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Review

Industry 4.0 Driven Green Supply Chain Management in Renewable Energy Sector: A Critical Systematic Literature Review

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Abstract: This paper is aimed at systematically reviewing the literature on the interface of Green Supply Chain Management (GSCM), Industry 4.0 and renewable energy. The aims of this review are to ascertain current state of the art in GSCM practices, to critically examine the role of industry 4.0 technologies in GSCM adoption, to examine sustainability and supply chain issues within the renewable energy sector, and to critically discuss tackling these issues using industry 4.0 driven GSCM. A total of 215 review and empirical papers from 2004 to 2023 gathered from three databases (ScienceDirect, Scopus and Web of Science) were reviewed. This research found several GSCM practices and succinctly categorized those based on their respective positions along any given value chain. The practices were categorized as related to: procurement and sourcing, product design, corporate relationship, organizational structure/strategy, logistics and transportation, waste and pollution management and manufacturing. We have found that the ten most mentioned GSCM practices are: Green purchasing, Eco-design, Cooperation with customers, Internal Environmental Management, Reverse logistics, Investment recovery, Green manufacturing, Green design, Collaboration with suppliers and Remanufacturing. Various Industry 4.0 technologies including blockchain, Internet of Things, Big Data and Artificial Intelligence were identified and their role in successful GSCM implementation is highlighted. Sustainability and supply chain related challenges within the renewable energy supply chain were found that include material sourcing and end-of-life management challenges. Finally, a perspective is given on the role of Industry 4.0 driven GSCM in tackling the renewable energy supply chain and sustainability challenges. This article concludes with a presentation of managerial implications and future research directions for managers within different sectors, especially the renewable energy industry.

Keywords: Industry 4.0; green supply chain management; sustainability; renewable energy

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1. Introduction

There has been considerable attention in recent years towards environmental concerns from both the academia and industry ([1–4]). These concerns have given birth to pressures emanating from the global competitive markets, while environmental regulations as well as customers are forcing firms worldwide to thoroughly think about the environmental footprints arising from their business operations. Therefore, industries have since embarked on a journey to reduce their environmental impacts through the adoption of newer business and management paradigms instead of their traditional practices [5].

GSCM is a management paradigm that incorporates "green" philosophy in manufacturing, distribution, procurement and logistics [6]. GSCM involves a set of managerial activities that firms adapt to in order to reduce pollution and energy consumption in an effort to attain sustainability. Arguably, competitive advantage is achieved due to the implementation of these practices [7]. In other words, GSCM buttresses on the integration of environmental aspects into different facets of supply chain management [8].

GSCM practices (GSCMPs) are a group of activities or actions that lead to the implementation of GSCM, which is characterized by reduction of environmental deterioration and pollution while improving performance, leading to customer and stakeholder satisfaction [2]. Through a critical review of the literature, Ref. [5] have found that internal environmental management, investment recovery, green procurement, cooperation with customers, reverse logistics, eco-design, and the design of packaging are the most important GSCM practices mentioned by researchers.

Furthermore, the development and adoption of digital technologies have since become a trendy area of discussion in the academia as well as the industry with the Industry 4.0 (I 4.0), or the fourth industrial revolution, facilitating digital transformation that is continuously gaining attention from industrialists and governments [9–11]. One of the merits of I 4.0 technologies is making manufacturing systems and operations efficient, sustainable and autonomous while building a smart system that integrates digital technologies and physical objects [12]. With the help of I 4.0, supply chain processes can efficiently and effectively be managed by making real-time data available in the presence of intelligent systems and devices [9].

That is why researchers were found in the extant literature to have exhibited interest in researching on the ways in which different digital technologies like I 4.0 could be used as tools for achieving efficiency in terms of manufacturing and engineering management. For example, Ref. [13] reviewed literature and in an indirect coverage of the GSCM looked at the role of I 4.0 in enhancing LARG (Lean, Agile, Resilient and Green) manufacturing, Ref. [14] focused on the role of machine learning in GSCM and Ref. [15] studied the role of Big Data Analytics in terms of linking GSCMP and competitiveness during COVID-19.

In recent times, the world is gradually seen to resort to renewable energy (RE) sources as the most effective alternatives to fossil fuels while trying to solve the global energy security challenges, but a major challenge also arises in the RE systems selection as the RE technologies arguably face sustainability challenges [16]. That is why this research aims to review the literature on these challenges within the renewable energy sector (RES) and critically discusses an I 4.0 powered GSCM to tackling such problems.

Renewable sources of energy are the sources in which clean energy is naturally regenerated directly from the sun in the form of thermal, photochemical and photoelectric energies, or through wind, hydropower and biomass [17], or through other environmental mechanisms and natural movements [18]. In other words, RE sources could be referred to as domestic resources that provide energy with little or no emissions in terms of greenhouse gases or pollutants [19].

Different researchers have studied the combination of supply chain management with different aspects of digitalisation and, in the course of that, various terminologies have been developed [20]. For instance, Smart GSCM [20], the fourth industrial revolution of supply chains or supply chain 4.0 [21,22], digitally enabled sustainable supply chains [23], and I 4.0-enabled sustainable supply chain [24] were used among others. Despite these efforts by scholars, the smartness of supply chains and sustainability have been studied disjointedly in recent years and, to this end, there is no consensus among scholars with regard to a framework of integrating smart supply chains with sustainability [25].

Based on the reviewed literature, no review paper was found that focused on a combined construct of GSCM and I 4.0 to tackle sustainability and supply chain problems in the RES.

Therefore, the current research is aimed at systematically reviewing the literature on GSCM, I 4.0 and RES. In other words, the objectives of this research are to ascertain state-of-the-art practices in GSCM literature in order to review the literature about GSCM and the I 4.0 combined construct while highlighting assertions made by researchers with regard to the role of I 4.0 technologies in the adoption and successful implementation of GSCM. Moreover, this research is aimed at highlighting the RE supply chain challenges and the role of I 4.0-powered GSCM in tackling such challenges. Furthermore, the extant literature presents GSCMP unsystematically, generally without proper categorization of

what GSCMP falls in what category for easier mapping of these practices, thereby enhancing adoption in a smoother manner. The current study therefore works on filling that gap by categorizing these GSCMP based on where they fall in a given value chain.

The rest of this article is structured as follows: Section 2 provides background on GSCM, I 4.0 and RES, Section 3 highlights the methodology of systematic literature review followed in this article, Section 4 presents results and analysis, and Section 5 presents the conclusion and future research directions.

2. Green Supply Chain Management, Industry 4.0 and the Renewable Energy Sector: Background

In the early 1990s, the concept of GSCM was first introduced [26], although it only became popular around the 2000s as evidenced by surging empirical publications ([27,28]). GSCM is among the numerous concepts of sustainability and sustainable practices; GSCM encapsulates the entire activities of delivering products and services from raw materials to disposal or end of life [29]. GSCM is a fundamental derivative of supply chain management, which is linked to strategically integrating environmental considerations through the implementation of a set of environmental practices, such as green design, green manufacturing, reverse logistics, waste management, green operations, among others, across the supply chain in an effort to minimize adverse environmental footprints [30].

It has been asserted by [6] that GSCM, which involves the integration of green philosophy into manufacturing, procurement, distribution and reverse logistics, arguably enhances environmental performance and sustainability of firms. According to [31], GSCM increases companies' competitive advantage and economic performance. They added that enhanced reputation, efficiency, effectiveness and revenue growth can also be achieved as a result of successful GSCMP implementation. This assertion by [32] holds an overly positivist view towards GSCM, while [33] refute what they call the fallacy of profitable GSCM and added that GSCM might present a trade-off when it comes to the nexus between economic performance and GSCM.

I 4.0 encapsulates different intelligent and innovative technologies like the Internet of things (IoT), cloud computing and big data analytics, which collectively facilitate seamless connectivity, communication and automation. Also, these technologies are useful in terms of data collection and information sharing across supply chains with regard to material quality, product life cycle and operations [9]. Furthermore, Ref. [12] asserted that I 4.0 technologies possess an embedded capability of drastically reducing set-up times, labour and material costs, and lead times, which can also increase design and production flexibility, thereby enhancing customization and productivity. In a different research, it was found that big data analytics, which is one of the I 4.0 technologies, could allow firms to make successful and informed decisions on green operations across supply chains [34].

The generic notion behind I 4.0 is that of the fourth industrial revolution brought about by the recent rapid technological advancements. Ref. [10] asserted that I 4.0 embeds computerisation and interconnection into the traditional mainstream industry. The authors added that the main objectives of I 4.0 are centred around providing IT-enabled mass customization of manufactured products to enable the efficient tracking of parts and products, to facilitate the flexible adaptation and automation of production process, to enable effective communication among components, parts and machines, and to bring to the fore new types of business models and services for interaction along value chains. To buttress on the effectiveness of I 4.0 technologies, Ref. [35] asserted that a survey of 300 leading companies in Southeast Asia showed that nine out of ten respondents believed in the effectiveness of I 4.0 technologies.

Green government and institutional policies, among many other reasons, have brought about a boost in RES with the global production and installed capacity of RE technologies continuing to spread worldwide in a substantially increasing manner [36]. Therefore, this research covers the interaction between GSCM, I 4.0 and the RES. In other words, this research work studies the literature on I 4.0 powered GSCM to tackle sustainability- and

supply chain-related problems within the RES. Figure 1 depicts the interaction between the different constructs.

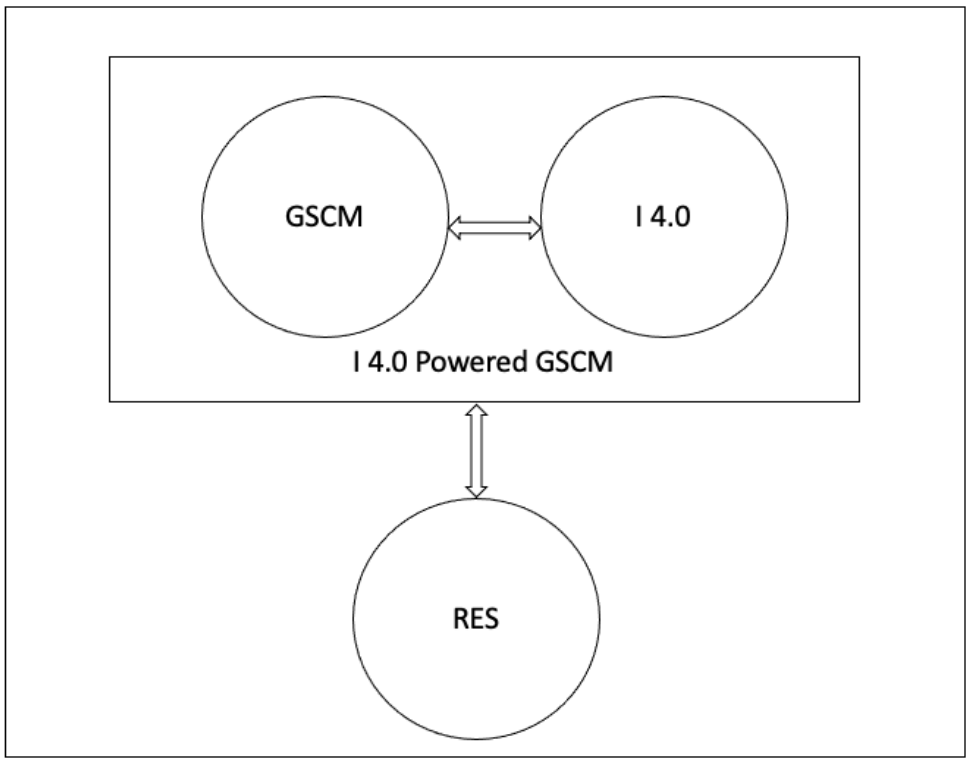

Figure 1. Interaction between constructs.

3. Methodology

In this section, the methodology used in this literature review is described. The seven-step methodology adopted from [37] was chosen. The latter was selected due to its robustness and rigour in terms of filtering research resources so also its elaboratively comprehensive nature. Figure 2 shows the steps involved and explains the steps taken in each stage.

3.1. Step 1 (Planning)

The initial stage is aimed at determining the constructs, which this literature review covers. Therefore, this study is scoped to focus on the combined constructs of GSCM and I 4.0. Interestingly, despite the fact that the literature on GSCM is growing exponentially [5], the answers to the following research questions this paper aims to answer are scarce. The following questions were coined for this systematic literature review:

Q1. What are the current state of the art practices in the GSCM literature?

The goal of this question is to ascertain the GSCMP found by researchers in different areas of focus and industries.

Q2. What is the role of I 4.0 technologies in the adoption of GSCMP?

The goal of this question is to examine the level of application of industry 4.0 technologies in driving the adoption of GSCM. So also, to ascertain the facets of I 4.0 that can be applied in what strata of Green Supply Chains.

Q3. What are the sustainability and supply chain related problems within the RES?

This is aimed at obtaining sustainability and supply chain related problems within the literature reviewed.

Q4. How can the combination of GSCMP and I 4.0 solve supply chain related problems in the RES?

The aim of this question is to ascertain the supply chain- and sustainability-related issues in the RE supply chain, and the ways in which I 4.0-powered GSCM will tackle these challenges.

ScienceDirect, Web of Science and Scopus were the databases identified for search purposes, and they were particularly chosen because of their wide coverage of articles. Microsoft Excel was used as the data extraction tool where a literature matrix was created. Endnote was used as the reference management software because of its versatility and unique features.

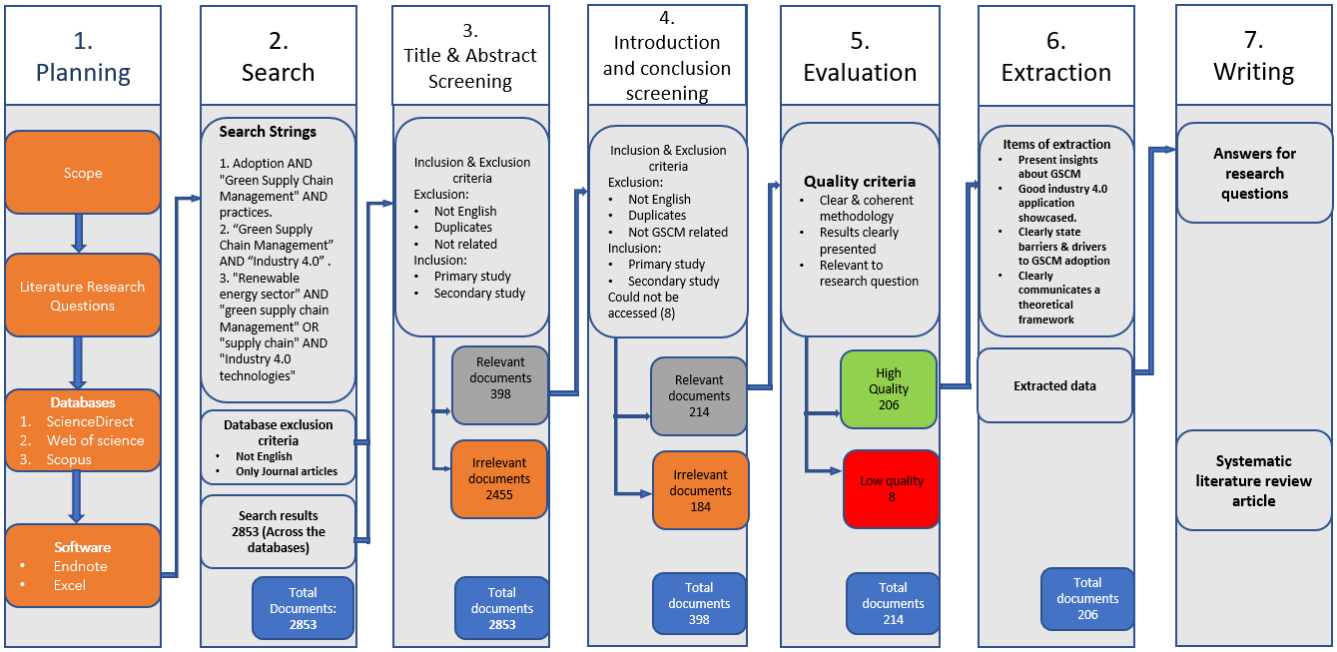

Figure 2. Systematic literature review process.

3.2. Step 2 (Search)

To conduct the literature search on the databases identified in Step 1, a set of search strings was designed after a prior literature search and consultation with a senior librarian in order to obtain robust search strings that are representative of the research questions. Each of the three strings mentioned below were searched independently in each of the three databases identified above;

1. Adoption AND "Green Supply Chain Management" AND practices
2. "Green Supply Chain Management" AND "Industry 4.0"
3. "Renewable energy sector" AND "green supply chain Management" OR "supply chain" AND "Industry 4.0 technologies"

The search was conducted on 09/11/2022 and on 04/03/2023. Another search of search string 3 (enhanced: ("Renewable energy") AND ("green supply chain") AND ("Industry 4.0" OR "Digital technologies") above was conducted on 22 September 2023 to make sure no valuable resources are left behind and to obtain up-to-date results. Nine (9) additional articles were obtained and reviewed alongside the initial 206, totalling 215. The search was carried out to look for relevant results that contain the elements of the search strings in their titles, abstracts and keywords. The exclusion criteria applied at this stage were:

- Not in English
- Only journal articles

3.3. Step 3 (Title and Abstract Screening)

At this stage, the results were imported into the reference management software (Endnote 20 Desktop) where duplicates were removed and the eligibility of papers was decided by screening and glancing through their titles and abstracts. Due to the high number of initial search results, it is practically impossible to read every article fully to decide on its inclusion, so filtration stages have to be in place, which is why we conducted our search in this way.

3.4. Step 4 (Introduction and Conclusion Screening)

After the title and abstract screening, a more in-depth reading was performed at this stage to reliably decide the suitability of resources for the systematic literature review. This stage is guided by inclusion and exclusion criteria, which include language clarity and relevance to the major constructs the research covers.

3.5. Step 5 (Evaluation)

More rigorous reading was performed here to finally decide on the quality of resources to work with. The following quality criteria were set:

- Clarity of methodology
- Results are discussed succinctly
- The resource is relevant to the research questions.

3.6. Step 6 (Extraction)

A thorough reading was carried out to extract answers to the identified research questions. Microsoft Excel was used to generate a literature matrix that served as the repository of all relevant data extracted from the resources used. Information relevant to research questions were appended to the matrix, as they appear in the article against each article's title on the same row. These gathered assertions by different researchers were extracted, synthesized and presented in this paper.

4. Results and Analysis

4.1. Sectors Covered

Several industries have been covered by researchers in the reviewed literature with variable frequency of coverage across sectors. Eight sectors were found to have been researched much more frequently than others. These included the manufacturing industry, totalling 56 papers—the highest amount—followed by those that focused on multiple sectors in their research amounting to 29 papers. Other sectors include: construction (9 papers), electronics (9 papers), mining (8 papers), and 31 other papers unfocused on the identified sectors. Figure 3 represents the frequency of the focus on industries covered by researchers in the reviewed literature.

4.2. GSCM Practices

The extensive literature review conducted revealed a wide range of GSCMP found by researchers in various industries and sectors. For the purpose of this paper, a categorization of these practices was conducted based on where they fall in any given value chain. This categorization is believed to be more robust and succinct than the one presented by [38], and the simplistic internal and external to organisation categorization of practices presented by [39] because, in this paper, product or service value chain as well as the most important corporate functions are put into consideration.

Figure 3 illustrates the number of times industries are covered by researchers while Figure 4 depicts ten most repeatedly mentioned GSCMP by researchers.

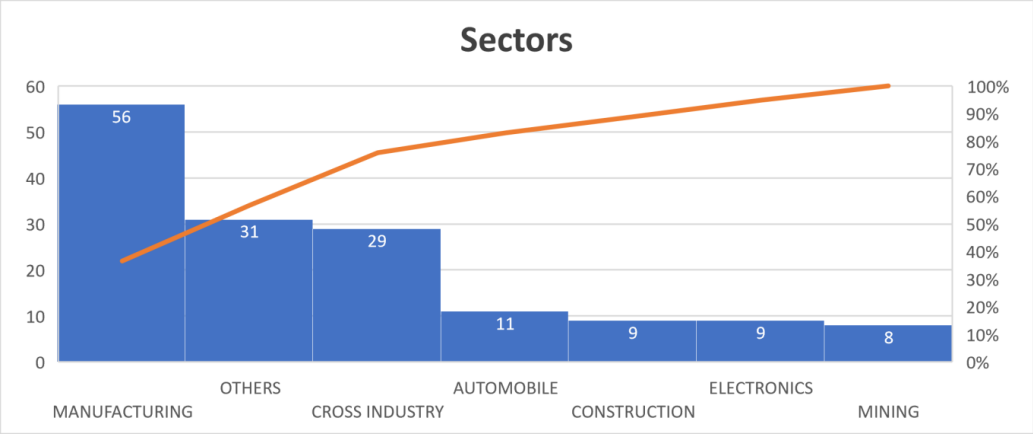

Figure 3. Number of times industries are covered by researchers (The line in this pareto graph represents the cumulative percentage of the total frequencies of the industries studies focused on with the most significant appearing first. This line is drawn on the chart to indicate the point at which 80% of the total frequency of the industries covered has been reached).

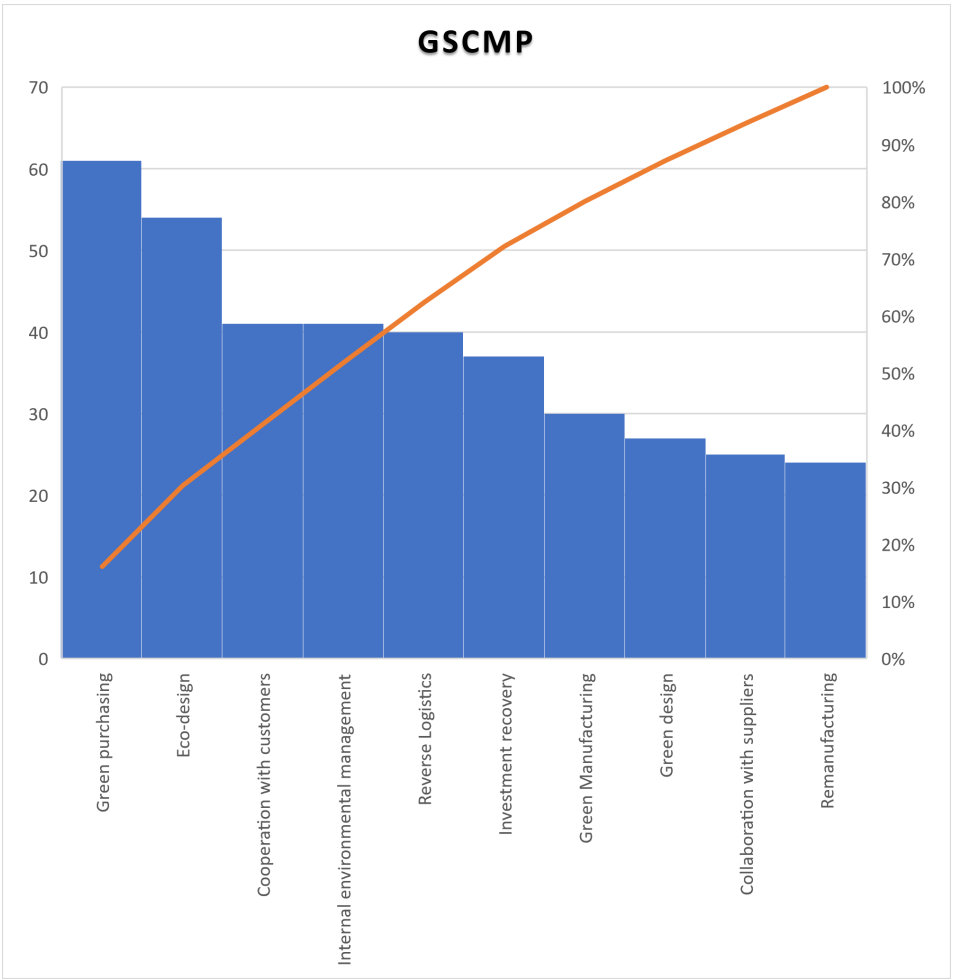

Figure 4. Ten most repeatedly mentioned GSCMP by researchers. The line in this pareto graph represents the cumulative percentage of the total frequencies of the individual GSCMP with the most significant appearing first. This line is drawn on the chart to indicate the point at which 80% of the total frequency of the GSCMP as they are mentioned by authors.

4.2.1. Procurement and Sourcing Related GSCMP

This category is termed as such because the practices mentioned under it have to do with company's procurement and sourcing decisions. In this category, Green purchasing ([2,9,33,40–44], and many others) was found to be the most mentioned practice among researchers, this practice appeared in at least sixty papers out of the papers reviewed.

Green Purchasing

As the name implies, Green Purchasing involves the incorporation of green consideration by a firm when deciding what suppliers to deal with as well as the sourcing of raw materials that meet industry and legal standards [45]. To achieve Green Purchasing, there are many other practices cited by researchers that have to do with effective management of corporate relationship. It is postulated that the achievement of Green Purchasing cannot thrive without other green practices like green supplier selection or selection of green suppliers based on environmental criteria. Even that is not obtainable without environmental disclosure among partners and information sharing regarding environmental regulations. The latter is also best achieved when digital technologies like I 4.0's blockchain, which brings about traceability and transparency in information sharing, are embedded. Table 1 lists the GSCMP related to procurement and sourcing.

Table 1. Procurement and sourcing related GSCMPs.

GSCMP	Country of Focus	Sector	Authors
Green purchasing	United Kingdom (2), Pakistan (2), Columbia, Brazil and Malaysia.	Automobile (2), Manufacturing (4) and Garment	[2,9,33,40–44]
Green procurement	Multi-regional	Hospitality	[29,46,47]
Green sourcing	Australia	Manufacturing	[48]
Green outsourcing	Saudi Arabia	Manufacturing	[31]
Sustainable sourcing	India	Manufacturing	[49]

4.2.2. Product Design Related GSCMP

This category is termed as such because the practices mentioned under it are related to product design. Eco-design ([31,33,39,50–55]) is the most repeatedly mentioned GSCM practice in this category.

Eco-Design or Green Design

Eco-design, otherwise called Green Design, is a green philosophy that juxtaposes environment thinking and economic perspective to innovatively design new products or enhance existing ones in an effort to replace less environmentally friendly products [2]. Scholars have stressed the need for product design to be eco-friendly for an organisation to adopt GSCM. Eco-design has been mentioned by several researchers in different countries and sectors. Table 2 lists the GSCMP obtained in different sectors and countries which are related to product design. Table 2 depicts GSCMP that were found to be related to product design.

Table 2. Product design related GSCMPs.

GSCMP	Country of Focus	Sector	Authors
Eco-design	United Kingdom, Saudi Arabia, Jordan, Mexico, India, Brazil, China (2)	Automobile, Manufacturing (4), Ceramics, High-tech, Multi-industry.	[31,33,39,50–55]
Green design	Not country specific	Not sector specific	[56]
Green Product design	Pakistan	Manufacturing	[57]
Environmental product design and Design for environment	India	Automobile	[58]

4.2.3. Corporate Relationship Related GSCMP

The corporate relationship related GSCMP are coined as such because the practices that fall under this category have to do with a firm's relationship management with its customers, stakeholders and/or suppliers. The most frequently mentioned practice in this category is "cooperation with customers" ([39,49,59–61]) and collaboration with suppliers [29].

Collaboration with Suppliers

It is postulated that for a firm to achieve successful greening of its supply chain, a lot of practices need to be adopted with regard to how the relationship of that firm is managed, especially with suppliers, customers and other stakeholders. Collaboration with suppliers to achieve environmental objectives has being found to be important in the implementation of GSCMP, but to procure suppliers that uphold the greening of the supply chain, supplier selection has to be conducted on the basis of green compliance.

Cooperation with Customers

Increased environmental cooperation and monitoring is often brought about by increased interaction of a firm with its customers on green issues and this has been found to positively enhance a firm's environmental performance, agility and quality [62]. This particular GSCMP has been mentioned by about 40 researchers and this is due to the importance of the end user's green ideology towards green consumerism, which generally aids organisations to comply with GSCM in the conduct of their businesses. Table 3 outlines corporate relationship-related GSCMP.

Table 3. Corporate relationship related GSCMP.

GSCMP	Country of Focus	Sector	Authors
Cooperation with customers	India, Ghana, Italy and Pakistan	Manufacturing (3), Textile	[39,49,59–61]
Environmental Data disclosure and transparency	China	Multi-Industry	[63,64]
Supplier/customer environmental cooperation	Spain	Aerospace	[65]
Information sharing regarding environmental regulations	India	Automobile	[58]
Environmental engagement and responsiveness	China	Multi-Industry	[64]
Environmental disclosure	Not country specific	Not sector specific	[63]
Collaboration with suppliers	India	SMEs	[29]
Cooperation with suppliers for eco-design	Not country specific	Not sector specific	[63]
Cooperation with suppliers for environmental objectives	Vietnam	Multi-industry	[66]
Supplier environmental collaboration	Not country specific	Not sector specific	[67]
Relationship with customers and suppliers	China	Manufacturing	[68]
Supplier selection in the context of sustainable sourcing	Not country specific	Not sector specific	[63]
Supplier education	Spain	Aerospace	[65]
Coaching and mentoring of suppliers	Spain	Aerospace	[69]
Supplier evaluation	Malaysia	Manufacturing	[32]
Supplier environmental management systems requirement	Spain	Aerospace	[69]
Green supplier selection	Not country specific	Not sector specific	[2]
Selection of suitable suppliers based on environmental criteria	Portugal	Manufacturing	[70]

Table 3. *Cont.*

GSCMP	Country of Focus	Sector	Authors
Environmental monitoring upon suppliers	Spain	Aerospace	[65]
Collaboration with suppliers for green innovations	Brazil	Footwear	[71]
Collaboration within the supply chain	Brazil	Automobile	[69]
Green collaboration with partners	Not country specific	Not sector specific	[56]
Supplier collaboration	Bangladesh	Textile	[72]
Supplier environmental collaboration	Not country specific	Not sector specific	[67]
Environmental co-operation	United Arab Emirates	Manufacturing	[73]
Green supply process management	Portugal	Manufacturing	[70]

4.2.4. Organizational Structure/Strategy Related GSCMP

This category is termed as such because the practices mentioned generally fall under a firm's organizational structure, culture and strategic positioning. Under this category, there are a lot of practices mentioned by researchers. The most frequently mentioned by researchers is Internal environmental management ([50,70,74]), Investment recovery [60] and Green Balanced Scorecard [75].

Investment Recovery

This is an important GSCMP mentioned by researchers, refering to the sale of assets that are no longer valuable to a firm in an effort to maximally recoup its investment; this also includes the sale of returned stock used equipment [38]. Although this sounds more business inclined, researchers consider it as a GSCMP because it minimizes a firm's waste generation and positively helps in the lifecycle extension of equipment.

Internal Environmental Management

Internal environmental management is about a firm's positioning in terms of its environmental policies and strategies, it is also about the activities around setting targets to achieve sustainability [41]. This is a very important GSCMP that is related to organisational structure (see Table 4) with numerous other practices obtained in this study supporting it. Other important related GSCMP include the adoption of environmental management systems like ISO 14001 certification, and others are about how green ideology and corporate environmentalism cascaded along the strata of the organisation because people drive GSCM adoption and that is why a lot of authors mentioned Green Human Resource Management (which involves Green Training) and Top Management commitment as important practices that help a firm achieve GSCM. Table 4 highlights other organisational structure/strategy-related GSCMP.

Table 4. Organisational structure/strategy-related GSCMP.

GSCMP	Country of Focus	Industry	Authors
Internal environmental management	Columbia, Jordan, Portugal	Manufacturing	[50,70,74]
Environmental management systems	Mexico	Manufacturing	[51]
Green information technology and systems	Not country specific	Not sector specific	[56]
ISO 14001 certification	Not country specific	Not sector specific	[2,67]
Environmental technology	Brazil	Footwear	[71]
Adoption of EMS including ISO 14001 certification	Not country specific	Not sector specific	[56]

Table 4. *Cont.*

GSCMP	Country of Focus	Industry	Authors
Investment recovery	Italy	Manufacturing	[60]
Green marketing	Bahrain	Shipping and Automobile	[76]
Green training	China	Multi-industry	[77]
Green human resource management	Not country specific	Not sector specific	[2]
Top management commitment for GSCM	India	SME	[29]
Total quality management			
Internal management support	Not country specific	Not sector specific	[67]
Total quality environmental management	Vietnam	Automobile	[78]
Green policy	Not country specific	Not sector specific	[2]
Green Performance, Green Organization and Environmental Strategy	Jordan	Manufacturing	[50]
Environmental activity management	Not country specific	Not sector specific	[63]
Environmental proactivity of firms (carbon index disclosure score)	Not country specific	Not sector specific	
Environmental performance	Pakistan	Retail	[34]
Corporate sustainability strategy	Not country specific	Not sector specific	[63]
Corporate environmentalism			
Corporate environmental strategy			
Supply network sustainability			
Low-carbon supply chain			
Carbon management	Not country specific	Not sector specific	[56]
Life cycle assessment	Brazil	Home appliance	[79]
Green supply	Columbia	Not sector specific	[74]
Life cycle analysis and measurements	NA	Not sector specific	[6]
Green-Source, Green-Return, Green-Plan and Green-Make	Not country specific	Not sector specific	[62]
Green finance	Not country specific	Not sector specific	[6]
Green electricity	Not country specific	Not sector specific	[2]
Green Construction	Indonesia	Construction	[80]
Green supply process management	Portugal	Manufacturing	[70]
End-of-Life practices and End-of-life management	India	Construction	[81]
Use of energy from renewable sources	India	SME	[29]
Information sharing regarding environmental regulations	India	Automobile	[58]
Data disclosure and transparency	China	Multi-Industry	[64]
Green technology	Not country specific	Not sector specific	[6]
Compliance with legal environmental requirements and auditing programs	Brazil	Electronics	[82]
Attending to external environmental management requirements	Mexico	Manufacturing	[51]
Green compliance	Brazil	Manufacturing	[38]

4.2.5. Logistics and Transportation Related GSCMP

This category is termed as such because the practices mentioned fall under logistics and transportation. The most important GSCMP under this category is Reverse logistics ([31,38,83]).

Reverse Logistics

Reverse logistics is a GSCMP that involves product returns, material substitution, remanufacturing, source reduction and recycling [40]. The successful implementation of reverse logistics definitely requires a high level of coordination among supply chain partners, and this is because products can easier be tracked back to the point of fault. It is for this reason that researchers have mentioned that a lot of GSCMP has to do with corporate relationship, like environmental information sharing among supply chain partners. Table 5 below contains logistics- and transportation-related GSCMP obtained in this review.

Table 5. Logistics- and transportation-related GSCMP.

GSCMP	Country of Focus	Sector	Authors
Green logistics	United Kingdom, Columbia and Thailand.	Automobile, Manufacturing and Electronics	[33,40,84]
Green transportation	India	Agro	[85]
Green distribution	Not country specific	Not sector specific	[39]
Greening inbound and outbound	Portugal	Manufacturing	[70]
Sustainable transportation	Europe	Logistics and Shipping	[86]
Green-Deliver	Not country specific	Not sector specific	[62]
Reverse logistics	Saudi Arabia, Brazil and India	Manufacturing (2) and Automobile	[31,38,83]
Green warehousing	Not country specific	Not sector specific	[2]
Warehousing and green building	Not country specific	Not sector specific	[39]
Optimization of transportation	Malaysia	SMEs	[87]
Operations and Logistics Integration	Ghana	Mining	[88]

4.2.6. Waste and Pollution Management Related GSCMP

This category is termed as such because the practices mentioned relate to pollution and waste management processes. Table 6 contains a list of practices obtained under this category.

Table 6. Waste and pollution management-related GSCMP.

GSCMP	Country of Focus	Industry	Authors
Waste management	India	SME	[29]
System for waste minimization			
Waste water treatment			
Solid waste management system			
Emission control system Waste minimization	India	Automobile	[58]
Toxic substance management	Malaysia	SMEs	[87]
Superior waste management	United Kingdom	Manufacturing	[89]
Reduction of pollutants	Taiwan	Shipping	[90]
Pollution prevention and mitigation	Brazil	Footwear	[71]
Final Waste Destination			
Environmentally friendly disposal	Oman	Manufacturing	[91]

4.2.7. Manufacturing Related GSCMP

This category is termed as such because the practices mentioned fall under manufacturing processes. Green manufacturing ([45,68,81,92]) is the most important practice mentioned under this category.

Green Manufacturing and Remanufacturing

Green manufacturing is a GSCMP that involves an environmentally conscious manufacturing practice, which is energy efficient, uses quick and dependable equipment that raises productivity and decreases wastage [31]. A lot of scholars have mentioned practices that augment Green manufacturing, linking sustainable raw material handling and processing, therefore reducing the use of hazardous materials and the blacklisting of raw materials. Others link it to green and renewable energy utilization like the use of energy from renewable sources as proposed by [29]. Scholars like [76] link Green manufacturing to Green or Eco-friendly packaging. To stress the fact that Green manufacturing is the incorporation of environmentalism in the end-to-end process of manufacturing, authors like [58] mentioned pollution and waste management GSCMP alongside end-of-life practices like toxic substance management and superior waste management. Table 7 outlines the GSCMP that are found to be related to manufacturing practice.

4.2.8. Conclusions

The GSCMP obtained in this review, as depicted in different tables according to where they belong in different business or organisational functions, are elaborately covered in the section. Despite the fact that these practices were found to improve firms' environmental performance, the role of digital technologies, like I 4.0 technologies, can never be overemphasized regarding the effective implementation of the practices. For example, one of the GSCMP is Environmental Data disclosure and transparency [63,93]. Implementation of this GSCMP indeed could prove difficult without proper digital technologies like the I 4.0′s blockchain enabling it.

4.2.9. Literature on the Role of Industry 4.0 Technologies in GSCM Adoption

Based on the literature reviewed, a handful of research papers covered the combined construct of GSCM and I 4.0. In an empirical research, Ref. [9] studied I 4.0 and GSCMP in Pakistan. They found that GSCMP mediate the effect of I 4.0 on environmental and economic performances. Correspondingly, their results indicated that GSCMP are affected positively by I 4.0. They showed that companies in Pakistan's manufacturing industry found the I 4.0 technologies helpful in the adoption of eco-friendly practices through the monitoring and evaluation of GSCMP and their impacts on economic performance as well as environmental performance.

Another empirical research conducted by [12] studied the link between GSCM and I 4.0. Their research focused on the automotive industry in Europe and the UK. Their study provides a robust empirical evidence on how the integration of I 4.0 technologies in the automotive supply chains corroborate the initiation of GSCMP and their respective impact on the improvement of GSCM performance measures in terms of operational, environmental and economic performances. The researchers recommended that future GSCM research should focus on linking technologies, like the Internet of Things (IoT), Blockchain, and Cyber Physical Systems (CPS), to drive the effective implementation of GSCM practices.

Ref. [11] empirically studied process innovation enhanced through I 4.0 technologies, GSCM and Lean manufacturing in a cross section of industries in Europe. They have found that organizations could obtain higher performance by investing in I 4.0 technologies. Ref. [35] investigated the relationship between GSCM and I 4.0 in event management companies in Indonesia. They have found a significant impact of I 4.0 on the implementation of GSCM.

Ref. [15] conducted an empirical research in Italy focusing on the food industry. The authors have examined the role of big data analytics in linking GSCMP with competitiveness during COVID-19. The findings of their study promote the notion that the incorporation of GSCM, environmental management, environmental visibility and a combination of big data analytics and artificial intelligence could enhance market competitiveness during periods of crises like COVID-19.

In another empirical research, Ref. [40] built and tested a set of hypotheses that suggested positive effects of digital technologies (I 4.0) and green human resource management on GSCM operational practices, also environmental and economic performances. The researchers carried out their study on manufacturing companies in Colombia. They found a strong support for their assumptions, suggesting that the effects of green human resource management and digital technologies on environmental and economic performances become higher when mediated by GSCM operational practices.

Ref. [34], in their own part, studied the moderating role of big data analytics on institutional pressures and GSCM to achieve organisational performance in retail points and superstores in Pakistan. The findings of their empirical research showed that the moderating effect of big data analytics strengthened the impact of GSCM on organisational performance positively.

Ref. [11] examined a cross-section of industries in Europe; their study focused on the I 4.0-powered process innovation strategy implemented by firms on green supply chains and lean practices. The authors found that with investment in I 4.0 technologies, firms can achieve higher organisational performance.

4.2.10. Industry 4.0 Technologies

Based on the research works conducted by the above authors, it is evident that I 4.0 technologies possess several features that enable the successful implementation of GSCMP in firms. It is therefore paramount to list these I 4.0 technologies and use cases in the business context as obtained in this review. The following are perceived as the most important industry 4.0 technologies [10] in the context of this article:

Internet of things (IoT)*:* IoT is referred to as a network of physical objects which are interconnected through various embedded technologies such as sensors to produce data, process and exchange it [94]. In other words, the IoT makes it possible for various smart devices to be connected and monitored, also allowing the devices to communicate among themselves [95]. In business sense, IoT facilitates the secure exchange of materials, goods and services-related information in global supply chains and since the advent of this technology, businesses have been transformed into advanced and smart entities [96].

Blockchain: As a decentralised peer-to-peer network, the blockchain provides a secure means to track data changes over time, for example, along a global supply chain [95]. Depending on the use case, some firms use blockchain to develop a system to track and trace emission data, while others use the technology to bring about transparency and visibility in the conduct of their business [97]. With regard to supply chains, blockchain technology enables a real-time flow of data, which could easily be processed to ramp up predictive capacity of possible disruptions and bottlenecks [98].

Artificial intelligence (AI): AI is one of the I 4.0 technologies that are considered to be the elementary units of I 4.0 and the basic tools at the forefront of industrial digitalization [25]. AI is referred to as the computer applications and systems that need human intelligence in performing tasks which, through data and algorithms, obtains the ability to learn and improve on thinking and perception [95]. AI brings about numerous benefits such as distributed and localised production based upon smart business models, as well as giving customer benefits through more responsive and flexible manufacturing practice with overall fewer delays and defects, thereby achieving faster delivery [24].

Big data analytics (BDA): BDA refers to the analytical capability to process a huge amount of data with high complexity, velocity and variety [95]. In the aviation sector, for instance, commercial aircrafts use BDA and other cloud services to promote informed inflight

decisions and flight route planning so that fuel consumption is minimized [99]. Ref. [100] added that BDA, through intelligent tracking systems, energy efficiency management, predictive maintenance and material assessment, enables companies to be extra competitive.

Augmented reality (AR): AR is referred to as the overlaying of digital information like texts, effects and images generated by a computer in the real world, which interact with users to provide real time instructions in a way that is user friendly [37,95]. AR enhances end user experience and minimizes workflow disruptions, particularly on the shop floor [37,100]. Furthermore, AR is found to be impactful in terms of employee productivity, training efficiency, error reduction and better equipment maintenance [37,101].

Virtual technologies and simulation: These are powerful tools that are capable of evaluating, optimizing, controlling and mimicking a system or real-world entity by digitally representing it under a cost-efficient environment that is risk-free [95]. Additionally, these tools provide an immersive environment that enhances productive interaction with information [102].

Cybersecurity: This refers to the practice of protecting and defending critical data, computers, servers, software and other IT infrastructure from malicious activities and cyber-attacks [103]. Cybersecurity involves use of different processes and technologies to ensure the integrity, confidentiality and availability of information systems [100].

Cyber-physical systems (CPS): CPS refer to the integration of virtual and physical processes of interconnected machines to obtain real-time information that positively impacts the decision-making for maintenance and production processes, alongside improving efficiency, control of production capacity and operational transparency [104]. Ref. [100] added that CPS, which enables effective interactions between humans and systems leveraging computational intelligence and physical elements, is aimed at achieving a high level of intelligence, connectivity and automation through the integration of both physical and cyber components.

Cloud computing (CC): CC technologies represent a central platform for the integration and storage of configurable information technology resources, which make accessing data and resources from decentralised locations feasible [100]. With regard to the buyer–supplier relationship, CC technologies are capable of facilitating more collaborative buyer–supplier relationships [105].

Additive manufacturing (AM): AM is an alternative production strategy that is different from traditional manufacturing processes, and can be referred to as the process of joining different materials to make objects out of 3D model data, usually layer upon layer, contrary to subtractive manufacturing methodologies [106]. Furthermore, AM, otherwise known as 3D printing, is considered as a generative manufacturing or layer-wised production through the addition of materials in a layered form to achieve the effective production of items at the required shape and size without any waste [100].

Autonomous robots: These are highly intelligent robots with the ability to self-organise, self-evaluate and make independent decisions to execute numerous tasks without human instructions [100]. In the RES, there has been the robotisation of the process of maintenance, for example, robots being deployed to clean PV panels or inspect wind turbines [107].

To put the application of I 4.0 technologies into context, it is important to highlight the business challenges with regard to sustainability and supply chain in which these technologies alongside GSCM can tackle. The next section highlights such business challenges within the RES.

4.2.11. Sustainability and Supply Chain Related Problems in the Renewable Energy Sector

Ref. [108] researched offshore wind turbines and numerous supply chains, as well as sustainability issues. It was noted by the author that the first generation of offshore wind turbines is about to be decommissioned, so a lot of end-of-life-related problems exist in the supply chain. Other supply chain problems noted by the author include high material (steel, concrete, glass, etc.) and resource needs during commissioning, human toxicity and freshwater and terrestrial ecotoxicity potentials of offshore wind. Ref. [109] reported

reliability, efficiency and transparency issues within the RE supply chains, which pose risk factors to consumers and processes reliant on the supply from these sources.

Another major challenge along the RE supply chains is the maintenance of wind power equipment, which is faced with a lot of issues as reported by [36] who studied the market challenges of wind turbines in China and Germany. This, according to the authors, is due to the fact that wind farms are mostly located in remote areas with harsh and difficult terrains; also, most of the crucial components of wind turbines are located on top of the towers, reaching to the top therefore poses a challenge. Another research conducted by [110] on wind turbine blades highlighted that by 2050, around 42 million tonnes of composite waste is predicted to be generated annually from wind turbines, which need to be handled sustainably.

Ref. [16] mentioned supply chain-related issues of the solar RE source or Photovoltaic life cycle. The authors found that the raw materials of PVs are rare and hazardous; PV design is not performed in a manner that supports recycling or refurbishment, lack of communication throughout the PV supply chain, lack of effective end-of-life management planning and the high cost of dismantling PVs such that landfill disposal costs are lower than dismantling costs. Ref. [111] have also reported supply chain-related issues in the sourcing of materials of lithium ion batteries, as well as end-of-life management. Tin, tungsten, gold and cobalt are the so-called conflict minerals, which are crucially relevant to the RE supply chain, posing high risks associated with sourcing these raw materials. The sourcing of these minerals particularly brings about concerns with regard to human rights and social risks [112].

It is obvious from the literature that the sustainability and supply chain challenges in the RES cut across different facets of the RE supply chains, from material sourcing to end-of-life management. To tackle these issues, we propose an I 4.0 powered GSCM solution to these problems.

4.2.12. Roadmap towards I 4.0 Powered GSCM Solutions to Sustainability and Supply Chain Problems in the RES

Several researchers have studied the fusion of supply chain management with different aspects of digitalisation and, in that process, several terminologies have already been developed [20]. For instance, Smart GSCM [20]; the fourth industrial revolution of supply chains or supply chain 4.0 [21,22], digitally enabled sustainable supply chains [23]; and the I 4.0-enabled sustainable supply chain [24] were used among others. According to [20], smart supply chains allow for a real-time sharing of data to achieve faster transactions and decisions, and that is made possible by technologies like IoT, big data analytics, cloud computing, blockchain, artificial intelligence, among other I 4.0 technologies.

Smartness of supply chains and sustainability have been studied disjointedly in recent years and, to this end, there is no consensus among scholars with regard to a framework of integrating smart supply chains with sustainability [25]. Ref. [22] opined that smart supply chain management or supply chain 4.0 is seen as a process that enables the adoption of industry 4.0 technologies coupled with environmental and human dimensions to make sustainability the centre of business development. Indeed, sustainability remains a priority of our time and is expected to remain relevant in the smart supply chain agenda [21].

Ref. [21] argues that unless their adoption leads to new business models, as well as redesigned business services and processes, technologies are pointless. That is why this research proposes I 4.0-powered GSCM to, in a more robust manner, join the efforts made by researchers to study different aspects like logistics, sustainability and digital transformation in trying to solve the managerial challenges and highlight the need for interdisciplinary approaches to solving business problems by embedding sustainability, digitalisation, resilience and efficiency into supply chain networks [21]. It is for this reason that this paper tries to draw a roadmap for tackling supply chain-related problems in the RES using this multidisciplinary I 4.0-powered GSCM approach.

I 4.0-enabled GSCM, otherwise termed as digitally enabled GSCM, is referred to as I 4.0-powered GSCM, which operates through new technologies and digital platforms [23]. Embedding industry 4.0 technologies into GSCM and manufacturing operations can bring about visibility and enable a more efficient tracking of materials, especially the so-called conflict minerals across supply chains [99]. Additionally, through the digital twinning technology (one of the I 4.0 technologies), RE consumers can obtain real-time data and an accurate estimation of energy consumption [24].

Furthermore, the blockchain is a crucial I 4.0 technology that provides transparency and traceability in terms of real-time transactions and product traceability. With blockchain technology, it is possible for business partners to track and trace the flow of products from manufacturing to consumption stages along the RE supply chains, which in turn bring about effectiveness and efficiency along the supply chains [109]. Furthermore, the upstream phase of the RE supply chain involves a lot of hazardous materials with delicate mining conditions and other industrial activities that demand a high level of vigilance that the blockchain can offer [113].

Ref. [23] have found that big data analytics are significantly applicable to sustainable supply chains (Green Supply Chains) in different ways, which include encouragement of ethical behaviour by partners allowing a high level of traceability and transparency; this may also lead to an increased commitment towards green practices, supplier collaboration on implementation of GSCMP, information sharing enhancement, monitoring of social sustainability issues like child labour, forced labour and slavery.

Finally, the GSCM proposes green practices (as were elaboratively mentioned and categorized in Tables 1–7) that are capable of tackling the supply chain challenges mentioned in the previous section. GSCMP, like green purchasing, represent a model that tackles issues relating to the sourcing of minerals. With a blockchain or big data-embedded GSCM, green purchasing practice, raw materials or mineral sourcing risks identified in the upstream RE supply chain can be tackled to a great extent because product traceability and provenance is created along the supply chain.

Table 7. Manufacturing-related GSCMP.

Practice	Country of Focus	Sector	Authors
Green manufacturing	India	Construction, Agro	[45,68,81,92]
Green/Eco-innovation	Ghana	Mining	[2,88]
Environmental quality controlling	China	Multi-industry	[77]
Sustainable manufacturing practices	Not country specific	Not sector specific	[63]
Product recovery	India	Automobile	[114]
Green production, Green operations and Green process	Portugal	Manufacturing	[70]
Cleaner production	India	Multi-industry	[115]
Green service	Not country specific	Not sector specific	[2]
Operational performance and Internal process improvement	India	Ceramic	[52]
Reduced use of hazardous materials	United Arab Emirates	Manufacturing	[73]
Green materials and design	Germany, Austria and Switzerland	Manufacturing	[116]
Black list of raw materials	Multi-regional	Multi-industry	[117]
Green electricity	Not country specific	Not sector specific	[2]
Use of energy from renewable sources	India	SMEs	[29]
Source reduction	Mexico	Manufacturing	[51]
Saving energy	India	Automobile	[58]
System for waste minimization and Waste water treatment	India	SMEs	[29]

Table 7. *Cont.*

Practice	Country of Focus	Sector	Authors
Solid waste management system	India	SMEs	[33]
Reduction of pollutants	Taiwan	Shipping	[90]
Environmentally friendly disposal	Oman	Manufacturing	[91]
Products' end of life management	India	Construction	[81]
Emission control system	India	SMEs	[33]
Green packaging	Bahrain	Shipping and Automobile	[76]
Reuse	India	SMEs	[29]
Recycle	United Kingdom	Manufacturing	[89]
Environmental packaging	Not country specific	Not sector specific	[63]
Eco-friendly packaging	India	SMEs	[33]
Design of packaging	India	Ceramics	[5]
Remanufacturing	Oman	Manufacturing	[91]
Upcycling	Multi-regional	Hospitality	[46]
Green recycling	Pakistan	Construction	[118]
Use of less expensive recycled raw materials	United Kingdom	Manufacturing	[89]

Another set of supply chain challenges in the RE supply chain has to do with end-of-life management bottlenecks. GSCM holds a plethora of practices of end-of-life management like remanufacturing and repurposing. Again, I 4.0-embedded remanufacturing would work even more efficiently in tackling product end-of-life challenges [99]. From a product development stage, GSCM's eco-design or green design encourages a model of design that is environmentally conscious of the product life cycle and end-of-life management to reduce the use of hazardous materials. I 4.0 technologies, like artificial intelligence, machine learning and human–robot collaboration, would enhance the practice of eco-design [119]. Table 8 contains the RE supply chain challenges and the respective I 4.0–GSCM mix to tackle the issues.

Table 8. Renewable energy supply chain challenges and I 4.0–GSCM solutions.

Renewable Energy Supply Chain Problems	Industry 4.0-GSCM	Reference
End-of-life management of wind turbines, batteries and solar panels	I 4.0 powered eco-design and remanufacturing.	[91,108,120]
Raw materials and mineral sourcing risks	IoT, big data and blockchain powered green purchasing.	[45,108]
Lack of visibility along the supply chain	Industry 4.0 powered collaboration with suppliers, environmental disclosure and green supplier selection.	[72,111]
Onshore and offshore wind turbine maintenance issues	Robot powered green operations and maintenance.	[36,70,108,121]
Production planning and scheduling challenge in the renewable hydrogen supply chain	Smart manufacturing powered green manufacturing and green operations.	[70,122]

5. Discussion

Based on this review, the following are the main findings: first, state-of-the-art GSCMP were obtained. Although, there is no consensus among researchers on an agreed upon framework of GSCMP that encapsulates business function peculiarities, sector and value chain specific GSCMP, this study has elaboratively categorized GSCMP based on business functions and where the practices fall in a given value chain. With regard to GSCMP adoption, this categorization presents a simplistic streamlined guide for managers and policy makers on mapping out how and what business functions should comply with sustainable practices within their organisations.

Second, this research has identified the role of I 4.0 technologies in GSCM adoption and carefully synthesized how I 4.0 goes hand in hand with GSCM by increasing effectiveness and efficiency of executing GSCMP. Furthermore, the major I 4.0 technologies were identified and their applicability in business contexts were highlighted with the citations of relevant use cases that practically depict the significance of the incorporation of the disruptive technologies with GSCM. This serves as a guide towards leveraging such technologies for more sustainable and efficient business functions.

Third, this review covered an overview of sustainability and supply chain-related challenges in the RES, which are found to be existent along the RES supply chains from upstream to downstream. Also, the literature has been reviewed on the I 4.0-GSCM makeup to tackle the identified challenges. A lot of the challenges for instance have to do with the procurement and sourcing of raw materials for the fact that most of the latter are sourced from conflict locations with high-risk factors bordering around issues of slavery and child labour, among others. It was succinctly portrayed that an I 4.0-powered GSCM will provide a traceability and transparency-enabled sustainable supply chain that has reduced risk factors. Other challenges identified are operational and end-of-life management-related challenges.

The outcome of this literature review provides an insight for researchers and industry practitioners on a wide range of GSCM practices that are implementable in different business functions, and I 4.0 technologies and their use cases in terms of achieving sustainability by leveraging such disruptive technologies to enhance the adoption GSCM, thereby achieving corporate sustainability in the RES. Moreover, the role of the proposed I 4.0-powered GSCM in tackling sustainability and supply chain-related issues, most especially in the RES, were critically discussed. In a nutshell, this work would provide managers with the wherewithal of GSCM implementation and I 4.0 integration with GSCM to achieve robust business problem solving. The current research also presents, for policy makers and managers within the RES, an overview of the I 4.0-GSCM approach to tackling numerous sustainability and supply chain issues within the RES.

6. Conclusions and Future Research

Main contributions of this article are based on its findings in response to the aim ad objectives of this review. This study aimed at systematically reviewing the literature on GSCM, I 4.0 and RES. The objectives of this research were to ascertain state-of-the-art practices in GSCM literature in order to review the literature about GSCM and the I 4.0-combined construct while highlighting assertions made by researchers with regard to the role of I 4.0 technologies in the adoption and successful implementation of GSCM. Moreover, this research aimed at highlighting the RE supply chain challenges and the role of I 4.0-powered GSCM in tackling such challenges.

A total of 215 systematically selected empirical and review research papers were reviewed in this study to obtain an up-to-date knowledge about GSCM and the I 4.0-combined construct. In line with the first objective of this research (Q1), different state-of-the-art GSCM practices in various areas of focus, countries and industries were obtained, and these practices were identified and categorized as being related to manufacturing, corporate relationship, procurement and sourcing, product design, logistics and transportation, waste and pollution management and organisational culture or strategy. We found that the ten most important GSCMPs mentioned by researchers are Green purchasing, Eco-design, Cooperation with customers, Internal Environmental Management, Reverse logistics, Investment recovery, Green manufacturing, Green design, Collaboration with suppliers and Remanufacturing.

In line with the second objective (Q2) of this literature review, the studies on the combined constructs of GSCM and I 4.0 technologies were identified and discussed. According to the findings of this literature review, there are limited studies conducted on the combined construct of I 4.0 and GSCM, specifically on the role and application of I 4.0 technologies in the implementation of GSCM. To fulfil the third objective (Q3) of this study, supply chain-

and sustainability-related challenges in the RE sector were identified, and based on the fourth objective (Q4), a critical discussion around solving them using Industry 4.0-GSCM integration was presented.

Future research work may be focussed on developing models of I 4.0-powered GSCMP implementation that succinctly identify sector-by-sector implementation roadmaps. This can be best achieved through studies that empirically develop the I 4.0-powered GSCMP framework and test that for a practical appraisal by industrial actors. Further studies on the combined construct of I 4.0 and GSCM are also needed because the extant literature provides scant studies in this regard. Significantly, research communities should work towards building comprehensive models of GSCMP, as there is no consensus among researchers on what constitutes GSCMP. In other words, there is a need for a unanimous categorization of GSCMP according to industry type and sector, so empirical studies on larger scales can be conducted.

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Abbreviations

GSCM	Green Supply Chain Management
GSCMP	Green Supply Chain Management Practices
I 4.0	Industry 4.0
IoT	Internet of things
BDA	Big Data Analytics
CPS	Cyber Physical Systems
AI	Artificial Intelligence
AR	Augmented Reality
CC	Cloud Computing
AM	Additive Manufacturing
RE	Renewable energy
RES	Renewable energy sector

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