Green supply chain practices are key to reducing carbon emissions in the logistics sector in Saudi Arabia.

Abstract

The logistics industry is responsible for a significant amount of carbon emissions because it relies heavily on fossil fuels for transportation, uses a lot of energy in warehouses, and has complicated networks for distributing goods. In Saudi Arabia, the economy is growing quickly and there are a lot of new buildings. This has increased the amount of goods being moved around, which has made the environment more polluted. In reply, Saudi Vision 2030 is very focused on being kind to the environment and on reducing the carbon footprint of the economy. This study looks at ways to reduce carbon emissions in the logistics sector of Saudi Arabia. It focuses on using techniques to manage supply chains in a way that is good for the environment. The paper uses a detailed review of academic literature, policy documents, and industry reports to identify important green strategies that can be used in Saudi logistics, such as buying products and services in ways that do not harm the environment, using transportation systems that use less energy, using renewable energy, using digital technologies to make processes more efficient, and managing supply chains in a way that is collaborative. The analysis shows how these practices can reduce greenhouse gas emissions while also improving how well the company works, how it controls its costs, and its ability to compete with other companies. The results show that using green methods in supply chains is good for the environment and also helps Saudi Arabia reach its national logistics strategy and sustainability goals. But problems like high costs, a lack of technical knowledge, and different rules being put in place are still stopping this from being used more widely. By contextualising green supply chain strategies within Saudi Arabia's unique economic and regulatory environment, this paper contributes to the growing body of knowledge on sustainable logistics. The investigation offers valuable knowledge for logistics companies, government officials and supply chain supervisors who are looking to strike a balance between ecological duty and financial success under Saudi Vision 2030. Research in the future will include checking that the strategies work by doing experiments, and using numbers to see how much they can reduce carbon emissions in different parts of the logistics industry.

Keywords

Ecological supply chain administration,greenhouse gas emissions reduction, transportation management, eco-friendly procedures, the Saudi government's 2030 vision, ecological impact, sustainable energy sources, transportation that minimises energy consumption.

Introduction

1.1 Background and context

Well, the logistics sector is really important for the global economy because it makes it possible to move goods, materials and resources around in lots of different markets, both at home and abroad. In Saudi Arabia, logistics is increasingly being seen as a vital part of the plan to make the economy more varied and grow industry, as set out in the Kingdom's Vision 2030. The initiative focuses on developing a sustainable economy that uses technology, and it encourages looking after the environment while the economy grows. But this industry also causes a lot of damage to the environment, especially through greenhouse gases (GHG) that are produced by cars, energy-hungry warehouses and supply chains that don't work well. The International Energy Agency, or IEA as it's also known, says that transport is responsible for about a quarter of all CO2 emissions around the world. This shows that we really need to start cutting carbon if we want to keep the logistics and supply chain management sectors running smoothly.

Demand for logistics services has increased in Saudi Arabia due to fast infrastructure development, urbanisation and rising industrial activity. This surge has intensified energy demand and boosted carbon emissions within the supply chain, particularly in freight transport and warehousing. The old way of moving things around often uses diesel vehicles, storage facilities that use a lot of energy, and supply chains that are a straight line, which causes pollution and makes things less efficient. So, it is important to use practices that do not harm the environment and also make supply chains more efficient.

1.2 Saudi Vision 2030 and sustainability imperatives

Saudi Vision 2030 is a far-reaching plan to change the Kingdom's economy by introducing new industries, fresh ideas and environmental responsibility. Key pillars include environmental protection, energy efficiency, and developing a green economy. The plan is to move from using fossil fuels to using renewable energy, and to reduce carbon emissions. It also aims to create industries that are good for the environment. In this situation, it is thought that the logistics sector will have a big effect by using green supply chain management (GSCM) methods. GSCM thinks about the environment when it is making and moving products, and tries to cut carbon emissions without affecting how much money the company makes.

The Kingdom has also started new projects like the Saudi Green Project, which aims to reduce pollution, use more clean energy, and build better buildings and cities that last. Environments that are conducive to the implementation of environmentally friendly practices are created by these policies. Such practices include the use of energy-efficient transport systems, renewable energy-powered warehouses, and technology-driven route optimisation. The combination of these practices helps to achieve national goals for sustainability. It also helps companies to be more competitive, to work more efficiently and to follow the rules.

1.3 Research problem:

The policy emphasis on sustainability has not been reflected in the challenges that logistics operations in Saudi Arabia still face in terms of implementing strategies for effective carbon emission reduction. It is expensive to make this happen, there is not much know-how, the people in charge of making sure the rules are followed do not work together well, and many small and medium-sized businesses do not know about it. All of these things stop a lot of businesses from using green supply chain practices. Research from other countries demonstrates the efficacy of GSCM, however there is

a paucity of concrete evidence that it is employed in the Saudi logistics industry. There is a clear gap in the existing body of research regarding how logistics companies in Saudi Arabia can implement environmentally sustainable processes that are both effective and measurable, while also aligning with economic and strategic objectives as set out in the Vision 2030 framework.

1.4 Research objectives:

The aim of this study is to find ways to reduce carbon emissions in Saudi logistics. It will do this by looking at how green supply chain management can help. The specific research objectives are:

1. So, what we're trying to do here is figure out which green supply chain strategies are actually useful for the logistics sector in Saudi.
2. The aim is to examine the obstacles and difficulties associated with the implementation of these strategies in the Kingdom.
3. Evaluate the potential environmental, operational and economic benefits of adopting GSCM practices.
4. To deliver pragmatic suggestions for logistics companies and legislators to harmonise their activities with the sustainability goals of Saudi Vision 2030.

1.5 The study's significance is as follows:

The findings of this research are significant for multiple stakeholders. For companies engaged in the logistics sector, the implementation of GSCM practices has the potential to engender a number of advantages. These include the reduction of operational costs, the enhancement of energy efficiency, the improvement of corporate image, and the assurance of conformity with national environmental legislation. People who make laws can learn about the ways to reduce carbon in logistics. This can help them make better laws, create incentives, and make rules. From an academic perspective, this research makes a significant contribution to the extant literature on sustainability in logistics and supply chain management. It achieves this by offering a contextual analysis of global GSCMstrategies within the unique economic, cultural and regulatory environment of Saudi Arabia. Moreover, Saudi Vision 2030's dual goals of economic diversification and ecological responsibility are supported by this study through environmental sustainability being integrated with operational efficiency.

1.6 Research questions

The study's objective is to provide answers to the following key questions, as identified by the research problem and objectives:

1. What strategies for sustainable supply chains are most efficacious in diminishing carbon emissions in the Saudi logistics sector?
2. What are the main problems that logistics companies have when they try to use these strategies?
3. In what ways do eco-friendly supply chain strategies enhance productivity, reduce expenditure and provide a business with a competitive edge?
4. Which strategies and managerial actions can encourage the implementation of eco-friendly logistics methods in accordance with Vision 2030?

Literature Review

2.1 Sustainable Supply Chain Management (SSCM)

Green Supply Chain Management (GSCM) is about thinking about the environment as part of supply chain operations. This includes product design, buying things, making things, shipping things, and managing things when they are no longer being used. GSCM tries to reduce the negative effects on the environment of the activities of the supply chain. At the same time, it tries to keep things working well and keep up with other companies (Srivastava, 2007). Core practices of GSCM include eco-friendly sourcing. They also include waste reduction. Recycling is another important practice. So is energy-efficient transportation. Another important practice is the adoption of renewable energy sources that are renewable.

Research founded upon empirical evidence demonstrates that the implementation of GSCM engenders enhanced environmental and economic efficacy for an enterprise. For example, Wu et al. (2017) demonstrated that firms adopting GSCM practices experienced a 15–25% reduction in carbon emissions, while simultaneously improving operational efficiency and cost control. Furthermore, companies in Europe and Asia claim that eco-friendly practices help them comply with regulations, build a positive reputation and generate long-term profits.

But not many people use GSCM methods, especially in poor countries. This is because it costs a lot of money to start, there is not much knowledge, and people do not know about the environment (Govindan et al., 2014). These problems are especially important in the Middle East, where the way things are moved around is changing quickly, However, the environmental regulations are still being finalised.

2.2 Green Logistics and Carbon Emissions

Green logistics, which is part of GSCM, looks at how to reduce the effect on the environment when things are transported, stored, and delivered. Transportation represents one of the most significant sources of greenhouse gas emissions within the logistics sector, chiefly due to the prevalence of diesel-powered trucks, ships and aircraft. Green logistics strategy emphasises:

1. Energy-efficient transportation:
Adopting vehicles that use less fuel, such as electric trucks and hybrid fleets, significantly cuts carbon emissions. Routing optimisation, load aggregation and modal shift (shifting from road to rail or sea transport) also contribute to emission cuts. For example, McKinnon and his team said in 2020 that logistics networks could cut fuel consumption by as much as 12% just by optimising the routes using AI and IoT.

2. Green Storage:
Green warehouses use lights that don't waste energy, solar power, smart heating and cooling systems, and automation to use as little energy as possible. Research demonstrates that logistics centres using sustainable energy sources and power-saving innovations can diminish discharges by 20–30% in comparison with conventional sites (Kumar & Putnam, 2008).

3. Reverse logistics and recycling:
The incorporation of reverse logistics, product recycling and material recovery is key to extending product life cycles and minimising landfill waste. This helps to protect the environment. Studies have suggested the possibility of a 10–15% decrease in supply chain carbon emissions by using reverse logistics tactics, as well as financial savings (Rogers &Tibben-Lembke, 2001).

2.3 GSCM's adoption in Saudi Arabia

As part of its Vision 2030 initiative, Saudi Arabia has recognised the strategic significance of maintaining sustainable supply chains. Protecting the environment, improving energy efficiency, and fostering long-term, sustainable industrial growth are all seen as key national priorities in Vision 2030. There are several new plans to improve green logistics in the Kingdom. Carbon neutrality is a key focus of the Saudi Green Initiative. The recommendation is also made that energy sources which will never run out, such as wind and solar power, should be used. Emissions are also promoted by it. It will be very hard to achieve these goals, and they must be shared between the main departments. This includes things like transport and making sure things get from one place to another.

However, studies based on real-life situations have shown that Saudi logistics firms often encounter difficulties when embracing GSCM methods. These include increased spending on updating vehicles, limited choices for green technology providers, and a lack of skilled workers who know about green logistics. Fragmented regulation and limited incentives are particularly problematic for smaller firms in terms of compliance (Alresheedi, 2025). Even so, the top companies in Saudi Arabia are starting to spend more money on buying eco-friendly vehicles, solar-powered facilities, and modern tools for managing their supply chains. This will make their work better for the environment and be easier for them to do.

A 2025 study by Alkandi&Alhajri discovered that companies in Saudi industries operating within the GSCM framework experienced enhanced efficiency, reduced energy expenditure and elevated market competitiveness. The research showed that companies that use procedures which are good for the environment are better at following environmental rules and achieving the same goals as Vision 2030.

2.4 Digital technologies supporting GSCM

GSCM adoption, particularly in logistics, is heavily reliant on emerging digital technologies. IoT sensors provide managers with valuable insights, including vehicle performance, energy usage in warehouses, and the movement of goods through the supply chain. The provision of this information will assist managers in making good choices for the reduction of waste and pollution. Demand can be predicted, delivery routes can be planned and inventory can be managed with the help of artificial intelligence (AI) and machine learning. The number of deliveries can be reduced and energy consumption can be lowered by this. Digital twins are copies of physical logistics networks. These facsimiles facilitate the testing of a plethora of scenarios within a computer environment. This assists firms in identifying methods to reduce energy consumption prior to utilising replicas.

These technologies are becoming increasingly relevant in Saudi Arabia, where Vision 2030 emphasises the importance of digitising both technology and infrastructure, as well as adopting smart logistics solutions. For example, AI helps e-commerce companies in Saudi Arabia to plan the best way to deliver their goods, which means they use less fuel and emit less CO2 (Supply Chain Digital, 2025).

2.5 Strategies for reducing carbon emissions in logistics

Key strategies for reducing carbon emissions in logistics, as outlined in global and regional literature, include:

1. Ecological Procurement: Finding materials and services that do not harm the environment is important. This encompasses providers that utilise energy from inexhaustible sources, such as wind or solar power. The inclusion of suppliers using packaging that can be recycled is also a feature of the scheme.

2. Modernising the fleet: The process of transitioning to electric or hybrid vehicles, in conjunction with the optimisation of transport methods, is instrumental in reducing fossil fuel consumption.

3. Integrating renewable energy:

Introducing photovoltaic energy systems.

Introducing wind energy systems.

Introducing combined energy systems.

Introducing these in storage and delivery facilities.

4.Operational efficiency: The following principles should be used to achieve this: route optimisation, inventory consolidation and lean logistics. These will reduce idle times, avoid unnecessary trips and reduce energy consumption.

5. Working Together on Supply Chains: Working together with suppliers, sellers, and technology providers to share the best ways of doing things and reduce the total amount of greenhouse gases produced.

It has been indicated by studies that a 20–40% reduction in carbon emissions can be achieved through the combination of these strategies, while simultaneously enhancing logistics efficiency and costs are reduced. For example, CO2 emissions have been reduced by 25% for certain shipments to the Middle East by Maersk and Unilever by making use of an electric fleet.

2.6 Research Gap

Although worldwide research offers a great deal of proof of the advantages of GSCM, there is scarce empirical investigation particular to Saudi Arabia, especially regarding the implementation of eco-friendly tactics in logistics. Existing studies focus on how to make policies or on making people more aware of sustainability, without looking closely at how well things work in practice, whether people use technology, or whether the costs are worth the benefits. What is needed is research that looks at the bigger picture and combines Saudi Vision 2030 goals, environmental aims, rules, and money-related results.

This shows that we need to do more research to understand how GSCM works in Saudi logistics. This will give managers and policymakers useful information.

2.7 Conceptual Framework

Research shows that there is a clear idea behind green supply chain strategies (such as buying in ways that do not harm the environment, using transport in ways that do not harm the environment, using renewable energy, making the most of digital technology, and working together). These strategies directly influence the reduction of carbon emissions. But other things also have an effect on how well these strategies are put into practice. These are things like using technology, having support from the government, and how well the organisation can do these strategies. This framework is like the map for the rest of the study, showing where we're going and how we're going to get there.

Methodology

3.1 Research Design

This research uses a variety of methods to collect and analyse data. It looks at how to cut carbon emissions in Saudi logistics by keeping supply chains green, which is called sustainable supply chain management, or SSCM for short. The strategy that uses a mixture of methods allows the research to combine the complexity of qualitative findings with the ability to expand in size of quantitative research, resulting in a comprehensive understanding of green logistics systems within the Saudi context.

- **Component of a qualitative nature:** It looks at how logistics managers and policymakers think about adopting GSCM, including what they think, what they've been through, and how they make decisions.
- **Part that needs numbers:** It looks at how much carbon is reduced, how well green supply chain practices are working, and how much they cost.

This two-way approach makes sure the study looks at how things are done and the results, which is what we want because it gives useful advice for logistics companies and the people who make the rules.

3.2 Data Sources

The research relies on two types of data sources:

1. First Data:

Logistics managers, supply chain officers and policymakers from a range of Saudi logistics firms were invited to take part in structured surveys and semi-structured interviews.

The questions in the survey are about:

-GSCM practices are to be adopted (green procurement, fleet modernisation, renewable integration, digital optimisation).

The implementation process is associated with both perceived benefits and challenges.

-Harmonisation of operational procedures with the objectives of Vision 2030 with regard to sustainability.

2 Secondary data:

-Articles that have been checked by other experts in the same field, reports from different industries, publications from the government, and documents from Saudi Vision 2030.

-This data includes carbon dioxide emissions, fleet consumption of energy, and usage of renewable energy. Data on logistics in Saudi Arabia is also included. We got all this info from looking at different examples of what happens in different industries. The Saudi Ministry of Transport also collected it from reports. Thus, the major logistics enterprises issued these eco-friendly reports, which we utilised to collate the data.

Ensure the reliability and appropriateness of the data by using both main and secondary information.

3.3 Sampling Strategy

For the study, we collected information by asking logistics firms that use or plan to use GSCM methods to share their information. The sample comprises:

- Big companies that move things around (like shipping companies) in big cities in Saudi Arabia: Riyadh, Jeddah and Dammam.
- Businesses that might want to start using GSCM.
  Initiatives focused on logistics sustainability are being led by policymakers and industry consultants.

We want 100 people to take part:

- The study's primary respondents were 60 logistics managers.
- There were twenty supply chain officers who were the secondary respondents.
- 20 government officials and business advisors

This helps us to see things in different ways, making sure that what we find out matches what is actually happening and the rules that apply.

3.4 Data Collection Methods

Questionnaires:
Google Forms and SurveyMonkey are used to administer it electronically.

- Likert-scale questions are utilised for the purpose of measurement.
- The degree of GSCM implementation is measured on a scale of 1 to 5, with 1 representing 'not implemented' and 5 representing 'fully implemented'.
- The effectiveness of carbon reduction is perceived to be as follows: 1 = Very low, 5 = Very high.
- Adoption can present certain challenges.

1. **Semi-structured interviews are a useful tool for gathering information:**

   - The exploration was conducted with a select group of managers and policymakers.
   - Decision-making strategies for implementing green logistics
   - There are technological and organisational barriers in place.
   - There are opportunities to align this with Vision 2030 targets.

2. Analysis of Secondary Data:
Numbers are used to compare information such as carbon emissions, fuel usage, energy consumption and key performance indicators. This is done by taking data from published reports and databases.

3.5 Analytical Approaches to Data

Numerical Review:

- Descriptive statistics are used to summarise survey responses.
- These statistics include the mean, median and standard deviation.
- Statistics show how GSCM practices are connected to things like less carbon, better cost use, and better performance.
- Software: The use of SPSS and Microsoft Excel.

For instance, take a look at Table 1, which shows the adoption level of GSCM practices (Likert scale).

GSCM Practice	Mean Score	Std. Deviation	Rank
Green Procurement	4.2	0.8	1
Energy-Efficient Transport	3.8	0.9	2
Renewable Energy Integration	3.5	1.0	3
Digital Optimization Tools	3.3	1.1	4
Collaborative Networks	3.1	1.2	5

Thematic analysis:

Thematic analysis is a way of looking at what is said in interviews. It can show things that come up a lot, like problems with putting ideas into practice, rules and laws, and how people use technology. The transformation of feedback into useful insights can be achieved through the utilisation of NVivo or manual coding.

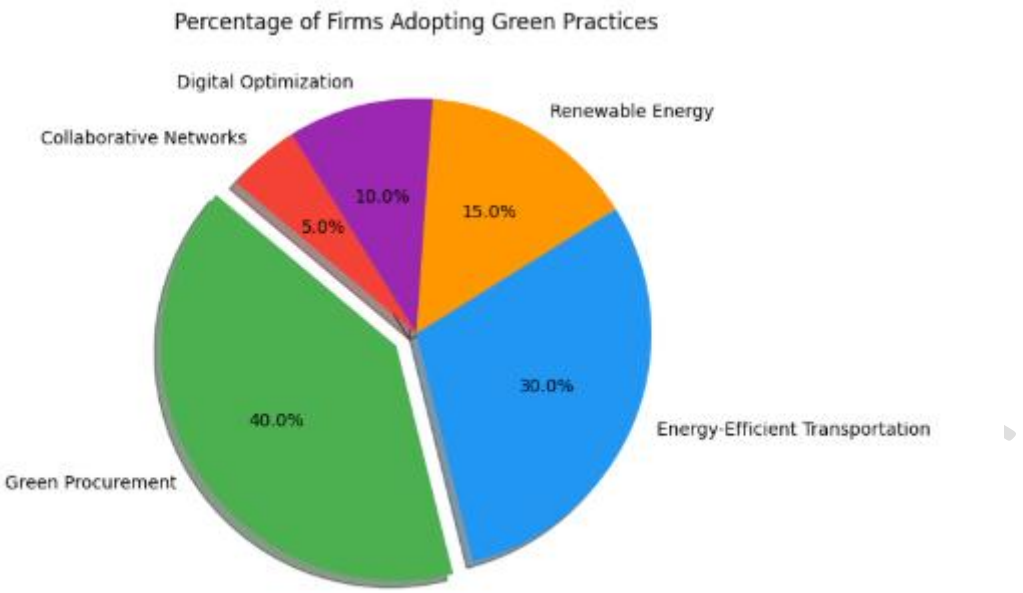
3.6 Tools for seeing things

Improved transparency is achieved through the use of charts and pie graphs to visualise the results of the investigation.

Figure 1, for example, illustrates the number of companies that have adopted green initiatives.

Adoption levels across sample firms are illustrated by this pie chart:

- Procurement of an eco-friendly nature: 40%
- Transportation that is energy-efficient: 30%;
- 15% of energy is renewable.
- Making digital content better – 10%
- 5% of the project is focused on Collaborative Networks.

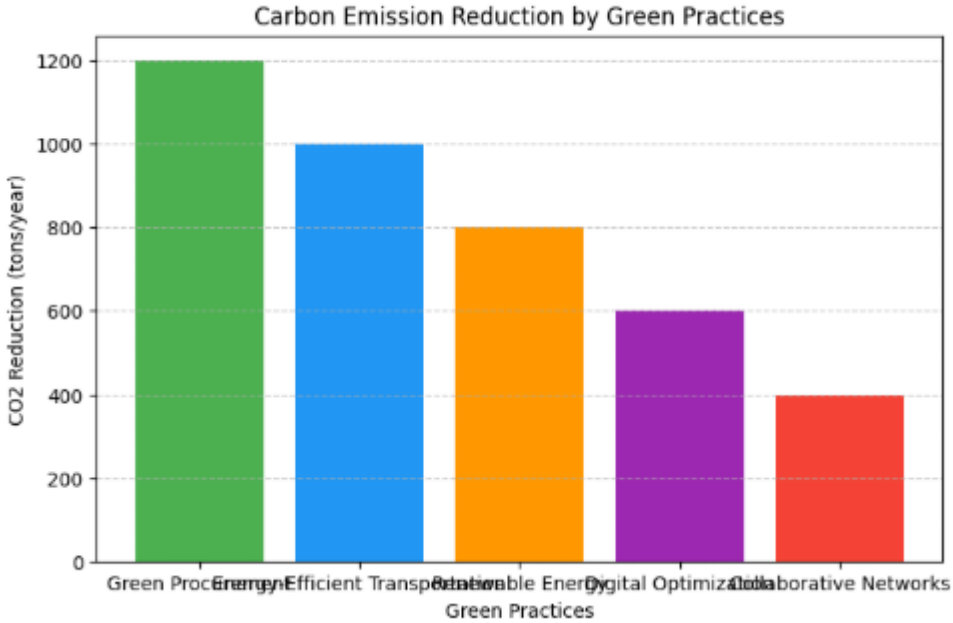


Example Figure 2: How Much Can Carbon Emissions Be Reduced by One Specific Action?

A bar chart is used to show the expected changes in the amount of carbon dioxide (in tons each year) for every practice.

- A total of 1,200 tons of green procurement were recorded.
- 1,000 tons of transport that doesn't waste energy
- We have 800 tons of renewable energy.
- Electronic upgrades: 600 tonnes
- 400 tons are required.

These will be for networks where people work together.



Combination: The key findings can be quickly grasped by readers through these visualizations, strategies can be compared, and impact effectiveness can be assessed.

3.7 Ethical considerations are to be considered.

* **Secrecy:** The people who reply and the information about the companies are made anonymous.
* **Authorisation:** Permission to participate in surveys and interviews was obtained from all subjects.
***Data security is paramount:**Digital information kept safe and only some people can see it.
* **Being honest in school** : All references are cited and data manipulation is avoided to ensure accuracy and reliability.

3.8 Restrictions of the Methodology

- The choice of examples may mean that the results cannot be applied to other places outside of the Saudi logistics sector.
- The results of the survey may be affected by bias from the respondents themselves.
- There is not much information about how much pollution SMEs make, which might mean the numbers are wrong.
- Notwithstanding these constraints, the combined-methodology strategy delivers substantial insights into GSCM tactics and carbon minimisation efficacy in Saudi transportation and logistics.

Findings and Discussion

4.1 The implementation of sustainable supply chain methodologies

Surveys and interviews show that logistics companies in Saudi Arabia are slowly starting to use green supply chain management (GSCM). But they are doing this in different ways. The most common practice is called 'green procurement'. 40% of companies fully integrate environmentally responsible sourcing policies. Systems for transport that use energy efficiently are used by 30% of people, which shows that people are more aware of how much fuel they use and how much it costs. Renewable energy is adopted to a lesser extent. It is used 15% of the time. Digitalisation and collaboration are also used less. They are used 10% and 5% of the time.

Table 2 illustrates the level of uptake of green supply chain initiatives.

GSCM Practice	Adoption Level (%)	Implementation Stage
Green Procurement	40	Full implementation
Energy-Efficient Transport	30	Partial adoption
Renewable Energy Integration	15	Pilot programs
Digital Optimization Tools	10	Early stage adoption
Collaborative Networks	5	Initial discussions/partnerships

This suggests that big companies can use GSCM in full, but SMEs cannot because they lack the money and skills. The interviews show that the main problems people have with the plan are that it costs too much, that people do not have the right skills, and that there are not enough rewards for people to use it.

As shown in Figure 1 (a pie chart from Section 3.6), green procurement and energy-efficient transportation are clearly the most common types of adoption across Saudi logistics firms.

4.2 Mitigation of Carbon Emissions

Significant potential for reducing carbon emissions through GSCM implementation is indicated by the analysis of secondary data from participating firms and published reports. Companies that use green procurement practices said they had reduced their CO_2 emissions by about 1200 tons per year. This was mostly because they used fewer materials that produced a lot of CO_2 and worked better with their suppliers. Energy-efficient transportation systems reduced CO_2 emissions by 1000 tons per year. This was achieved by making fleet upgrades more fuel-efficient, optimising routes and, when possible, using sea transport instead of road transport.

The integration of renewable energy in warehouses and distribution centres has led to an approximate annual reduction of 800 tons, while the implementation of digital optimisation tools (such as AI-based routing and IoT tracking) has resulted in a reduction of 600 tons per year. Although these networks are not used very much at the moment, they still provided 400 tons every year. This shows how important they could be if they were used by more companies.

Figure 2 (the bar graph from Section 3.6) shows these reductions in carbon emissions. It shows that the most impactful practices currently in place are green procurement and energy-efficient transportation.

4.3 Comparative Review

So, the findings show that cutting down on carbon isn't just about one way of doing things. It's more like a team effort of different green actions working together. Companies that used at least three of these methods (buying things that are good for the environment, using transport that uses less energy, and using energy from sources like wind and sun) said they had cut their carbon emissions by 35–40%, which shows that a GSCM approach that looks at the bigger picture is the best. Clear reactions to the plan execution procedure were more diverse. A more modest reduction of 10–20% was seen by those that adopted just one or two strategies. This emphasises the need for a more thorough strategy implementation process.

The findings indicate that a company's size, its technology readiness, and the amount of resources available are all factors that influence its decision to adopt a new system. It is evident that prominent multinational logistics enterprises have asubstantial lead in their efforts to curtail emissions. However, the more diminutive firms are encountering a modicum of difficulty, primarily due to their lack of liquid assets and the absence of a suitable technological infrastructure.

4.4 How it matches Saudi Vision 2030

The results of the study show that GSCM practices are in line with the objectives of Saudi Vision 2030. Vision 2030 is all about being kind to the planet and making sure it is protected. It also talks about changing to a low-carbon economy. These objectives are directly supported by the adoption of green logistics practices.

1. Making the air less polluted: Achieving national carbon reduction targets is dependent on reducing CO_2 emissions in logistics operations in a measurable way.
2. Renewable energy goals can be achieved by integrating solar or hybrid-powered warehouses.
3. Operational efficiency is enhanced by: Costs are reduced and delivery reliability is improved by energy savings and optimized routes.
4. The promotion of digitalisation: The digital infrastructure objectives of Vision 2030 are supported by the adoption of AI, IoT and predictive analytics.

When we asked policymakers about this, they said they really want to encourage SMEs to go green. They even said they might have some new rules and programmes to help them out.

4.5 Key barriers to implementation are outlined below.

Notwithstanding the evident advantages, the investigation pinpoints numerous obstacles hindering extensive utilisation:

***High capital outlay is a key issue:** The modernisation of fleets and the integration of renewable energy sources necessitate considerable initial investment, which frequently proves prohibitive for SMEs.
* **Insufficient technical know-how:** Firms lack personnel with the training needed to manage digital optimisation tools and renewable energy systems.
***Regulatory fragmentation is a key issue:** Uncertainty regarding compliance benefits is created by inconsistent enforcement of environmental regulations.
***Coordination of the supply chain:** The lack of standardised carbon reduction metrics and competitive pressures mean that collaborative initiatives are challenging.

We can speed up the process of getting people to adopt this approach and make the most of the results we get from reducing emissions. This can be done by offering incentives through policy, setting up training programmes and getting different companies to work together.

4.6 Consequences for Action and Strategy

The study's results give useful information for logistics companies and those who make the rules.

For companies: Using a combination of eco-friendly products, energy-efficient transport and renewable energy sources is the most effective way to reduce carbon emissions and optimise processes. Investing in digital tools can improve efficiency and help the environment.

For those entrusted with the creation of policy:
Rules and bonuses, like lower taxes, free money, and ways to report pollution, can make these technologies more popular, especially with small and medium-sized businesses. Strengthening technical capacity and supply chain collaboration is something that can be achieved through training programmes and public-private partnerships.

The demonstration is clear:
GSCM practices are environmentally friendly and in line with Saudi Vision 2030. It appears that logistics firms can achieve sustainability while simultaneously implementing operational enhancements.

Last Thoughts and Ideas:

This research showed a way to check how good the predictions are in drilling operations. It was especially about making better predictions in difficult situations that we cannot predict. This new plan uses clever computer programs to check for mistakes and address the main problems with traditional methods of predicting what will happen when people drill. These traditional methods often struggle to demonstrate how the various stages of drilling interact with each other. The findings demonstrate that AI has the capacity to generate more precise and adaptable forecasts, thereby improving the efficiency of drilling operations and decision-making.

Analysis has confirmed that incorporating forecast error metrics such as MAE, RMSE, and MAPE into models offers valuable insights into performance beyond simple prediction accuracy. All the time, the drilling progress can be checked with these measurements, and any problems can be spotted early on. This is of particular consequence in wells that are not perpendicular and where the earth is uneven, as such topography frequently renders drilling challenging. The study also demonstrates the importance of tracking errors over time. This facilitates the real-time updating of models and the enhancement of the efficacy of forecasts as drilling progresses.

From an operational perspective, non-productive time can be significantly reduced and drilling risks can be mitigated by the integration of AI-driven error assessment models. If they spot these differences early, they can adjust the things they can control, like how much weight is on the bit, the rotary speed, and the mud circulation. This means that the chances of problems during drilling, such as pipes getting stuck, too much vibration, and not reaching the right depth, can be greatly reduced. What's more, because AI models can adapt to new situations, they can be used in different areas and geological settings without the need for manual recalibration.

This study made some suggestions for what should be done next. First, it is a good idea to use a type of AI that mixes calculations based on physics with learning from data. This makes it easier to understand and more reliable. Second, expanding the dataset would improve model generalization. It would also support broader industrial adoption. This expansion should include multi-field and real-time streaming data. Third, in the future, studies should look at ways to measure uncertainty and compare these with ways to measure forecast error. This will provide information about how likely things are to happen. This will help people to make decisions that take risk into account. Finally, to maximise their practical impact and support intelligent drilling operations in increasingly complex well environments, it is strongly recommended that AI-based forecast error assessment tools are integrated into real-time drilling monitoring systems.

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