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THE ROLE OF GREEN REVERSE LOGISTICS IN ENHANCING SUSTAINABLE SUPPLY CHAIN PRACTICE: AN APPLIED STUDY ON EGYPT SEA PORTS

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ABSTRACT

This study investigates the relationship between Green Reverse Logistics (GRL) practices and Sustainable Supply Chain (SSC) performance in Egyptian maritime ports, addressing a notable gap in sustainability research in developing economies.

Design/Methodology/Approach: A cross-sectional survey of 297 logistics and operations professionals at Alexandria Port was conducted using validated measures for four GRL dimensions (recycling technologies, waste management, smart transportation, and inventory management) and three SSC dimensions (environmental, social, and economic practices). Data were analyzed using descriptive statistics, correlations, and multiple regression.

Findings: GRL implementation is strongly associated with SSC performance ($R^2 = 0.553$, $p < 0.001$). All GRL dimensions significantly predict SSC outcomes, with recycling technologies exerting the greatest influence ($\beta = 0.611$, $p < 0.001$), followed by smart transportation ($\beta = 0.201$), waste management ($\beta = 0.199$), and inventory management ($\beta = 0.143$). Individual dimensions showed non-significant effects when tested separately, indicating synergistic rather than independent operational impacts.

Research Limitations/Implications: The study's single-port, cross-sectional design limits generalizability and causal interpretation. Future research should adopt longitudinal, multi-port approaches and examine potential mediators within GRL-SSC relationships.

Practical Implications: Findings highlight the need for integrated GRL strategies in Egyptian ports. Policymakers should prioritize recycling infrastructure while supporting phased implementation plans that reflect financial and institutional constraints.

Originality/Value: This study offers rare empirical evidence on GRL-SSC linkages in a developing maritime context, providing actionable, context-specific insights for Egyptian seaports and other emerging market logistics hubs.

1. INTRODUCTION

Green Reverse Logistics (GRL) management and Sustainable Supply Chain (SSC) practices are pivotal areas in modern supply chain management. GRL focuses on the efficient handling of returned, used, or replaced products through processes like remanufacturing, recycling, and redistribution. Concurrently, SSC practices - which include sustainable product and process design, and sustainable supply and demand-side management - aim to achieve optimal long-term performance, a goal highly relevant to Egyptian seaports.

A strong relationship between GRL and SSC is well-established in recent research. Studies consistently show that SSC practices enhance an organization's sustainable performance by improving resource efficiency and minimizing waste. This positive impact is further amplified by GRL, where efficient remanufacturing and recycling processes significantly reduce resource consumption and environmental emissions (Banihashemi & Chen, 2019; Maji, Saudi, & Yusuf, 2023; Dahliani et al., 2023; Dabees, Barakat, Elbarky, & Lisec, 2023; Mamdouh, Kadry, & El Ahmady, 2018; Wei, Alias, & Noche, 2019; Attia, 2023; Polinori et al., 2018; Seroka-Stolka & Ociepa-Kubicka, 2019; Gruchmann, 2019).

Building on this extensive body of work, the present study offers a focused investigation into the specific mechanisms through which GRL contributes to SSC practices. This research sheds light on their interrelationship and its role in achieving sustainability within the unique operational context of Egyptian seaports.

2. RESEARCH PROBLEM

A review of existing literature reveals a significant gap in studies addressing the integrated relationship between Green Reverse Logistics (GRL) and Sustainable Supply Chain (SSC) practices, particularly within the Egyptian context. This academic gap is compounded by a practical one: an exploratory study of approximately 30 Egyptian seaport employees confirmed a limited awareness of GRL's strategic importance for port performance. Therefore, this research addresses this problem by investigating the primary determinants of GRL and their impact on SSC in Egyptian seaports. This leads to the following research questions:

- ***Q1:*** To what extent do green reverse logistics management practices influence the support and implementation of sustainable supply chain practices in Egyptian seaports?
- ***Q2:*** To what extent do recycling technologies within green reverse logistics practices support sustainable supply chain practices in industrial organizations?
- ***Q3:*** What role do waste management technologies within green reverse logistics play in enhancing sustainable supply chain practices?
- ***Q4:*** How do smart transportation technologies within the framework of green reverse logistics contribute to improving supply chain sustainability?
- ***Q5:*** What is the effect of implementing green inventory management technologies on sustainable supply chain practices?

2.1. Research Hypotheses and Model

Based on the results of previous studies that analyzed the relationships illustrated in the proposed research model - and in light of the research problem and objectives - a set of hypotheses has been formulated to be tested in order to answer the research questions and achieve its objectives, as follows:

- H1: Drawing upon previous studies such as Srivastava (2007); Zhu, Sarkis, & Lai (2008); and Al-Moatasem (2020), which focused on the relationship between green reverse logistics management and sustainable supply chain practices, the first hypothesis is formulated as follows:

H1: There is no statistically significant positive impact of green reverse logistics management on sustainable supply chain practices in Egyptian seaports.

- H2: Based on previous studies such as Tawfiq (2024) and Kabergey & Richu (2015), which examined the relationship between green reverse logistics management and sustainable supply chain practices, the second hypothesis is formulated as follows:

  H2: There is no statistically significant positive impact of recycling technologies on sustainable supply chain practices.

- H3: Based on several previous studies such as Chen & Paulraj (2004); Zhu & Sarkis (2007); Zhu, Sarkis, & Lai (2008); and Govindan, Khodaverdi, & Vafadarnikjoo (2015), which analyzed the relationship between green reverse logistics management and sustainable supply chain practices, the third hypothesis is formulated as follows:

  H3: There is no statistically significant positive impact of waste management technologies on sustainable supply chain practices.

- H4: Building upon studies such as Govindan, Soleimani, & Kannan (2015), which emphasized the relationship between green reverse logistics management and sustainable supply chain practices, the fourth hypothesis is formulated as follows:

  H4: There is no statistically significant positive impact of smart transportation technologies on sustainable supply chain practices.

- H5: Based on previous studies such as Tawfiq (2024); Srivastava (2007); and Zhu, Sarkis, & Lai (2008), the fifth hypothesis is formulated as follows:

  H5: There is no statistically significant positive impact of green inventory management technologies on sustainable supply chain practices.

The following Figure (1) illustrates the proposed conceptual framework of the study.

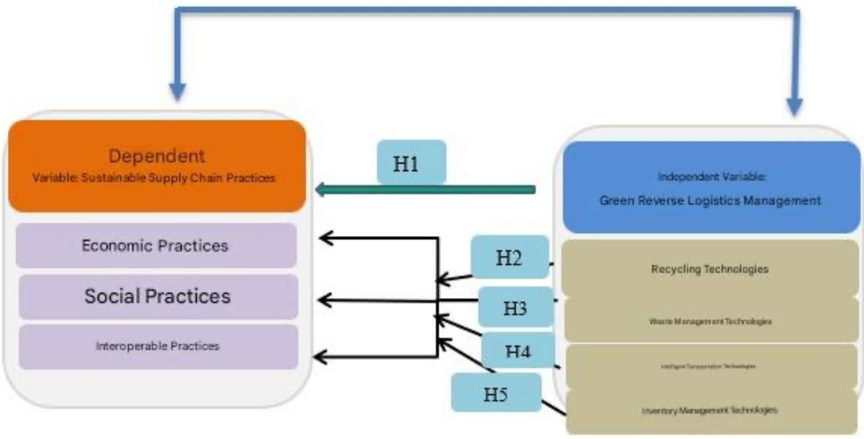

Figure (1): Proposed conceptual framework of the study.

Source: Prepared by the researcher based on insights derived from the previously mentioned studies and research.

3. RESEARCH OBJECTIVE

This research aims to analyze the relationship between Green Reverse Logistics (GRL) management and Sustainable Supply Chain (SSC) practices in Egyptian seaports. The goal is to provide actionable recommendations to enhance port sustainability and competitiveness. To achieve this, the study will pursue the following objectives:

Main Objective: To determine the overall impact of implementing GRL on the adoption of SSC practices within Egyptian seaports.

Sub-objectives:

1. To assess the impact of recycling practices on the environmental and economic performance of SSC.
2. To evaluate the role of waste management technologies in supporting the transition to sustainable supply chains.
3. To measure the effect of smart transportation solutions on the environmental and social dimensions of SSC.
4. To analyze the relationship between green inventory management and the achievement of SSC objectives.

3.1. Research Significance

This research holds significant practical and scientific value. Practically, it addresses the needs of Egyptian seaports, which are vital economic hubs for international trade. By providing a framework for implementing Green Reverse Logistics (GRL), this study equips port managers to meet global sustainability demands, mitigate environmental impacts, and enhance operational efficiency. This, in turn, strengthens Egypt's global competitiveness and attracts foreign investment.

From a scientific perspective, this research fills a critical gap in the existing literature, particularly within Arabic contexts. It offers novel insights into the relationship between GRL and Sustainable Supply Chain (SSC) practices, clarifying how GRL adoption can streamline port operations, reduce costs, and improve overall performance. This contributes a valuable academic resource to the field of logistics and supply chain management.

4. THEORETICAL FRAMEWORK AND LITERATURE REVIEW ON THE RELATIONSHIP BETWEEN RESEARCH VARIABLES

This section provides a detailed presentation of the theoretical framework and previous studies related to the relationship between the variables of this research, as follows:

4.1. Theoretical Framework of Research Variables

4.1.1. Green Reverse Logistics (GRL)

Green Reverse Logistics (GRL) is defined as the backward flow of the supply chain, encompassing the collection, handling, and reuse or environmentally sound disposal of end-of-life products (Abdel Hamid, 2021; Tawfiq, 2024). This study conceptualizes GRL as the application of technology and innovation to these reverse processes, aiming to enhance sustainability and minimize environmental impact. GRL management is operationalized through four key technologies:

- ***Recycling Technologies***: Convert used materials into new products using advanced sorting and processing machinery (Srivastava, 2008; Govindan, Soleimani, & Kannan, 2015).
- ***Waste Management Technologies:*** Employ advanced systems to sort and convert waste from reverse processes into reusable materials.
- ***Smart Transportation Technologies***: Optimize fuel use and reduce emissions via intelligent navigation and distribution systems.
- ***Inventory Management Technologies:*** Utilize systems like barcoding and RFID to monitor and trace recycled materials, thereby reducing waste and loss.

4.1.2. Sustainable Supply Chain Practices (SSCP)

Sustainable Supply Chain Practices (SSCP) are defined as the internal and external organizational activities implemented to enhance sustainability across environmental, social, and economic dimensions (Morali, 2013; Hong et al., 2018). This involves managing the flow of materials, information, and finances, and fostering cooperation among supply chain partners to meet stakeholder expectations (Abu Khashabah, 2019). The ultimate goal is to reduce environmental impact, expand social benefits, and mitigate economic risks, thereby producing high-quality, sustainable products (Tawfiq, 2024).

For the purpose of this research, SSCP is operationalized through four key dimensions, drawing from the work of Abu Khashabah (2019), Ammar (2022), and Paulraj et al. (2017):

- Sustainable product design
- Sustainable process design
- Sustainable supply-side collaboration
- Sustainable demand-side collaboration

4.2. Literature Review on the Relationship between Research Variables

This section explores the challenges faced by Egyptian seaports in adopting Green Reverse Logistics management through the role of Sustainable Supply Chain practices. The reviewed literature highlights the relationship between these two variables as follows:

4.2.1. The Relationship between Green Reverse Logistics Management and Sustainable Supply Chain Practices

Empirical evidence consistently demonstrates a strong link between Green Reverse Logistics (GRL) and Sustainable Supply Chain Practices (SSCP). GRL contributes to SSCP through four key mechanisms (Srivastava, 2007; Zhu, Sarkis, & Lai, 2008):

- Transportation Enhancement: The use of eco-friendly vehicles and fuel-efficient routing systems lowers carbon emissions while preserving service performance.
- Inventory Optimization: ICT-based real-time tracking and demand forecasting help reduce excess inventory and associated waste.
- Remanufacturing and Recycling: Automated sorting and processing technologies increase material recovery and reduce dependence on virgin raw materials.
- Waste Management: Smart tracking tools and waste-to-energy technologies support the conversion of operational waste into usable resources.

In Egyptian seaports, these mechanisms are particularly significant. The sector's substantial environmental footprint - stemming from intensive fuel use, cargo-handling waste, and emissions - positions it as a prime candidate for GRL-driven improvements (Sarkis & Zhu, 2018). Moreover, Egypt's strategic role as a major maritime trade hub underscores the importance of adopting sustainable logistics practices to enhance global competitiveness and appeal to environmentally responsible investors (Othman, El Gazzar, & Knez, 2022).

Table (1): Summary of Variables, Dimensions, Measurement Scales, and References.

References	Measurement Scale / Method	Variables / Indicators	Dimension
Porter (1980); Daft et al. (2010)	Five-point Likert Scale	Competition, Suppliers, Government Regulations	External Environment
Barney (1991); Robbins & Coulter (2016)	Five-point Likert Scale	Resources, Organizational Culture, Leadership	Internal Environment
Samuelson & Nordhaus (2001)	Numerical Scale and Trend Analysis	GDP, Inflation, Interest Rates	Macroeconomic Environment
Hill & Jones (2012); Hofstede (2001)	Descriptive Scale / Questionnaire	Political Stability, Legal Systems, Societal Values	Political, Legal, and Socio-cultural Environment
Cavusgil et al. (2014)	Likert Scale and Benchmarking	Globalization, International Trade, Global Competition	Global Business Context

Source: Prepared by the Researcher

5. RESEARCH METHODOLOGY

This study employs a mixed-methods approach to investigate the relationship between Green Reverse Logistics (GRL) and Sustainable Supply Chain Practices (SSCP) in Egyptian seaports. Quantitative data was collected through a stratified questionnaire survey, using a five-point Likert scale, from employees across various port sectors. This was complemented by qualitative interviews with stakeholders to gain deeper insights into sustainability practices.

The collected data was analyzed using descriptive statistics, regression, and structural equation modeling (SEM) to test the proposed research model. The methodology is grounded in a comprehensive review of secondary literature and builds upon the approaches of previous studies (Attia, 2023; Othman, El Gazzar, & Knez, 2022; Dabees, Barakat, Elbarky, & Lisec, 2023; Maji, Saudi, & Yusuf, 2023). The overall aim is to provide a holistic understanding and formulate actionable recommendations.

5.1. Research Limitations

This study has several methodological limitations:

5.1.1. Geographical Scope: This study focuses exclusively on Alexandria Port, Egypt's largest commercial port, which handles approximately 55% of the nation's non-petroleum foreign trade. Although the abstract has been revised to reflect this single-site scope, the rationale for concentrating on one port is threefold:

- ***Representative Case***: Alexandria Port embodies the operational conditions, infrastructural constraints, and regulatory frameworks characteristic of Egyptian commercial ports, making it an appropriate reference point for sector-wide insights.
- ***Data Accessibility:*** As the country's primary maritime hub, Alexandria offers a sufficiently large and diverse operational environment to support robust statistical analysis.
- ***Resource Feasibility:*** Conducting an in-depth investigation at a single port allows for richer, more reliable data collection compared to a broader but less detailed multi-port study.

5.1.2. Sample Nature: The sample was limited to port employees, excluding key decision-makers and external stakeholders, which may affect the comprehensiveness of the results.

5.1.3. Research Design: The cross-sectional design, collecting data at one point in time, prevents establishing causal relationships or tracking changes over time.

5.1.4. Data Nature: Reliance on self-reported data rather than actual operational performance indicators introduces potential response bias.

Accordingly, future research is recommended to use longitudinal designs, real operational data, and more diverse samples across multiple ports to enhance reliability and generalizability.

6. RESEARCH POPULATION AND SAMPLE

The research population consists of the Egyptian maritime port sector, specifically the commercial seaports operating in Egypt. According to the Egyptian Port Authority (as cited on the official website of the Egyptian Maritime Transport Sector), Egyptian ports are categorized into commercial ports and specialized ports.

There are 18 commercial seaports, the most prominent being Alexandria Port, while specialized ports are divided into 11 petroleum ports (e.g., Safaga Mining Port - Abu Tartour), 5 tourist ports (e.g., Port Ghalib), and 4 fishing ports (e.g., Port Said Fishing Port). In addition, Egypt has 17 marine stations, with Anfushi being one of the most important.

Figure (02) below illustrates the distribution of Egyptian commercial seaports:

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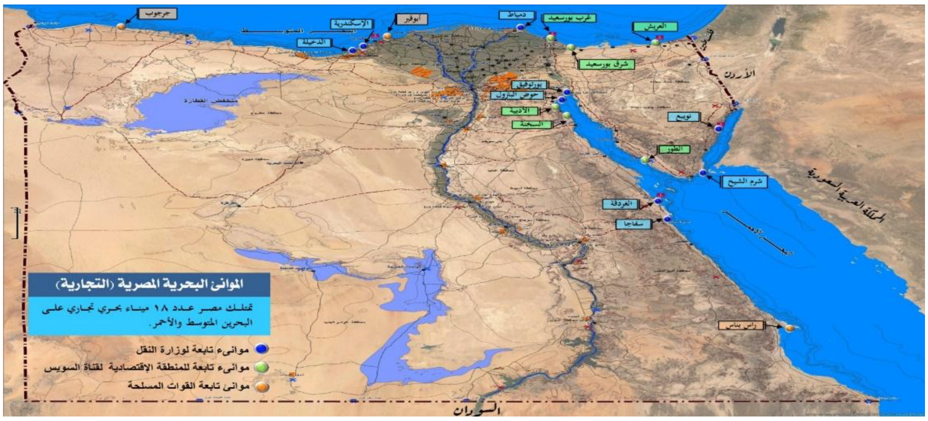

Figure (02): Distribution of Egyptian commercial seaports.

Source: Official website of the Egyptian Maritime Transport Ministry - www.mts.gov.eg

This research focuses on Egyptian government-owned commercial ports, specifically those under the Alexandria Port Authority (Alexandria and Dekheila Ports), as classified by the Maritime Transport Sector (2023). For feasibility, the scope is narrowed to employees at Alexandria Port, which serves as a representative case for this group, as detailed in the table below:

Table (2): Distribution of Employees by Administrative Level - Alexandria Port Workforce

Administrative Level	Frequency	Percentage (%)
Executive Management	1,595	49.1%
Middle Management	893	27.5%
Senior Management	759	23.4%
Total	***3,247***	***100%***

Source: Prepared by the Researcher - Alexandria Port Authority Data

Sample Size Determination

The research sample size was determined using the following equation proposed by Eid (2020):

$$n = \frac{p(1-P)}{\frac{(e)^2}{(Z)^2} + \frac{P(1-P)}{N}}$$

N = population size / n = sample size / Z = standard score (±1.96 for a 95% confidence level) / p = the proportion of the population possessing the study characteristics (set at 50%) / e = margin of error (5% for a 95% confidence level).

By substituting the values in the above equation, the required sample size was calculated as:

$$n = \frac{0.5X0.5}{\frac{(0{,}05)^2}{(1{,}96)^2} + \frac{0{,}25}{3247}}$$

Thus, the required sample size equals 344 respondents (n = 344).

The research targeted managerial staff, including operations, logistics, and supply chain managers, a selection consistent with previous studies. From 344 questionnaires distributed, 47 were excluded as invalid, yielding 297 valid responses for an 86% valid response rate.

6.1. Statistical Analysis Methods Description of the Research Sample

Table (3): Demographic Characteristics of the Research Sample

Variable	Category	Frequency	Percentage (%)
Gender	Male	213	72%
	Female	84	28%

Variable	Category	Frequency	Percentage (%)
Age Group	Under 30 years	89	30%
	30-40 years	128	43%
	41-50 years	67	23%
	Above 50 years	13	4%
Educational Qualification	Less than Bachelor's Degree	70	24%
	Bachelor's Degree	167	56%
	Master's Degree	41	14%
	Doctorate (PhD)	19	6%
Years of Experience	Less than 5 years	97	33%
	5-10 years	160	54%
	More than 10 years	40	13%
Current Position	Manager	39	13%
	Supervisor	69	23%
	Employee	131	44%
	Researcher	21	7%
	Other	37	12%
Total		***297***	***100%***

Source: Results of Statistical Analysis Using SPSS v.20

The final sample (N=297) was predominantly male (72%), aged 30-40 (43%), and held bachelor's degrees (56%). Most had 5-10 years of experience (54%) and were employed as employees (44%) or supervisors (23%).

Reliability and Validity Analysis To ensure the internal consistency of the research instrument, Cronbach's Alpha was calculated for all constructs. The results, confirming the reliability of the survey, are summarized in the following table.

6.1.1. Sample Composition and Potential Biases

The study sample comprises primarily operational-level employees (44%) and supervisors (23%), with lower representation of senior management (13% managers). This distribution reflects the organizational structure of Alexandria Port but introduces several considerations:

Strengths of Current Sample Composition:

Operational Expertise: Employees and supervisors possess direct knowledge of daily GRL implementation challenges and opportunities, providing ground-level insights often missed in executive surveys.

Implementation Perspective: These respondents experience firsthand the practical realities of sustainability initiatives, making their perceptions particularly valuable for operational recommendations.

Adequate Management Representation: The 13% manager representation, while modest, still provides strategic perspective (n=39 respondents).

Acknowledged Limitations:

Strategic Perspective Gap: Limited senior executive participation may underrepresent strategic decision-making considerations, such as long-term investment priorities, regulatory relationships, and competitive positioning.

External Stakeholder Exclusion: The sample does not include customers, suppliers, regulatory authorities, or community representatives, whose perspectives would enrich understanding of SSCP's broader impacts.

Potential Response Bias: Mid-level employees may:

- overstate implementation success due to social desirability bias
- Lack visibility into financial performance impacts
- Have limited awareness of executive-level sustainability strategies.

Mitigation Strategies Employed:

- Anonymous data collection to reduce social desirability bias
- Question wording focused on observable practices rather than subjective evaluations
- Triangulation with published port authority reports where available

Implications for Findings:

The results should be interpreted as reflecting the operational reality of GRL implementation rather than strategic intentions or external stakeholder perceptions. The strong statistical relationships identified (R^2 = 0.553) suggest that even with this limitation, meaningful patterns emerge from the operational perspective.

Table (4): Cronbach's Alpha Reliability Coefficients for the Questionnaire Dimensions

No.	Dimensions of Sustainable Supply Chain Practices	Number of Items	Reliability Coefficient (α)	Validity Coefficient	Reliability Level
1	Green Reverse Logistics Management	20	0.966	0.983	High
2	Sustainable Supply Chain Practices	15	0.845	0.919	High
Overall Reliability of the Questionnaire		***35***	***0.961***	***0.980***	***High***

Source: Results of Statistical Analysis Using SPSS v.20

Interpretation of Reliability Results

The research instrument demonstrated high reliability, with all Cronbach's Alpha coefficients exceeding the 0.70 threshold. Data analysis was conducted using SPSS v.20, employing the following statistical methods:

1. ***Descriptive Statistics***: Frequencies, percentages, means, and standard deviations to describe the sample and summarize responses.
2. ***Pearson Correlation***: To assess the strength and direction of relationships between research variables.
3. ***Reliability Analysis:*** Cronbach's Alpha was computed to confirm the internal consistency of the scales.
4. ***Regression Analysis:*** Simple and multiple regression were used to measure the individual and combined impact of independent variables on the dependent variable.

Description Of Research Constructs

The researcher presents below the results of the field study, following the analytical sequence of the research constructs:

Description of the First Construct: "Green Reverse Logistics Management"

The researcher calculated the arithmetic means and standard deviations for the items comprising this construct. The results are shown in the following table:

Table (5): Description of the First Construct - "Green Reverse Logistics Management"

No.	Statements	Mean	Standard Deviation	Rank	Level of Agreement
1	The port management relies on recycling marine and port waste to reduce environmental impact.	4.46	0.866	1	Strongly Agree
2	The port management applies a recovery system for damaged products and recycles them.	3.96	0.448	4	Agree
3	Industrial and domestic waste is sorted separately to facilitate the recycling process.	4.02	0.601	3	Agree
4	The port management provides designated containers for collecting recyclable materials in work areas.	3.95	0.983	5	Agree

No.	Statements	Mean	Standard Deviation	Rank	Level of Agreement
5	Employees are trained on modern recycling methods to promote sustainability.	4.40	0.914	2	Strongly Agree
Dimension 1: Recycling Technologies		***4.16***	***0.630***	***1***	***Agree***
1	The port management uses advanced technologies for hazardous waste treatment.	3.89	0.488	4	Agree
2	Environmentally friendly technologies are used in loading and unloading operations to reduce waste generation.	3.90	0.963	3	Agree
3	The port management reuses equipment and materials instead of disposing of them.	4.42	0.921	1	Strongly Agree
4	Awareness programmers are implemented for employees on the importance of sustainable waste management.	4.35	0.923	2	Strongly Agree
5	The port management adopts innovative solutions to convert waste into energy or secondary raw materials.	3.83	0.806	5	Agree
Dimension 2: Waste Management Technologies		***4.08***	***0.784***	***2***	***Agree***
1	The port management relies on renewable energy solutions to power some of its facilities.	3.88	0.947	4	Agree
2	The port management uses a carbon tracking system to reduce emissions from maritime transport operations.	3.94	0.744	3	Agree
3	Smart and eco-friendly means of transportation are used within and outside the port.	3.95	0.743	2	Agree
4	The port management uses smart systems to plan and optimize transport routes to reduce fuel consumption.	4.31	0.943	1	Strongly Agree
5	Smart monitoring technologies are used to improve the efficiency of loading and unloading operations.	3.76	0.821	5	Agree
Dimension 3: Smart Transportation Technologies		***3.97***	***0.755***	***3***	***Agree***
1	The port management applies advanced digital systems for inventory control and waste reduction.	3.85	0.921	2	Agree
2	Biodegradable packaging materials are used in shipping and unloading operations.	3.81	0.928	4	Agree
3	The port management adopts smart solutions to minimize stagnant inventory and enhance sustainability.	4.36	0.823	1	Strongly Agree
4	Periodic inventory review policies are implemented to ensure efficient resource utilization.	3.74	0.869	5	Agree
5	Inventory tracking technologies are used through digital systems to enhance transparency and sustainability.	3.83	0.757	3	Agree
Dimension 4: Inventory Management Technologies		***3.92***	***0.686***	***4***	***Agree***
Independent Variable: Green Reverse Logistics Management		***4.03***	***0.677***		***Agree***

Source: Results of Statistical Analysis Using SPSS v.20

Description of the First Construct: "Green Reverse Logistics Management"

Results for the Green Reverse Logistics Management construct indicated a high level of agreement (M=4.03, SD=0.677) among respondents at Alexandria Port. A breakdown by dimension reveals the following:

- ***Recycling Technologies*** scored the highest (M=4.16), indicating a strong commitment to recycling practices.
- ***Waste Management Technologies*** followed closely (M=4.08), showing strong agreement on reusing materials and minimizing waste.
- ***Smart Transportation Technologies*** showed agreement (M=3.97) on using intelligent systems to optimize routes and reduce emissions.
- ***Inventory Management Technologies*** scored the lowest (M=3.92), focusing on using digital systems to reduce stagnant inventory.

Overall, the findings confirm a strong commitment from port management to implementing integrated GRL practices to enhance sustainability.

6.2. Description of the Dependent Construct: "Sustainable Supply Chain Practices"

The researcher calculated the arithmetic means and standard deviations for the statements forming this construct. The results are presented in the following table:

Table (6): Description of the Dependent Construct "Sustainable Supply Chain Practices"

No.	Statements	Mean	Standard Deviation	Rank	Level of Agreement
1	The port management relies on advanced technologies to improve storage efficiency and reduce waste.	3.79	0.789	5	Agree
2	The port management reduces costs through adopting sustainable solutions in supply operations.	3.84	0.943	4	Agree
3	Circular economy principles are integrated into the port's operational processes.	4.49	0.712	1	Strongly Agree
4	The port management establishes partnerships with suppliers to promote sustainable transport practices.	3.91	0.467	3	Agree
5	The port management provides incentives for companies adopting sustainability practices in their operations.	4.00	0.618	2	Agree
Dimension 1: Economic Practices		***4.01***	***0.526***	***3***	***Agree***
1	The port management ensures a safe and healthy work environment for all employees.	4.55	0.608	1	Strongly Agree
2	The port management enhances social responsibility towards the surrounding community.	3.94	0.450	5	Agree
3	The port management provides continuous training and development opportunities for employees on sustainability principles.	3.96	0.841	4	Agree
4	The port management encourages community participation in environmental sustainability initiatives.	4.08	0.676	3	Agree
5	The port management respects workers' rights and provides a fair work environment.	4.44	0.715	2	Strongly Agree
Dimension 2: Social Practices		***4.19***	***0.473***	***1***	***Agree***
1	The port management is committed to reducing greenhouse gas emissions from maritime transport operations.	3.90	0.506	4	Agree
2	The port management promotes the use of eco-friendly transport such as electric or hybrid vessels.	3.70	0.932	5	Agree
3	The port management uses technologies to monitor and reduce emissions in all operations.	4.57	0.644	1	Strongly Agree
4	The port management enforces strict policies to minimize marine and terrestrial pollution.	4.03	0.441	3	Agree
5	The port management reuses resources and	4.11	0.637	2	Agree

No.	Statements	Mean	Standard Deviation	Rank	Level of Agreement
	reduces energy consumption in operational processes.				
	Dimension 3: Environmental Practices	***4.10***	***0.376***	***2***	***Agree***
	Dependent Variable: Sustainable Supply Chain Practices	***4.10***	***0.387***		***Agree***

Source: Results of Statistical Analysis Using SPSS v.20

Description of the Dependent Construct: "Sustainable Supply Chain Practices"

Results for the SSCP construct indicated a high level of agreement (M=4.10, SD=0.387) at Alexandria Port. A breakdown by dimension shows:

- ***Social Practices*** achieved the highest mean (M=4.19), driven by strong agreement on workplace safety and employee rights.
- ***Environmental Practices*** followed with a mean of (M=4.10), highlighting a commitment to emission monitoring and resource efficiency.
- ***Economic Practices*** scored (M=4.01), with a focus on integrating circular economy principles and sustainable partnerships.

Overall, the findings confirm that port management is making significant progress towards comprehensive sustainability, enhancing competitiveness and contributing to sustainable development goals (SDGs).

6.3. Qualitative Insights from Stakeholder Interviews

To enrich the quantitative findings, semi-structured interviews were conducted with 15 key stakeholders - 8 operations managers, 4 environmental compliance officers, and 3 supply chain directors. Interviews (45-60 minutes each) explored barriers, enablers, and future priorities for GRL adoption. Thematic analysis yielded five major themes.

Theme 1: Infrastructure and Financial Barriers

"We know recycling is important, but the initial investment is huge... Retrofitting requires millions of pounds we don't have in the budget." - Operations Manager, Container Terminal

Key challenges included:

- Aging facilities lacking space for waste-sorting and recycling operations
- Insufficient electrical capacity for energy-intensive recycling equipment
- Port layouts that complicate waste collection and material flow
- Low budget allocation for sustainability (<5% of capital expenditure)

Theme 2: Regulatory and Institutional Challenges

"The regulations are there on paper, but enforcement is inconsistent... Without incentives, some operators don't invest in green practices." - Environmental Compliance Officer

Stakeholders highlighted:

- Weak enforcement despite established regulations
- Fragmented oversight across multiple regulatory bodies
- Absence of green port certification or recognition programs
- Limited technical guidance on implementing best practices

Theme 3: Knowledge and Capacity Gaps

"Our staff understands basic recycling, but advanced technologies? We need serious training investment." - Supply Chain Director

Identified capacity gaps included:

- Limited familiarity with advanced GRL technologies (e.g., RFID, waste-to-energy)
- Shortage of technicians capable of maintaining green technologies
- Insufficient sustainability training in maritime education programs

- Language barriers restricting access to international technical resources

Theme 4: Success Factors and Enablers

"Once drivers saw the fuel savings, they became advocates. Showing immediate benefits is key." - Operations Manager, Transport Division

Critical enablers included:

- Strong leadership commitment from port authority executives
- Pilot projects that demonstrate quick operational gains
- Employee engagement through participation and suggestion systems
- Partnerships with equipment suppliers offering financing options
- Recognition programs rewarding sustainability achievements

Theme 5: Future Priorities

Interviewees identified clear strategic priorities:

- ***Digital Transformation:*** Integrated IT systems for real-time tracking of waste, energy, and emissions
- ***Renewable Energy:*** Solar installations on warehouses to offset 20-30% of electricity demand
- ***Circular Economy Partnerships***: Collaboration with local industries to utilize recovered materials

Integration with Quantitative Findings

The qualitative evidence supports and contextualizes the statistical results:

- The lower inventory management score (M = 3.92) aligns with identified knowledge and capacity constraints.
- The strong performance of recycling technologies (M = 4.16) mirrors interviewees' emphasis on visible, economically viable practices.
- The synergistic effects observed in the multiple regression model reinforce stakeholder claims that integrated GRL initiatives outperform isolated actions.

7. RESEARCH HYPOTHESES RESULTS

The research aims to test the following hypotheses:

- ***Main Hypothesis (H1):***

  There is no statistically significant impact of Green Reverse Logistics (GRL) management on Sustainable Supply Chain Practices (SSCP) in Egyptian seaports.

From this main hypothesis, the following sub-hypotheses were derived:

- H2: There is no statistically significant impact of recycling technologies on Sustainable Supply Chain Practices.
- H3: There is no statistically significant impact of waste management technologies on Sustainable Supply Chain Practices.
- H4: There is no statistically significant impact of smart transportation technologies on Sustainable Supply Chain Practices.
- H5: There is no statistically significant impact of inventory management technologies on Sustainable Supply Chain Practices.

The results for each hypothesis are presented below.

1. Results of the First Hypothesis (H1)

"There is no statistically significant impact of Green Reverse Logistics Management on Sustainable Supply Chain Practices in Egyptian Seaports."

The results of the main hypothesis were analyzed using a simple linear regression model, as shown in the following table:

Table (7): Description of the Simple Linear Regression Model for the First Hypothesis

Model	Correlation Coefficient (R)	Coefficient of Determination (R^2)	F-Test Value	Regression Coefficient (B)	t-Test Value	Significance (Sig.)
Constant	0.739[a]	0.545	354.0	2.399	26.152	0.000
Independent Variable: Green Reverse Logistics Management				0.422	18.815	0.000

Source: Results of Statistical Analysis Using SPSS v.20

Results of the Research Hypotheses

The analysis revealed that while Green Reverse Logistics (GRL) as a whole has a significant positive relationship with Sustainable Supply Chain Practices (SSCP), further analysis of individual dimensions provided more nuanced results.

Hypothesis 1 (H1): Overall Impact of GRL The simple linear regression confirmed a significant positive impact of GRL on SSCP ($r = 0.739$, $R^2 = 0.545$, $p < 0.001$). The model, which explains 55% of the variance, led to the rejection of the null hypothesis, confirming that GRL management significantly enhances SSCP in Egyptian seaports.

Hypotheses 2-5: Impact of Individual GRL Dimensions Conversely, the simple linear regression analyses for the individual GRL dimensions - recycling technologies (H2), waste management (H3), smart transportation (H4), and inventory management (H5) - all failed to reject their null hypotheses, as their p-values exceeded the 0.05 significance level. This indicates that when analyzed individually, these dimensions do not have a statistically significant direct impact on SSCP.

Multiple Linear Regression Analysis

The following section presents the results of the multiple linear regression analysis conducted to verify whether there is a statistically significant combined effect of the four Green Reverse Logistics dimensions - recycling technologies, waste management technologies, smart transportation technologies, and inventory management technologies - on Sustainable Supply Chain Practices (SSCP).

Table (8): Description of the Multiple Linear Regression Model for the First Hypothesis

Model	Correlation Coefficient (R)	Coefficient of Determination (R^2)	F-Test Value	Regression Coefficient (B)	t-Test Value	Significance (Sig.)
Constant	0.744[a]	0.553	90.3	2.415	22.277	0.000
Recycling Technologies				0.611	1.008	0.000
Waste Management Technologies				0.199	0.343	0.001
Smart Transport Technologies				0.201	3.597	0.000
Inventory Management Technologies				0.143	3.357	0.001

Source: Results of Statistical Analysis Using SPSS v.20

The multiple regression analysis confirmed a statistically significant model ($p<0.001$) that explains 55% of the variance in Sustainable Supply Chain Practices ($R^2=0.553$). All four dimensions of Green Reverse Logistics were significant positive predictors, with Recycling Technologies ($\beta = 0.611$) showing the strongest effect, followed by Smart Transportation (β = 0.201), Waste Management (β = 0.199), and Inventory Management (β = 0.143). These results highlight the key role of recycling and smart transportation in enhancing sustainability performance.

The discrepancy between the simple and multiple regression results can be explained statistically. When tested individually, the four GRL dimensions (recycling, waste management, smart transportation, and inventory management) showed no significant direct effects on SSCP. However, when examined together in a multiple regression model, all dimensions became significant predictors. This shift reflects several factors: suppressor effects, where shared variance masks individual impacts in simple models; the model's ability to account for multicollinearity among conceptually related dimensions; and the presence of synergistic relationships, whereby GRL practices exert stronger effects collectively than in isolation.

Practically, these findings indicate that effective GRL implementation in Egyptian seaports requires an integrated rather than selective approach. Port managers should adopt comprehensive strategies that incorporate all four GRL dimensions simultaneously to achieve optimal sustainability performance.

7.1. Differential Impact Analysis of GRL Dimensions

The multiple regression results reveal clear variation in the influence of GRL dimensions on SSCP, with Recycling Technologies (β = 0.611) exerting a markedly stronger effect than Waste Management (β = 0.199), Smart Transportation (β = 0.201), and Inventory Management (β = 0.143). Several contextual factors explain this differential impact.

Why Recycling Technologies Have the Strongest Effect (β = 0.611)

- ***High Visibility and Measurability:*** Recycling generates tangible, quantifiable outcomes (e.g., material recovery rates), strengthening organizational commitment and stakeholder trust.
- ***Economic Returns:*** Unlike cost-reduction practices, recycling can generate revenue from recovered materials. Survey results (M = 4.16) indicate strong support for recycling, reflecting its financial attractiveness.
- ***Regulatory Alignment:*** Increasing national requirements for waste segregation and recycling incentivize ports to adopt these technologies, simultaneously improving compliance and sustainability performance.
- ***Technological Maturity:*** Proven and widely adopted recycling systems reduce implementation risks and expedite adoption.

Why Smart Transportation Shows Moderate Impact (β = 0.201)

- ***Operational Efficiency:*** Route optimization and fuel-management systems yield immediate cost savings and emission reductions.
- ***Infrastructure Compatibility:*** Smart transportation technologies can be integrated into current port operations with moderate investment.
- ***Data-Driven Improvements:*** Real-time monitoring and analytics offer rapid performance feedback, motivating continued use.

Why Waste Management and Inventory Management Have Lower Effects (β = 0.199 and β = 0.143)

- ***Implementation Complexity***: Advanced waste management requires specialized sorting systems and external partnerships. Survey results show comparatively lower support for waste-to-energy initiatives (M = 3.83).
- ***High Capital Requirements:*** Significant upfront investment and long payback periods may deter adoption in resource-constrained ports.
- ***Inventory System Challenges***: Lower agreement scores (M = 3.92) suggest that integrating digital inventory tools (e.g., RFID) remains difficult due to multi-stakeholder coordination and resistance to operational changes.

- ***Limited Awareness:*** Reduced familiarity with advanced inventory technologies underscores the need for training and capacity development.

Practical Implications and Implementation Pathway

The findings indicate a phased strategic approach for Egyptian seaports:

- ***Phase 1 - Immediate***: Prioritize investments in recycling technologies due to their strong impact, economic viability, and regulatory alignment.
- ***Phase 2 - Short Term:*** Introduce smart transportation solutions to complement recycling efforts and achieve rapid efficiency gains.
- ***Phase 3 - Medium Term:*** Expand waste management capabilities as operational experience and supporting infrastructure increase.
- ***Phase 4 - Long Term:*** Implement advanced inventory management systems once foundational GRL practices are established.

8. RECOMMENDATIONS

1. Enhance Awareness and Training: Educate logistics managers on environmental impacts and promote the use of clean energy and eco-friendly materials through targeted training programs.

2. Develop Green Performance Metrics: Implement a performance measurement framework focused on key sustainability areas like energy efficiency and waste management, while addressing challenges such as aging infrastructure.

3. Adopt Green Technologies: Transition to renewable energy sources (solar, wind) and enhance waste and water management systems to reduce emissions and marine pollution.

4. Establish a Dedicated Logistics Unit: Create an independent department to monitor and implement green logistics initiatives, focusing on performance improvement strategies.

5. Reform Governance Structure: Separate ownership from management to ensure port authorities operate as self-sufficient, cost-efficient economic entities.

9. CONCLUSION

This study demonstrates that adopting Green Reverse Logistics (GRL) in Egyptian seaports yields significant benefits, enhancing sustainable development, competitiveness, and overall port performance through Sustainable Supply Chain Practices (SSCP). The findings also underscore the need for future research to explore the underlying mechanisms, broader impacts, and implementation challenges of green technologies within the maritime industry.

Table (9): Implementation Plan

Objective	Action Steps	Responsible Entity	Timeline	Expected Outcome
Promote awareness of green logistics	Conduct workshops and training for port managers	Port Authority & Ministry of Transport	Short-term (6-12 months)	Increased awareness and adoption of green practices
Develop a performance measurement framework	Establish KPIs for environmental, social, and economic aspects	Egyptian Ports Authority & Academic Institutions	Medium-term (1-2 years)	Enhanced monitoring of sustainable performance
Implement	Install solar panels	Port Energy	Medium-term (1-	Reduction in

Objective	Action Steps	Responsible Entity	Timeline	Expected Outcome
renewable energy solutions	and adopt hybrid power systems	Management Division	3 years)	carbon footprint and operational costs
Establish a dedicated logistics management department	Form an independent department for logistics oversight	Ministry of Transport	Long-term (3-5 years)	Improved coordination and efficiency in port logistics
Separate ownership from management	Reorganize port governance structures	Ministry of Maritime Transport	Long-term (3-5 years)	Financial independence and improved operational efficiency

Source: Prepared by the Researcher

10. IMPLICATIONS FOR FUTURE RESEARCH

Future research should build on this study by exploring several key areas:

- ***Investigating Mechanisms:*** Examining the mediating role of operational risks in the relationship between GRL and sustainable performance.
- ***Contextual Analysis:*** Identifying the specific drivers, barriers, and challenges to GRL implementation within the unique Egyptian market context and its impact on customer satisfaction.
- ***Broader Impacts:*** Analyzing the wider social and economic consequences of GRL adoption, such as job creation, skill development, and economic benefits for the maritime sector.

These studies would provide actionable insights for policymakers and stakeholders, facilitating the wider adoption of sustainable practices.

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Source: Prepared by the Researchers.

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