supply Chains) y, which have a significant significance.

<u>2- Test significant independent variable: t. test</u>

The results of the previous table confirmed the existence of a statistically significant impact of all dimensions (Green Hydrogen Technological Innovation) x on the (Sustainable Supply Chains) y according based on the Test (t) = (6.430), where we find that the level of indication is less than 0.01.

3- Test quality reconcile the regression model: F. test

To test quality of the conciliation model, was used for test (F-test), where the value of the test is (41.351), which are significant at a level less than (0.0١), which indicates the quality of the impact significant of the regression model on (Sustainable Supply Chains) y.

4-Equation of the form:

Sustainable Supply Chains = .591 + .736 Green Hydrogen Technological Innovation x

-Prove the hypothesis research:

We accept the statistical alternative hypothesis that there is an Effect of " Green Hydrogen Technological Innovation on Sustainable Supply Chains ".

The following sub-hypotheses branch out from this hypothesis:

H1a. The (Green Hydrogen Technological Innovation) x has a statistically significant positive impact on the dimensions of (Sustainable Procurement). Y1.

Simple liner regression was used to examine the impact of the effect of Green Hydrogen Technological Innovation (independent variable) on the

Sustainable Procurement y1 (dependent variable), as following**:**

Table (4): Simple Liner Regression to the impact of (Green Hydrogen Technological Innovation) on (Sustainable Procurement)

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
constant	1.020	2.035	0.01**	30.086	.01*	46.2%
Green Hydrogen Technological Innovation x	0.680	5.485	0.01**			

**** Significant level 0.01**

From the above table it is clear that:

- **<u>(R^2): coefficient of determination</u>**

We find that the independent variable (Green Hydrogen Technological Innovation) x explains (46.2%) of the total change in the dependent variable (**Sustainable Procurement** y1), which have a significant significance.

- **<u>Test significant independent variable: t. test</u>**

The results of the previous table confirmed the existence of a statistically significant impact of all dimensions (Green Hydrogen Technological Innovation) x on the (Sustainable Procurement y1) according based on the Test (t) = (5.485), where we find that the level of indication is less than 0.01.

- **<u>Test quality reconcile the regression model: F. test</u>**

To test quality of the conciliation model, was used for test (F-test), where the value of the test is (30.086), which are significant at a level less than (0.01), which indicates the quality of the impact significant of the regression model on (Sustainable Procurement y1).

❖ **Equation of the form:**

Sustainable Procurement y1= 1.020 + .680 Green Hydrogen Technological Innovation x

-Prove the hypothesis research:

We accept the statistical alternative hypothesis there is an Effect of " Green Hydrogen Technological Innovation on **Sustainable Procurement** y1".

H1b The (Green Hydrogen Technological Innovation) x has a statistically significant positive impact on the dimensions of (Sustainable Production y2).

Simple liner regression was used to examine the impact of the effect of Green Hydrogen Technological Innovation (independent variable) on the **Sustainable Production** y2 (dependent variable), as following

Table (5): Simple Liner Regression to the impact of (Green Hydrogen Technological Innovation) on (Sustainable Production y2)

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
constant	1.075	1.361	0.18	10.056	.01*	22.3%
Green Hydrogen Technological Innovation x	0.472	3.171	0.01**			

** Significant level 0.01

From the above table it is clear that:

(R^2): coefficient of determination

We find that the independent variable (Green Hydrogen Technological Innovation) x explains (22.3%) of the total change in the dependent variable (**Sustainable Production** y2), which have a significant significance.

- **Test significant independent variable: t. test**

The results of the previous table confirmed the existence of a statistically significant impact of all dimensions (Green Hydrogen Technological Innovation) x on the (Sustainable Production y2) according to the Test (t) equal (3.171), where we find that the level of indication is less than 0.01.

- **Test quality reconcile the regression model: F. test**

To test quality of the conciliation model, was used for test (F-test), where the value of the test is (10.056), which are significant at a level less than (0.01), which indicates the quality of the impact significant of the regression model on (**Sustainable Production** y2).

- **Equation of the form:**

Sustainable Production y2= 1.075 + .472 Green Hydrogen Technological Innovation x

-Prove the hypothesis research:

We accept the statistical alternative hypothesis there is an Effect of " Green Hydrogen Technological Innovation on **Sustainable Production** y2".

H1c The (Green Hydrogen Technological Innovation) x has a statistically significant positive impact on the dimensions of (Sustainable Distribution y3).

Simple liner regression was used to examine the impact of the effect of Green Hydrogen Technological Innovation (independent variable) on the **Sustainable Distribution** y3 (dependent variable), as following

Table (6): Simple Liner Regression to the impact of (Green Hydrogen Technological Innovation) on (Sustainable Distribution y4)

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
constant	0.677	0.889	0.38	15.257	.01*	30.4%
Green Hydrogen Technological Innovation x	0.551	3.906	0.01**			

**** Significant level 0.01**

From the above table it is clear that:

- **<u>(R^2): coefficient of determination</u>**

We find that the independent variable (Green Hydrogen Technological Innovation) x explains (30.4%) of the total change in the dependent variable (**Sustainable Distribution** y3), which have a significant significance.

- **<u>Test significant independent variable: t. test</u>**

The results of the previous table confirmed the existence of a statistically significant impact of all dimensions (Green Hydrogen Technological Innovation) x on the (**Sustainable Distribution** y3) according based on the Test (t) = (3.906), where we find that the level of indication is less than 0.01.

- **<u>Test quality reconcile the regression model: F. test</u>**

To test quality of the conciliation model, was used for test (F-test), where the value of the test is (15.257), which are significant at a level less than (0.01), which indicates the quality of the impact significant of the regression model on (**Sustainable Distribution** y3).

Equation of the form:

Sustainable Distribution y3= .677 + .551 Green Hydrogen Technological Innovation x

-Prove the hypothesis research:

We accept the statistical alternative hypothesis there is an Effect of " Green Hydrogen Technological Innovation on **Sustainable Distribution** y3".

H1d: The (Green Hydrogen Technological Innovation) x has a statistically significant positive impact on the dimensions of (Investment Recovery y4).

- Simple liner regression was used to examine the impact of the effect of Green Hydrogen Technological Innovation (independent variable) on the **Investment Recovery** y4 (dependent variable), as following

Table (7): Simple Liner Regression to the impact of (Green Hydrogen Technological Innovation) on (Investment Recovery y4)

Independent variables	β	t. test		F. test		R^2
		Value	Sig.	Value	Sig.	
constant	0.862	1.386	0.17	22.194	.01*	38.8%
Green Hydrogen Technological Innovation x	0.623	4.711	0.01**			

**** Significant level 0.01**

From the above table it is clear that:

- **(R^2): coefficient of determination**

We find that the independent variable (Green Hydrogen Technological Innovation) x explains (38.8%) of the total change in the dependent variable (**Investment Recovery** y4), which have a significant significance.

- **Test significant independent variable: t. test**

The results of the previous table confirmed the existence of a statistically significant impact of all dimensions (Green Hydrogen Technological Innovation) x on the (**Investment Recovery** y4) according based on the Test) t)equal (4.711), where we find that the level of indication is less than 0.01.

- **Test quality reconcile the regression model:F. test**

To test quality of the conciliation model, was used for test (F-test), where the value of the test is (22.194), which are significant at a level less than (0.01), which indicates the quality of the impact significant of the regression model on (**Investment Recovery** y4).

- **Equation of the form:**

Investment Recovery y4= .862 + .623 Green Hydrogen Technological Innovation x

-Prove the hypothesis research:

We accept the statistical alternative hypothesis there is an Effect of " Green Hydrogen Technological Innovation on **Investment Recovery** y4".

12. Study Results:

Throughout this study, the researcher reached several results that can be categorized into general results and statistical results with measurable coefficients in the Suez Canal Economic Zone. These results are as follows:

11.1. General Results:

- **Cronbach's Alpha Reliability Coefficient**: It was found that all reliability coefficients exceeded 70%, indicating high reliability and understanding of the questionnaire content, thereby confirming the realism of the responses. The total coefficient was 0.853.
- **Internal Consistency for the Dimension (Green Hydrogen Technological Innovation)**: The correlation coefficients ranged mostly between 0.537 and 0.832, which indicates that the statements in the questionnaire were well understood and relevant to the respondents.
- **Internal Consistency for the Dimension (Sustainable Supply Chains)**: The correlation coefficients ranged mostly between 0.510 and 0.863, which also indicates that the statements in the questionnaire were well understood and relevant to the respondents.

11.2. Sample Characteristics:

- It was confirmed that most employees in the Suez Canal Economic Zone have a high level of awareness and continuous engagement in understanding the requirements of their work and the importance of **Green Hydrogen Technological Innovation** in enhancing their professional levels. This suggests the credibility of the results measured by the researcher.

- The results showed that 76% of the sample were male and 24% were female, which reflects the nature of their work.
- All the sample had appropriate educational level, 38% held postgraduate degrees, while 62% had university-level qualifications.
- More than half of the sample had work experience ranging between 5 to over 10 years, accounting for 92%. This is a strong indication of the credibility of the respondents' opinions, as it reflects their experience.

Based on the results obtained by the researcher, it is evident that the selection of the sample was appropriate in terms of experience and competence, as most participants had between 5 to over 10 years of experience, which enhances the reliability and accuracy of the data collected. This extensive experience reflects a deep understanding of the dimensions of green hydrogen technological innovation and its impact on sustainable supply chains. The high reliability of the statistical coefficients, whether related to innovation or supply chains, indicates that the participants clearly understood the content of the questionnaire and responded realistically. Therefore, it can be concluded that this study provides a strong foundation for effective recommendations that can be applied in the Suez Canal Economic Zone to enhance technological innovation and achieve sustainability in supply chains.

A- Through Descriptive Statistics

Two measurements were derived for the study variables: **The Effect of Green Hydrogen Technological Innovation on Sustainable Supply Chains.**

1- Regarding the first measurement related to the dimension of Green Hydrogen Technological Innovation:

This dimension included **12 statements** within the Suez Canal Economic Zone. It has a considerable level of agreement and neutral approval among its components, making it a reliable tool for future studies.

- **Key Strengths** in the statements related to **Green Hydrogen Technological Innovation**:
  - The statement "Encouraging companies to integrate hydrogen technologies into their operations within the region" received a **90%** approval rate.
  - The statement "The local government is promoting collaboration between the public and private sectors to enhance hydrogen technology in the region" received an **86%** approval rate.
  - The statement "Exploring investment opportunities in research and development to boost hydrogen technology in the area" received an **85%** approval rate.

The results related to the scale of green hydrogen technological innovation indicate strong support from workers in the Suez Canal Economic Zone for the idea of integrating hydrogen technologies into business operations. The statement encouraging companies to incorporate these technologies received a high approval rate of **90%**, reflecting a deep conviction of the importance of innovation in improving performance and increasing efficiency. Additionally, the high approval rate of **86%** regarding the local government's role in promoting cooperation between the public and private sectors demonstrates the workers' awareness of the significance of these partnerships in advancing innovation. Furthermore, the **85%** of participants willing to explore investment opportunities in research and development indicates a positive trend towards enhancing innovation in the field of green hydrogen.

- **Key Weaknesses** in the statements related to **Green Hydrogen Technological Innovation**:
  - The statement "The industrial sector in the region is engaging in research and development to implement hydrogen technology in its operations" received a **49%** approval rate.
  - The statement "Assessing the ability of workers in the region to adopt hydrogen technology and develop their skills." received a **46%** approval rate.

The results highlight notable weaknesses in the adoption of green hydrogen technological innovation within the industrial sector of the Suez Canal Economic Zone. The statement regarding the industrial sector's participation in research and development received a **49%** approval rate, indicating a gap in interaction and effective participation in this area. Additionally, the **46%** approval rate for assessing workers' ability to adopt hydrogen technology and develop their skills reflects a lack of confidence or necessary support to equip workers with the appropriate knowledge and skills. These results underscore the importance of enhancing investments in training and development, as well as encouraging the industrial sector to actively engage in research and development initiatives, to ensure the realization of the potential benefits of green hydrogen technological innovation.

2- The second measurement concerning the dimensions of Sustainable Supply Chains included four dimensions within the Suez Canal Economic Zone. The measurement enjoys a high level of agreement and positive responses in most of its contents, making it reliable for future studies.

Key Strengths Regarding the Dimensions:

- **Dimension 1 (Sustainable Procurement):** The statement "Sustainable procurement processes in the region face specific challenges, and an investigation is underway to understand and overcome them" received an 89% approval rating.

- **Dimension 2 (Sustainable Production):** The statement "Collaboration between companies and the government is encouraged to promote sustainable practices in production processes" also garnered an 89% approval rating.
- **Dimension 3 (Sustainable Distribution):** The statement "Collaboration between companies and the government is encouraged to promote sustainable distribution within the region" received an 88% approval rating.
- **Dimension 4 (Investment Recovery):** The statement "Initiatives are in place to promote collaboration among companies to jointly improve investment recovery operations" achieved an 90% approval rating.

This indicates that the study reflects a strong recognition of the importance of sustainable supply chain practices, with a significant consensus on the need for collaboration and initiatives to promote sustainability. The high approval ratings suggest that stakeholders are aware of the existing challenges and are proactive in addressing them, highlighting a positive attitude towards enhancing sustainable procurement, production, distribution, and investment recovery within the region.

Key Weaknesses Regarding the Dimensions:

- **Dimension 1 (Sustainable Procurement):** The statement "Employees' understanding of concepts and practices related to sustainable procurement is verified through appropriate training" received a 68% approval rating.
- **Dimension 2 (Sustainable Production):** The statement "Companies encourage the use of clean and sustainable production technologies within the region" only garnered a 48% approval rating.
- **Dimension 3 (Sustainable Distribution):** The statement "The impact of sustainable distribution on the overall performance of companies within the region is evaluated and analyzed" received a 64% approval rating.
- **Dimension 4 (Investment Recovery):** The statement "Encouragement is given for the reuse of equipment and materials in investment operations to enhance sustainability" achieved a 75% approval rating.

These results indicate significant gaps in understanding and implementing sustainable practices within the supply chain. The low approval ratings for employee training in sustainable procurement and the use of clean production technologies highlight the need for more robust training programs and support mechanisms. Additionally, the moderate agreement on evaluating the impact of sustainable distribution suggests a lack of comprehensive analysis and commitment to sustainability practices. Addressing these weaknesses is crucial for fostering a deeper understanding and application of sustainable practices, ultimately leading to more effective supply chain operations.

B- Through inferential statistics:

Main Hypothesis: There is a statistically significant relationship at $\alpha \leq 0.05$ between the Effect of Green Hydrogen Technological Innovation on Sustainable Supply Chains (confirming the validity of the hypothesis as a whole).

The independent dimension (Green Hydrogen Technological Innovation), have a positive effect on the overall dependent variables (Sustainable Supply Chains), with a coefficient of determination R^2 of 54%. This impact is significantly effective; however, factors that promote and enhance the effectiveness of Green Hydrogen Technological Innovation should be considered generally. Additionally, the correlation coefficient (beta β) between them is strong and positive, reaching 0.736.

1- First Sub-Hypothesis: There is a significant effect of the dimension (Green Hydrogen Technological Innovation) on the dependent variable (Sustainable Procurement) (confirming the validity of the hypothesis as a whole).

The coefficient of determination R^2 is 46%, and the correlation coefficient (beta β) is strong and positive, measuring 0.680. This indicates a robust relationship between green hydrogen technological innovation and sustainable procurement. The results suggest that advancements in hydrogen technology significantly influence the sustainability of procurement processes, highlighting the importance of integrating these innovations to enhance procurement efficiency and effectiveness.

2- Second Sub-Hypothesis: There is a significant effect of the dimension (Green Hydrogen Technological Innovation) on the dependent variable (Sustainable Production) (confirming the validity of the hypothesis as a whole).

The coefficient of determination R^2 is 22%, and the correlation coefficient (beta β) is strong and positive, measuring 0.472. While the relationship is significant, the lower impact indicates that the effect of green hydrogen technological innovation on sustainable production is less pronounced compared to procurement. This suggests that while there is a positive relationship, further efforts are needed to enhance the integration of green hydrogen technologies in production processes to realize their full potential for sustainability.

3- Third Sub-Hypothesis: There is a significant effect of the dimension (Green Hydrogen Technological Innovation) on the dependent variable (Sustainable Distribution) (confirming the validity of the hypothesis as a whole).

The coefficient of determination R^2 is 30%, and the correlation coefficient (beta β) is strong and positive, measuring 0.551. This indicates that there is a noteworthy relationship between green hydrogen technological innovation and sustainable distribution practices. While the impact is positive, it suggests that the integration of innovative technologies in distribution processes requires further enhancement to fully leverage their potential for sustainability.

4- Fourth Sub-Hypothesis: There is a significant effect of the dimension (Green Hydrogen Technological Innovation) on the dependent variable (Investment Recovery) (confirming the validity of the hypothesis as a whole).

The coefficient of determination R^2 is 39%, and the correlation coefficient (beta β) is strong and positive, measuring 0.623. This shows that green hydrogen technological innovation significantly influences investment recovery processes. The relatively high R^2 value suggests that integrating these technologies can greatly improve the efficiency of recovering investments, thereby supporting sustainability objectives in the sector.

The independent variable with the most significant effect is (Sustainable Procurement), followed by (Investment Recovery), (Sustainable Distribution) and finally (Sustainable Production). The t-test values further support these findings, with respective values of 5.485, 4.711, 3.906, and 3.171 indicating strong statistical significance.

2- The Second Main Hypothesis: There are statistically significant differences between the demographic characteristics (gender, job, education, and work experience) concerning the dimensions of The Effect of Green Hydrogen Technological Innovation on Sustainable Supply Chains (rejecting the hypothesis as a whole).

No statistically significant differences were found in the primary data (gender/job/education/experience), which indicates a consensus of opinions regarding all dimensions of the study, whether independent or dependent variables. This uniformity in responses underscores agreement among participants regarding the impact of green hydrogen technological innovation on sustainable supply chains, suggesting a collective understanding and perception of its importance across demographic groups.

13. Study Recommendations:

Considering the previous results, the researcher has reached a set of the most significant recommendations. The following table outlines the key recommendations of the study, along with an explanation of each recommendation:

No.	Recommendation Content	Responsible for Implementation	Implementation Mechanisms	Required Time
1	Comprehensive training programs should be designed for workers that include both technical and managerial aspects of hydrogen technology, helping them adopt the necessary skills to achieve sustainable development.	Human Resources Management	Organizing workshops and training courses	6 months
2	Current administrative procedures should be reviewed and constraints that hinder innovation should be removed, adopting new methods that facilitate the effective adoption of green hydrogen technology.	Institutional Development Management	Reviewing current policies and preparing new proposals	4 months
3	Policies should be established to enhance cooperation between the public and private sectors, contributing to the development of a conducive environment for investment in hydrogen technology.	Ministry of Planning	Forming joint committees and establishing clear cooperation mechanisms	8 months
4	Enhancing awareness of sustainable practices requires providing training programs that address sustainable purchasing strategies, helping employees make more effective decisions.	Training and Development Management	Offering training programs and workshops to enhance understanding	5 months
5	Budgets should be allocated to support innovative projects, along with providing moral incentives for creative employees, enhancing a creative work environment.	(R & D) Research and Development Management	Allocating special budgets to support innovation	3 months

No.	Recommendation Content	Responsible for Implementation	Implementation Mechanisms	Required Time
6	A clear reward system should be established that links performance to training quality, motivating employees to improve their performance after completing training in hydrogen technology.	Human Resources Management	Designing a reward system that aligns with the performance	4 months
7	Regular assessments should be conducted to determine the impact of sustainability in production processes, contributing to overall performance improvement and achieving strategic goals.	Production Management	Preparing periodic reports and data analysis	Every 6 months
8	Evaluating the effectiveness of sustainable distribution strategies requires conducting analytical studies addressing overall performance, enhancing the effectiveness of logistical operations.	Distribution Management	Conducting case studies and performance analysis	Every 6 months
9	The investment environment should be enhanced by providing attractive incentives, contributing to improving investment returns and increasing the economic feasibility of projects.	Ministry of Investment With investors service department	Providing incentives for investors and enhancing the business environment	1 year
10	Raising environmental awareness requires organizing events and awareness campaigns that address the environmental benefits of hydrogen technology, increasing community interest.	Environmental Management with Ministry of communication and information	Organizing awareness campaigns and environmental workshops	6 months

No.	Recommendation Content	Responsible for Implementation	Implementation Mechanisms	Required Time
11	A platform should be established to enhance communication among researchers and exchange knowledge, contributing to benefiting from the latest studies and research in the field of green hydrogen technology.	(R & D) Research and Development Management	Creating a knowledge exchange platform and providing suggestions	3 months
12	Strategic partnerships should be established with academic institutions to develop joint research, enhancing innovation and accelerating the application of hydrogen technology in the industry.	(R & D) Research and Development Management with Ministry of Higher Education and Scientific Research	Signing cooperation agreements with universities and research centers	6 months

14. Areas for Future Research:

The researcher suggests conducting additional related studies in the following areas:

- Creating a list based on other companies or factories outside the geographical scope.
- Integrating Green hydrogen technologies into operations in different sectors and industries.
- Working on serious scientific researches that cover all aspects of hydrogen technologies.

- Focusing on supporting the use of environmentally friendly transportation methods and sustainable technologies in sustainable distribution operations.
- Conducting comparative studies between traditional systems and those that operate under hydrogen technology systems.

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