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Sustainable Operations Management in the Energy Sector: A Comprehensive Review of the Literature from 2000 to 2024

Mariana Losada-Agudelo and Sebastian Souyris *

Lally School of Management, Rensselaer Polytechnic Institute, Troy, NY 12180, USA; losadm@rpi.edu
* Correspondence: souyrs@rpi.edu

Abstract: This study centers on sustainable operations management within the energy sector, identifying and synthesizing effective strategies for integrating sustainability into business practices. We perform a systematic literature review covering contributions from January 2000 to June 2024 extracted from Web of Science and Scopus databases. The methodology includes an explicit search and selection protocol to ensure relevant and unbiased insights into the evolution of sustainable practices in the energy sector. The results indicate an increase in publications over the years, particularly in areas such as low-carbon economies, environmental management, and innovation, all of which are crucial for reducing carbon footprints and enhancing operational sustainability. This study categorizes existing research into five main streams: Closed Loop Supply Chains (CLSC), Low Carbon Economy (LCE), Environmental Management and Performance (EMP), Innovation (INN), and Social Responsibility (SR). The review underscores the significant gap between current practices and the potential for incorporating renewable energy sources into existing systems. In addition, it highlights the need for robust governmental policies and international cooperation in order to foster a more rapid transition towards sustainable operations on the energy sector. Furthermore, our findings suggest that despite technological advances, significant implementation gaps remain that require focused research and policy adjustments in order to achieve sustainability targets in the energy sector.

Keywords: energy sector; closed loop supply chains; low carbon economy; environmental management and performance; innovation; social responsibility

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1. Introduction

In a world facing climate and environmental challenges, the pressure from governmental and social entities to adopt sustainable practices within organizations has increased over the last few decades, positively impacting those organizations that choose to respond to these demands [1]. This urgency has generated interest in understanding the impact of integrating sustainability goals into operations. Consequently, there is a need for modeling and analysis to measure performance and make strategic, tactical, and operational decisions to optimize supply chains while reducing carbon footprints and enhancing efficiency and sustainability in manufacturing and services [2]. Closed loop supply chains, green products, and lean operations enhanced with operational research tools can drive efficiency and competitiveness, providing an essential framework to address sustainability challenges [3].

Given climate change and the environmental impact of fossil fuels consumption, the transition towards sustainable energy operations becomes even more crucial [4]. The energy sector, historically dependent on fossil fuels, emerges as one of the main contributors to global greenhouse gas emissions, accounting for 34% of greenhouse gas emissions by 2019, as illustrated in Figure 1 [5,6].

Energy transitions are complex multi-sector processes that unfold over extended periods, indicating that shifting to a low-carbon economy is likely to be slow and gradual, requiring government intervention and the protection of niche markets [7]. Governance for the transition to sustainable energy systems is a highly political process, and governance decisions can enable or restrict sustainable changes in energy systems [8]. Therefore, it is necessary to accelerate the process through effective governmental policies, international cooperation, and technologies such as energy efficiency and smart grids [4]. However, despite advances in renewable technologies and energy efficiency policies, significant gaps remain in effective implementation and sustainable operational management on a large scale.

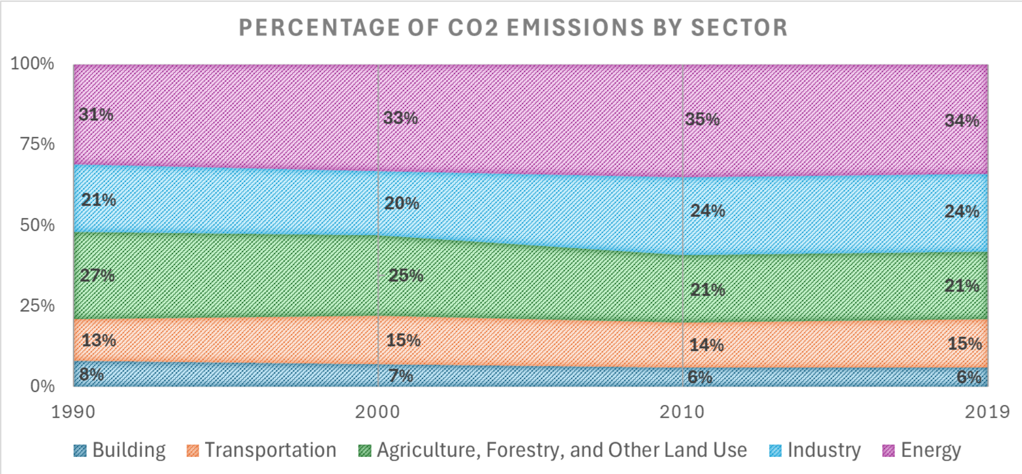

Figure 1. Percentage of CO_2 emissions by sector. Data source: https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview, accessed on 25 July 2024, U.S. Environmental Protection Agency.

This article focuses on thoroughly reviewing the existing literature on sustainable operations management in the energy sector, highlighting recent advancements and methodologies used to improve the sustainability of operations. This survey uses the classification framework proposed by [9], which reviews papers on sustainability in the operations management literature and divides them into five main categories: Closed Loop Supply Chains (CLSC), Low Carbon Economy (LCE), Environmental Management and Performance (EMP), Innovation (INN), and Social Responsibility (SR). The chronological evolution of these topics is analyzed along with their impact both within and outside the field of operations management. Regarding sustainable operations management in the energy sector, while various publications have addressed components of this topic, notable discrepancies and unresolved challenges remain, such as the integration of renewable energy sources into the existing grid and sustainably managing energy demand, which we discuss later in this survey paper.

This review aims to identify and synthesize the main strategies and practices that have proven effective as well as to highlight areas requiring further research. This work provides a holistic understanding of how operations in the energy sector can evolve toward more sustainable practices. The conclusions of this review are expected to help guide future research and policy decisions in pursuit of a sustainable energy future.

The rest of this paper is organized as follows. Section 2 details the methodology used for a systematic literature review, describing searching processes using databases such as Web of Science and Scopus. Section 3 provides a literature review, where results are analyzed under a classification framework that includes categories such as Closed Loop Supply Chains (CLSC), Low Carbon Economy (LCE), and Social Responsibility (SR), among others. Finally, Section 4 discusses key findings, emphasizing the implementation of sustainable management practices in the sector and the influence of technologies while suggesting future directions for research in this area.

2. Methodology

This survey undertakes a comprehensive review of contributions made through scientific articles to elucidate the current state of sustainable operations management within the energy sector from 1 January 2000 to 30 June 2024. Drawing upon the works of various authors, this study aims to map the evolution and current trends in this critical area of research [9–12]. The main research question guiding this survey is: What has been the development in sustainable operations management in the energy sector over the past two decades? This question seeks to identify the major trends, challenges, and opportunities that have emerged in this field.

According to the methodology delineated by [13], we executed a systematic literature review, adhering to a predetermined set of criteria and organizing the information in order to offer an overview of the current state of knowledge as well as to outline a future research agenda. To this end, we performed an initial search across two databases: Web of Science (WoS) and Scopus. This approach aims to mitigate biased outcomes owing to the scope encompassed [14]. The search was confined to articles and reviews in English published since 2000 utilizing the following search query:

TITLE-ABS-KEY: {*energy sector* OR *energy industry*}
AND
TITLE-ABS-KEY: {*sustainability*}
AND
TITLE-ABS-KEY: {*operations management* OR *supply chain*},

where TITLE-ABS-KEY: {*words*} means that the title, abstract, or keywords contain the *words* in between curly brackets.

After applying the search query, we filtered the result by document type to *article* and *review* (excluding *conference papers*, *books*, *notes*, *letters*, etc.). Then, we limited the journal subject areas to the following: for WoS, *Energy Fuels*; *Engineering*; *Business Economics*; and *Operations Research and Management Science*; and for Scopus, *Energy*; *Business, Management and Accounting*; *Engineering*; *Economics, Econometrics, and Finance*; and *Decision Science*.

From this search, we identified 34 articles from WoS and 84 from Scopus, of which 25 were present in both databases; see Figure 2.

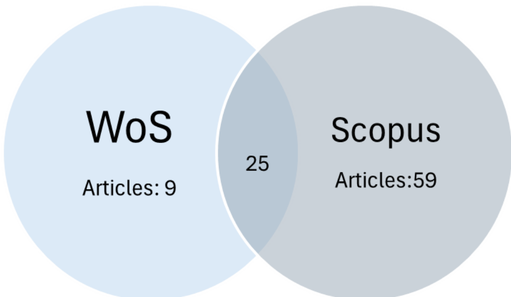

Figure 2. Articles per database.

Upon reviewing the literature, 29 documents were excluded from the selection due to their lack of relevance to the scope of this survey. This exclusion process was based on predefined criteria set by the authors, including factors such as the relevance of the study to sustainable operations management specifically within the energy sector and alignment with our research streams (e.g., Closed-Loop Supply Chains, Low-Carbon Economy, Environmental Management, Innovation, and Social Responsibility). The goal was to refine the selection to documents that contribute valuable insights directly related to our research objectives. This resulted in 64 articles being selected for review. The process is described in Figure 3, and the summary of the articles can be found in the Appendix A.

After we had identified the articles, we categorized them into five major streams following the classifications established by [9]: Closed Loop Supply Chains (CLSC), Low Carbon Economy (LCE), Environmental Management and Performance (EMP), Innovation (INN), and Social Responsibility (SR). In the following section, we develop each of these clusters in detail, describing the papers that consolidate them.

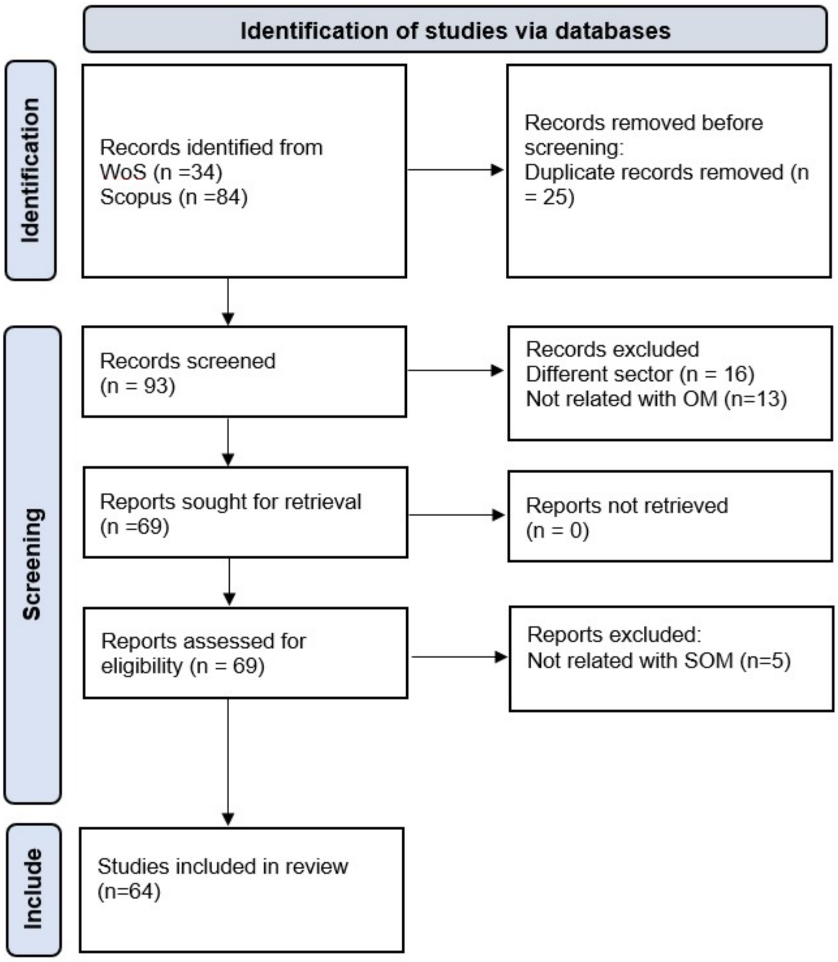

Figure 3. Identification of studies via databases.

3. Literature Review

A preliminary descriptive analysis of the search results indicates that the earliest publications in the field of sustainable operations management in the energy sector date back to 2000. Since then, an average of five articles per year have been published up until the beginning of 2024. Figure 4 illustrates the distribution of articles by year according to the categories defined by [9].

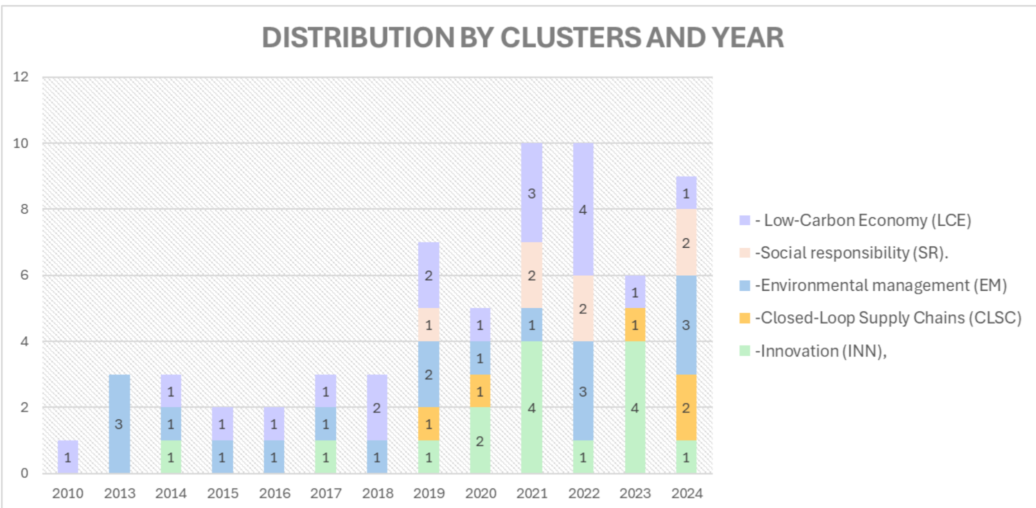

Figure 4. Distribution by clusters and year.

In Figure 5, it can be observed that the cluster with the most publications corresponds to *Low Carbon Economy*, followed by *Innovation* and *Environmental Management*. According to the definition for each cluster provided by [9], we conducted a descriptive analysis of the articles within each cluster to provide a deeper understanding of problems, methods, and contributions identified in the literature related to sustainable operations management in the energy sector.

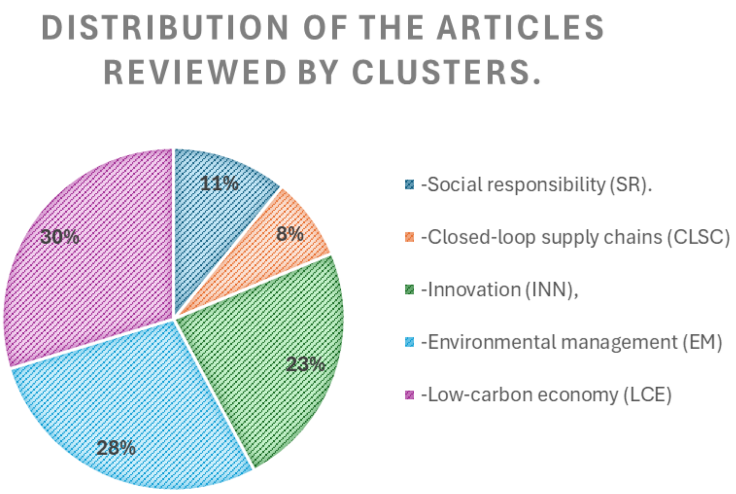

Figure 5. Distribution of reviewed articles by clusters.

3.1. Closed Loop Supply Chains (CLSC)

The Closed Loop Supply Chain category describes 8% of the articles located and selected for review. This category focuses on sustainability by maximizing resource utilization, minimizing waste, and conserving natural resources through more efficient resource cycles. According to the definition of this cluster in [9], it covers a broad variety of topics ranging from consumer returns management to remanufacturing and recycling. We included life cycle assessment in this category, as it is a relevant topic in the energy sector. The strategies covered in this category align closely with circular economy principles, which emphasize the importance of creating closed loop systems to achieve sustainable development goals.

From the perspective of the energy markets, ref. [15] demonstrated how circular economy approaches can significantly support sustainable development. The author emphasized the need for a shift from linear ("take–make–dispose") to circular and sustainable economic systems as a strategic response to global environmental and socioeconomic challenges. Similarly, ref. [16] developed a flexible stochastic programming model to design a sustainable supply chain in the solar industry aimed at reducing CO_2 emissions and enhancing sustainability. This model integrates both forward and reverse material flows within the supply chain. The proposed model addresses the collection, separation, recycling, and recovery of components at the end of their lifecycle, thereby closing the product lifecycle and minimizing environmental impacts.

Regarding the materials necessary for the energy transition, ref. [17] highlights the current state of corporate commitment and strategies towards *end-of-life* management, which refers to strategies and practices implemented to handle products. In this case, a study of lithium batteries within the energy sector revealed that many companies have limited engagement with extended producer responsibilities when batteries reach the end of their useful life. The authors emphasized the importance of comprehensive end-of-life management practices to ensure that environmental and economic impacts are addressed effectively throughout the product lifecycle.

To assess the environmental impacts of products/processes, the authors of [18] analyzed Consequential Life Cycle Assessment (CLCA) through various tools and approaches, highlighting the importance of considering the direct and indirect environmental impacts of technological, economic, and social changes while emphasizing the importance of choosing the evaluation model to ensure the transparency of the results. Similarly, ref. [19] reviewed the CLCA methodology in the energy sector, emphasizing the importance of evaluating both direct and indirect environmental impacts. They concluded that the choice of model depends on the study's objectives and data availability, and underlined the importance of transparency and sensitivity analysis to enhance the reliability of the results.

3.2. Low Carbon Economy (LCE)

Low carbon economy refers to an economic system that aims to minimize carbon dioxide emissions to combat climate change. According to [9], this category includes the effects of regulation and regulatory instruments on carbon emissions, the impact of reduction strategies on companies' performance, incentives to adopt clean energy, and consumer behavior toward more sustainable practices. In this category, we located 30% of the articles and identified a number of subcategories.

3.2.1. Policies and Strategies for Sustainable Energy Transition

This subcategory includes articles that discuss the importance of policies, strategies, and governance in the transition towards renewable energy. Articles in this category emphasize the need for robust and coherent policies, stakeholder engagement, and strategic decision-making frameworks to support the sustainable transition.

Environmental awareness, regulatory frameworks, and energy demand are crucial for the transition to renewal energy through analyzing the energy transition using a multi-level perspective (MLP) that includes workshops with policymakers. Ref. [20] identified the need to dismantle fossil fuel infrastructure and promote geothermal innovations through fiscal incentives and favorable regulations. Refs. [21,22] also highlighted the challenges and opportunities to increase renewable energy through a Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) analysis that examines stakeholders involved in the energy industry, emphasizing the need for robust and coherent policies to attract investments and improve infrastructure. Ref. [23] analyzed the transition trajectory towards a low-carbon electrical system, comparing different scenarios and their technological implications, finding that flexible policies and an integrated approach that considers demand and supply are necessary for a successful transition and reducing emissions.

In this context, ref. [24] analyzed the importance of political dynamics and international relations as a foundation for disseminating and enhancing competitiveness in the business of technologies for renewable energy expansion. To this end, the authors used a comparison approach between the leaders in the market and included supply factors and technological policies. Similarly, ref. [25] employed the Fermatean Fuzzy Set (FFS) to model uncertainty, the Criteria Importance Through Intercriteria Correlation (CRITIC) method to determine criteria weights, and the Complex Proportional Assessment (COPRAS) method for ranking barriers, seeking to identify and prioritize the barriers that hinder the adoption of sustainable practices in clean energy supply chains. They highlighted "limited governmental policies", "monitoring and control issues", and "mismatch of expertise" as the primary obstacles. Using a case study on biofuel production, ref. [26] stressed the importance of a collaborative approach among governments, businesses, and other stakeholders to develop and implement strategies that ensure energy sustainability while promoting economic growth and environmental protection. Ref. [27] evaluated the drivers and barriers of Green Supply Chain Management (GSCM), identifying stakeholder pressure as a key motivator, while the lack of regulations, government support, and customer awareness are significant barriers. Ref. [28] explored the effects of the COVID-19 pandemic on energy investment, revealing the urgent need to reform international investment agreements to incorporate sustainability and human rights principles. This ensures that public policies can adapt to future crises without compromising economic stability or sustainable development goals. Policies and regulations can foster collaborative innovation in the energy sector's innovation, effectively meeting the demands of energy [29].

3.2.2. Risk Management and Decision-Making Tools

Under this subcategory, we have identified articles that focus on evaluating and managing risks within the energy sector, including supply chain and geopolitical risks. This category highlights the use of sophisticated decision-making tools such as fuzzy cognitive maps, multi-regional input–output methodologies, and stochastic programming models:

Decision frameworks that consider the preferences of stakeholders in financial and sustainability matters are essential to ensuring transparency in evaluating projects related to renewable energies while managing uncertainty and improving the evaluation of alternatives; examples include robust frameworks utilizing decision and simulation models [30]. Ref. [31] proposed a multi-objective robust optimization model for addressing uncertainty in prices and demand in order to balance costs, efficiency, and sustainability in the hydrocarbon supply chain. This model provides a reliable framework for resource management under uncertain conditions. Ref. [32] underscored the significance of managing environmental, social, and governance risks in the energy sector, noting the lack of prioritization of these issues among small and new companies.

Using an extended methodology that quantifies the geographical diversification of suppliers and the quality of governance, ref. [33] emphasized the importance of evaluating risk in supply chains and making investment decisions to reduce dependence on fossil fuels. In addition, they considered geopolitical aspects that are often obscured as a way to minimize reliance on countries with different governance systems. Ref. [31] highlighted the importance of considering multiple objectives such as cost minimization, environmental considerations, and uncertainties in the supply chain to assess trade-offs between operational and strategic options under price and demand uncertainty through a stochastic programming model. Ref. [34] analyzed the impact of financial incentive schemes on bioenergy production through a fuzzy multi-objective programming model, highlighting the significant impact on profitability indicators due to changes in incentives. This oversight could lead to the creation of incentives for organizations with sustainable business models.

Variations in government investment in energy research and development (R&D) in OECD countries are influenced by factors such as internal R&D spending and the political orientation of the government, which are essential for fostering the transition to sustainable energy [35] Decision-making tools such as fuzzy cognitive maps become useful as they enable experts and stakeholders to manage the complexity and uncertainty of economic and political factors, which are vital for improving the management of energy supply chains and addressing issues of scarcity [36]. Finally, through a literature review on the modeling of energy systems, ref. [37] proposed a classification based on approach and field of study, highlighting the importance of combining approaches from process systems engineering and energy economics to achieve a comprehensive and effective perspective for the modeling and simulation of energy systems.

3.3. Environmental Management

The environmental management category contains 28% of the articles selected for review. According to [9], this category includes environmental management practices such as standardization and instruments, supply chain activities, and pollution control. We also included financial and marketing in green operations, as there are relevant topics in the energy sector.

An effective supply chain is crucial for the development of the energy sector. Ref. [38] identified political, technical, economic, and management barriers through a literature review and proposed measures such as public–private partnerships, access to financial incentives, and the use of Key Performance Indicators (KPIs) to enhance sustainability. Additionally, ref. [39] provided a literature review on the evolution of logistics practices in the energy sector and the transformation of logistical channels for energy products due to global events, highlighting the need for sustainable logistical practices and the use of digital technologies to enhance the efficiency and resilience of energy supply chains and the importance of international cooperation. Similarly, ref. [40] analyzed the integration of energy resources into supply chain management to improve the environmental and economic performance of companies, highlighting the necessity of transitioning to renewable energies and developing a low carbon supply chain approach. Regarding sustainability certifications, ref. [41] addressed the need to develop harmonized and widely accepted sustainability criteria for the certification of renewable hydrogen, emphasizing the importance of integrating diverse perspectives from professionals in the energy sector to ensure a sustainable energy transition. Similarly, for the assessment of project sustainability, ref. [42] developed a Fuzzy-AHP-based method to evaluate sustainability, identifying the most important lifecycle phases and enhancing evaluation precision and robustness. Ref. [43] used data envelopment analysis to identify effective investment strategies, showing that investment in innovative technologies can improve economic performance and reduce CO_2 emissions. Ref. [44] employed a mixed-integer linear programming model and fuzzy decision techniques to minimize costs and greenhouse gas emissions in the biomass supply chain for clean energy generation, finding that investment and operational costs are the major components of total cost and that energy production impacts emissions more than transportation. Supply chain disruptions significantly affect Return on Assets (ROA) in the renewable energy sector; however, companies can mitigate these effects by reducing expansion and redirecting funds towards research and development (R&D). Additionally, building long-term relationships with suppliers and using advanced technologies can enhance resilience and sustainability [45].

Technological advancements such as big data and artificial intelligence are key to improving sustainability. Ref. [46] used fuzzy inference systems and sustainability indices to provide a decision-making tool for policymakers and businesses. Ref. [47] applied the TOPSI theory and a five-dimensional evaluation system consisting of economy, innovation, environment, coordination, and safety to conclude that strategies such as increased investment in research and development (R&D), promoting clean coal usage, and improving supply chain coordination are required to enhance sustainability. Refs. [48,49] emphasize the need to integrate SCM functions and continuously improve operations management while identifying and mitigating environmental impacts by collaborating with suppliers and business partners to develop carbon reduction strategies.

Ref. [50] developed a scale for measuring green marketing practices, including statistical analyses to ensure reliability, highlighting that implementing green marketing strategies can improve corporate image, stakeholder satisfaction, and business performance. Ref. [51] identified factors such as corporate social responsibility, governmental policies, resource scarcity, and avoiding negative media attention as influential in adopting sustainable supply chain management, thereby providing a guide for implementing sustainable practices in the thermal energy sector.

In terms of financial sustainability and environmental management, ref. [52] highlighted the crucial role played by environmental management and debt financing in enhancing financial sustainability, and proposed policy development to promote financial sustainability through environmental standards, diversification of financing, and governmental support. In the context of integrating sustainability into business models, ref. [53] advocated for the participation of various stakeholders and the combination of bottom-up and top-down decision-making approaches, as well as the active role of the government in setting multiple goals to address conflicting interests and promote sustainable practices. Ref. [54] proposed a framework to involve stakeholders early and continuously to enhance the credibility of sustainability disclosures in the supply chain.

3.4. Innovation

Under this category, we identified 23% of the reviewed articles; the defined topics are related to process improvement, adoption of new technologies and practices, product and service design, and innovation for sustainable business models.

Industry 4.0 has the potential to improve green supply chain management in the renewable energy sector by digitizing and automating industrial processes using technologies such as IoT, blockchain, big data, and artificial intelligence. Implementing smart factories and new technologies can increase efficiency and foster the development of more sustainable products and supply chains [55,56]. Ref. [57] explored how to effectively integrate technologies to improve efficiency, ensure energy security, and promote environmental sustainability; the authors analyzed the current state and trends in the transformation of the energy industry, where a transition to renewable energies is expected as energy demands continue to grow.

Eco-efficiency, digital transformation, and energy transition all impact environmental sustainability. In this regard, ref. [58] used data from the G-15 economies between 1995 and 2022 to highlight that eco-efficiency and digitalization are key to reducing CO_2 emissions, whereas the exploitation of natural resources and energy transition have mixed effects. As such, governmental policies, especially environmental taxes, are crucial for improving environmental outcomes. Similarly, as a consequence of the need for governmental support and strategic policies to foster innovation, ref. [59] proposed creating learning and communication platforms to facilitate knowledge transfer among companies, suppliers, and customers, concluding that innovation consultants, brokerage organizations, and online platforms are essential at different stages of the supply chain. Business models can support sustainable innovation, highlighting the importance of strong relationships with suppliers and customers as well as governmental support to encourage the adoption of sustainable technologies [60].

Investment in technology and sustainable practices is necessary in order to meet customer expectations. Ref. [61] used multi-criteria techniques to analyze innovation strategies in supply chain management, noting that sustainable management can enhance competitiveness and corporate image, although it may involve high costs. For the development of energy technologies such as ocean energy, ref. [62] identified effective multi-criteria decision-making methodologies to improve accuracy and reduce uncertainty. They addressed environmental, social, and economic aspects which can contribute to sustainable and efficient designs. Ref. [63] analyzed how the benefits of Industry 5.0 can address sustainability challenges in the renewable energy supply chain, prioritizing these advantages through fuzzy methods and concluding that advanced technologies can optimize resource use and minimize waste.

For zero waste management in companies, ref. [64] carried out a quantitative approach and regression analysis to examine how the effective implementation of technologies and green supply chains can make a significant contributes to zero waste management while considering the impact of corporate social responsibility intentions. Regarding technological innovation, ref. [65] presented a smart grid architecture that facilitates the integration of renewable energy resources through innovative flexibility markets, improving the operational efficiency of distribution networks and reducing costs through dynamic management and optimal investment strategies. Ref. [66] used an evaluation of bio-energy supply chains to highlight how the implementation of green and proactive sustainable technologies can improve efficiency and reduce environmental impact while offering significant economic and environmental benefits. Similarly, ref. [67] evaluated new photovoltaic technologies that can offer more sustainable options at lower cost. However, these may present environmental challenges, underscoring the need for supportive policies to foster the research and development of cleaner and more efficient solar technologies.

On the other hand, ref. [68] analyzed how the Internet of Things (IoT) and other technologies can create threats in the energy sector's supply chain, identifying the need to implement cybersecurity measures proactively and flexibly. Ref. [69] explored how microgrids and blockchains can enable collective energy communities, thereby improving the integration of decentralized energy resources and the resilience of the energy system. The combination of microgrids and blockchain can address technical, social, and economic challenges, promoting innovation in the transition to sustainable energy supply.

3.5. Social Responsibility

A wide variety of topics are located within the social responsibility cluster, including supplier selection, incentives adopted by buyers, social responsibility practices and their impact, and improvements in the efficiency of non-governmental and nonprofit organizations. This category contained 11% of the articles selected for review

Corporate social responsibility can provide a competitive advantage to energy companies, achieving a greater impact than economic aspects and highlighting the importance of product and service quality, education in the supply chain, and energy security [70]. Through a literature review on supply chain management, ref. [71] emphasized the need to include more social sustainability and improve coordination and communication among stakeholders. Enhancing social sustainability improves corporate reputation and contributes to community development and labor equity. In this context, ref. [72] assessed social issues in the sustainability of energy supply chains in India and the USA through surveys and literature reviews, identifying barriers such as lack of regulations and government support while highlighting the importance of ethical responsibility and the inclusion of marginalized populations. Similarly, ref. [73] used a structural equation model to analyze the impact of sustainable supply chain practices on the competitiveness of companies in the energy sector. They found that operational, social (for employees), and community practices enhance competitiveness, while environmental practices and supply chain integration do not have significant impacts. This highlights the importance of policies that promote sustainable practices and align governmental objectives with those of energy companies. Ref. [74] analyzed another barrier related to the management of green talent, concerning professionals with skills to promote green talents, underscoring the need for strategies and training programs to improve responsible practices and contribute to the achievement of corporate sustainability goals. Ref. [75] reviewed social sustainability indicators in the energy sector, emphasizing their importance in the economic and environmental pillars and the challenges associated with their implementation, with those related to employees being crucial. Ref. [76] analyzed how soft dimensions such as human behavior and organizational culture influence the implementation of sustainability practices in thermal energy supply chains, emphasizing the importance of organizational commitment and the inclusion of sustainability in the vision and mission of companies.

4. Discussion

Our review of recent studies reveals a significant increase in research on sustainable operations management (SOM) in the energy sector over the past 24.5 years. Notably, these studies emphasize decision models that involve various stakeholders to evaluate the adoption of sustainability strategies focused on reducing environmental impact while ensuring operational efficiency and profitability. Additionally, there is a notable concentration of research on adopting green technologies and process optimization, both of which have proven effective in reducing carbon footprints and enhancing market positioning.

4.1. The Evolution of SOM in the Energy Sector

The growing concern around the environmental and social impact of business operations has led social and governmental entities to demand the integration of sustainable practices in industrial operations. Consequently, there is significant interest in understanding and transforming supply chains to meet sustainability demands. In this context, the energy sector serves as a critical example, facing unique challenges in balancing supply demands with sustainable and energy-efficient operations, especially in a context aimed at transitioning to clean energy.

The evolution of sustainable operations management in the energy sector from 2000 to 2024 reflects a dynamic shift in both scientific research and practical applications. This period captures the rise in consumer demand and global policies aimed at adopting sustainable practices to reduce environmental impact. Additionally, it highlights the integration of new technologies to improve efficiency while implementing sustainable practices in industry.

In the early 2000s, the focus on low-carbon economy sought to analyze the adoption of strategies in economic systems in order to reduce emissions, including the implementation of policies and decision-making tools to encourage the integration of sustainable practices. This approach highlighted the adoption of modeling techniques and decision analysis to evaluate different scenarios. On the other hand, advances in environmental management emphasized the need to improve efficiency and standardize processes through the adoption of certifications and their impact on operations, the use of multi-criteria analysis techniques for evaluating and implementing sustainable operations, and a focus on proper resource management to minimize environmental impacts. This laid the foundation for integrating sustainability into energy operations, particularly through the adoption of optimization techniques and mathematical programming.

As the field evolved, especially after 2014, the focus expanded to include Innovation (INN). This shift was driven by global climate policies, consumer demand, and the urgent need to decarbonize energy systems, following the trend of low-emission economies. Research during this period highlighted the importance of reducing carbon footprints and exploring innovative approaches to achieve sustainability goals. An emphasis on Industry 4.0 technologies and their evolving relationship with the efficiency of sustainable energy operations began to take center stage, often being studied through trend analysis and regression analysis. Thus, innovation for sustainable business models gained importance within sustainable operations, revolutionizing sustainable operations management in the energy sector.

In recent years, particularly since 2019, there has been a growing interest in incorporating Closed Loop Supply Chains (CLSC) to reduce waste generation and develop strategies for reintegrating resources into the supply chain once they have completed their lifecycle. In this context, the use of stochastic programming models applied to the design of sustainable supply chains has been particularly noteworthy. More recently, topics related to social responsibility within energy operations have gained greater relevance, particularly the concern to include communities that may be affected by energy operations in decision-making processes and assessments to reduce environmental impacts on nearby communities. Here, tools such as surveys to understand social impacts and quantitative analysis to understand the effects of operations on communities have become prominent.

4.2. The Future of SOM in the Energy Sector

Despite evidence of sustainable operations management in the energy sector, we identified several emerging research areas in the reviewed literature. Many studies highlight the need for public policies, incentives, and investments in research and development (R&D) to encourage the adoption of sustainable practices and facilitate the financial transition to renewable energy [15,20,24,26,29,36,48]. However, several barriers delay progress in this area. These include limited government policies [25] that do not offer consistent support and incentives for sustainable energy investments and monitoring, as well as control issues that hinder the implementation of existing regulations. In addition, financial constraints such as high initial investment costs, inadequate access to funding, and resistance to change from established fossil fuel-based practices further delay the transition. Addressing these barriers through targeted policies and increased R&D investment is critical. With a strong and consolidated infrastructure, Industry 4.0 technologies can spread across companies, enabling automation, increasing productivity, and reducing costs [77]. This will also improve transparent measurement and reporting of environmental impacts and help to establish robust and consistent standards for sustainability monitoring across companies and sectors.

The development of Industry 4.0 technologies has enabled significant advancements in the energy sector through the adoption of data analytics for real-time monitoring of energy consumption, which in turn facilitates improvements in energy distribution via smart grids and storage systems. Likewise, blockchain technologies enable real-time energy management, enhance energy distribution, and ensure secure transactions [55]. However, there remains a critical need to integrate these technologies into renewable energy sources such as solar and wind in order to enhance the efficiency and reliability of these systems. These advancements would allow such systems to meet demand more effectively and reduce energy waste, which are key factors for optimizing energy operations.

On the other hand, there is an urgent need to explore innovations in sustainable energy storage, particularly concerning the sourcing of materials for battery production, emphasizing the importance of addressing the operational and logistical challenges associated with sustainably sourcing the materials needed for energy distribution and storage. Moreover, it is essential to ensure the sustainability of these products throughout their lifecycle. In this regard, the Closed Loop Supply Chain (CLSC) concept emerges as an important topic in the literature on sustainable operations management, contributing to the return of resources to the supply chain. However, this area remains underexplored in the energy sector. Addressing these issues would contribute to more sustainable energy solutions and the development of a circular economy by identifying technological advancements and exploring strategies for managing materials such as solar panels, wind turbine blades, and lithium batteries at the end of their lifecycles [60].

Similarly, Social Responsibility (SR) has gained importance in research by highlighting the energy sector's shortcomings in integrating social aspects into its operations, a factor that is becoming increasingly important due to companies' relationships with communities. Most research in this area has focused on job creation, human talent in the renewable energy sector, employee relations, and their impact on companies [74,76]. However, there is a notable gap in studies examining relationships with external stakeholders and the impact of energy supply chains on local communities. Addressing this gap is essential for a holistic approach to sustainable energy operations management.

For policymakers, it is crucial to develop comprehensive policies that provide financial incentives for Low Carbon Economies (LCE), such as subsidies or tax breaks, as a means to lower barriers to investment in sustainable technologies. Clear regulations and standards are also necessary to guide companies in measuring, reporting, and improving their environmental impacts consistently. Additionally, it is recommended to explore how sustainable supply chains integrating environmental, economic, and social factors can be strengthened and how companies can collaborate to address environmental challenges through joint initiatives via supply chains involving different stakeholders. The reviewed literature on Environmental Management (EM) emphasizes the importance of public–private partnerships, the use of standardized practice and Key Performance Indicators (KPIs) to improve sustainability, and the need for widely accepted criteria for sustainability certification in renewable energies such as hydrogen. Collaboration between stakeholders, including government, businesses, and research institutions, is essential to foster knowledge sharing and address the challenges in implementing sustainable practices effectively.

5. Conclusions

This study provides a comprehensive review of the literature on Sustainable Operations Management (SOM) in the energy sector from 2000 to 2024, highlighting significant advances in adopting practices and technologies to reduce carbon emissions and environmental impacts. Key findings include the evolution of SOM, from an initial focus on low-carbon economies and environmental management to integrating advanced technologies such as Industry 4.0 and closed-loop supply chains. However, several gaps remain, particularly the lack of empirical studies on the practical implementation of Industry 4.0 technologies such as AI and the IoT in sustainable operations management. While these technologies have shown great potential for optimizing efficiency and sustainability in the energy sector, the current literature lacks studies that assess their practical implementation and associated challenges.

Another important gap is related to the social impacts of sustainable practices in the energy sector, particularly concerning Corporate Social Responsibility (CSR) and social justice. Most studies focus on environmental and economic aspects, overlooking analysis of how sustainable practices affect local communities and workers. This limited approach may hinder a comprehensive understanding of sustainability in the sector.

The implications of these gaps are significant for the broader field of sustainable operations management. The lack of empirical research on the applications of advanced technologies may limit the development of robust theoretical frameworks and practical guidelines for implementation. Moreover, the lack of attention to the social aspects of sustainability could result in policies and practices that do not adequately address the needs of all stakeholders, potentially reducing the effectiveness and acceptance of sustainable initiatives.

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Appendix A

In this appendix, a summary of the 64 articles selected for the review is presented, distributed in Tables A1–A3. It provides an overview of the reviewed literature, including the title of each article, the methodology used, the main findings, and the cluster to which it belongs.

Table A1. Papers selected for the literature review, Part 1.

Authors	Title	Methodology	Findings	Clusters
Vavatsikos, A. P., Tsesmetzis, E., Koulinas, G., & Koulouriotis, D.	A robust group decision making framework using fuzzy TOPSIS and Monte Carlo simulation for wind energy projects multicriteria evaluation	Fuzzy extension of the TOPSIS method with Monte Carlo simulation	Evaluates and ranks wind energy projects, ensuring robustness by examining a range of potential outcomes	Low Carbon Economy (LCE)
Haiyun, C., Zhi1iong, H., Yüksel, S., & Dinçer, H.	Analysis of the innovation strategies for green supply chain management in the energy industry using the QFD-based hybrid interval valued intuitionistic fuzzy decision approach	Hybrid decision-making approach integrating QFD (Quality Function Deployment) with interval-valued intuitionistic fuzzy (IVIF) DEMATEL and IVIF MOORA methods	Identifies effective customer relationship management and technological investments as the most impactful innovation strategies, enabling energy companies to enhance market share and competitiveness	Innovation (INN)
Cader, J., Koneczna, R., & Smol, M.	Corporate social responsibility as a significant factor of competitive advantage-a case study of energy companies in Poland	Survey-based approach. It utilizes Corporate Social responsibility indicators across social, economic, and environmental dimensions, selected through expert evaluation and statistical analysis.	Social CSR indicators, particularly those related to supplier relationships and education, have the highest impact on competitive advantage, followed by environmental factors such as energy security and efficiency	Social Responsibility (SR)
Papageorgiou, K., Carvalho, G., Papageorgiou, E. I., Bochtis, D., & Stamoulis, G.	Decision-Making Process for Photovoltaic Solar Energy Sector Development using Fuzzy Cognitive Map Technique	Fuzzy Cognitive Maps (FCMs) constructed using input from experts and stakeholders	Economic and political factors, particularly government incentives and energy prices, play a crucial role in the development of the photovoltaic solar energy sector	Low Carbon Economy (LCE)

Table A1. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Xu, X. L., & Chen, H. H.	Exploring the relationships between environmental management and financial sustainability in the energy industry: Linear and nonlinear effects	Uses a mediation model and threshold effect model to explore the relationship between environmental management It employs least squares dummy variable (LSDV) and two-stage least squares (TSLS) methods, along with a system generalized method of moments (GMM).	Environmental management positively impacts financial sustainabilit. The relationship between debt financing and financial sustainability exhibits a nonlinear threshold effect, where higher levels of environmental management amplify the positive impact of debt financing on financial sustainability	Environmental Management (EM)
Gardas, B. B., Mangla, S. K., Raut, R. D., Narkhede, B., & Luthra, S.	Green talent management to unlock sustainability in the oil and gas sector	The study employs Total Interpretive Structural Modeling (TISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify and analyze barriers to sustainable human resource management with a focus on green talent management	The most significant barriers include uncertain career growth, industry dynamism, and a lack of training programs. These barriers strongly influence the sustainability of human resources.	Social Responsibility (SR)
Zioło, M., Bąk, I., & Spoz, A.	Incorporating ESG Risk in Companies' Business Models: State of Research and Energy Sector Case Studies	Employs a systematic literature review combined with statistical analysis to examine how companies in the energy sector incorporate ESG (Environmental, Social, and Governance) risks into their business models.	Identifies that large and medium-sized enterprises, particularly in developed regions, frequently integrate ESG risk management into their business models. It highlights regional differences, with developed countries prioritizing ESG in decision-making and sustainable business strategies, whereas developing countries focus more on sustainable supply chains	Low Carbon Economy (LCE)

Table A1. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Ghobakhloo, M., & Fathi, M.	Industry 4.0 and opportunities for energy sustainability	Uses Interpretive Structural Modeling (ISM) and MICMAC analysis to explore how Industry 4.0 technologies contribute to energy sustainability.	Identifies ten key functions through which Industry 4.0 promotes energy sustainability, such as energy sector digital transformation, improved production methods, and smart energy management systems.	Innovation (INN)
Mastrocinque, E., Ramírez, F. J., Honrubia-Escribano, A., & Pham, D. T.	Industry 4.0 enabling sustainable supply chain development in the renewable energy sector: A multi-criteria intelligent approach	Uses a multi-criteria decision-making (MCDM) approach incorporating Fuzzy Inference Systems and Industry 4.0 technologies to assess the social, economic, and environmental sustainability of photovoltaic (PV) supply chains.	Industry 4.0 technologies, particularly big data and cloud computing, significantly enhance the environmental sustainability of PV supply chains. Social and economic sustainability also improve, though to a lesser extent.	Environmental Management (EM)
Subtil Lacerda, J., & Van den Bergh, J. C.	International Diffusion of Renewable Energy Innovations: Lessons from the Lead Markets for Wind Power in China, Germany and USA	Uses a comparative analysis of the lead market framework, focusing on the international diffusion of wind power technologies in China, Germany, and the USA	Identifies that lead markets for wind power are influenced by a combination of domestic demand, policy support, and technological capabilities.	Low Carbon Economy (LCE)
Dobrowolski, Z.	Internet of Things and Other E-Solutions in Supply Chain Management May Generate Threats in the Energy Sector-The Quest for Preventive Measures	Uses a narrative summary combined with literature searching to identify potential threats associated with IoT and e-solutions in supply chain management within the energy sector	Identifies that IoT and Big Data pose significant risks, including cyberattacks and data privacy issues, which can disrupt energy supplies and compromise security.	Innovation (INN)
Hasheminasab, H., Gholipour, Y., Kharrazi, M., & Streimikiene, D.	Life cycle approach in sustainability assessment for petroleum refinery projects with fuzzy-AHP	Utilizes a life cycle approach combined with Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) to assess sustainability in petroleum refinery projects	Identifies the operation phase as the most critical stage for environmental and economic sustainability, while the construction phase is key for social concerns. Key sustainability indicators include education, atmosphere, and financial aspects, emphasizing the need to focus on specific high-impact areas during each project phase	Environmental Management (EM)

Table A1. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Vilkaite-Vaitone, N., Skackauskiene, I., & Díaz-Meneses, G.	Measuring Green Marketing: Scale Development and Validation	Develops and validates the Green Marketing Scale (GMaS) through a multi-step process, including exploratory factor analysis (EFA) and confirmatory factor analysis (CFA).	Validated 14-item GMaS identifies four key dimensions of green marketing: Strategy, Internal Marketing, Product, and Marketing Communication. The scale effectively measures green marketing practices, emphasizing its utility for organizations in assessing their green marketing efforts and identifying strengths and weaknesses	Environmental Management (EM)

Table A2. Papers selected for the literature review, Part 2.

Authors	Title	Methodology	Findings	Clusters
Subramanian, A. S. R., Gundersen, T., & Adams, T. A.	Modeling and Simulation of Energy Systems: A Review	The review categorizes energy system models into computational, mathematical, and physical models. It combines Process Systems Engineering (PSE) and Energy Economics (EE) approaches to analyze energy systems,	The study finds that integrating PSE and EE models provides a more comprehensive understanding of energy systems.	Low Carbon Economy (LCE)
Jelti, F., Allouhi, A., Büker, M. S., Saadani, R., & Jamil, A.	Renewable Power Generation: A Supply Chain Perspective	Conducts a systematic literature review of renewable power generation from a supply chain perspective.	Identifies technical, economic, regulatory, and managerial barriers that hinder renewable energy supply chains	Environmental Management (EM)
Widya Yudha, S., & Tjahjono, B.	Stakeholder Mapping and Analysis of the Renewable Energy Industry in Indonesia	Uses a PESTLE analysis to map and analyze stakeholders in Indonesia's renewable energy sector. It examines Political, Economic, Social, Technological, Legal, and Environmental factors	The study finds that Indonesia's renewable energy sector faces challenges due to inadequate policies, economic barriers, and technological limitations.	Low Carbon Economy (LCE)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Barton, J., Davies, L., Dooley, B., Fo1on, T. J., Galloway, S., Hammond, G. P., & Thomson, M.	Transition pathways for a UK low-carbon electricity system: Comparing scenarios and technology implications	Uses scenario analysis to compare three transition pathways for the UK's low-carbon electricity system by 2050. It combines stakeholder workshops, narrative storylines, and technical modeling to assess different governance approaches	It finds that different governance models lead to varying outcomes in electricity demand, generation capacity, and carbon reduction. The "Market Rules" pathway sees higher demand and more centralized generation, while the "Thousand Flowers" pathway, driven by community initiatives, achieves lower demand and greater use of decentralized renewable sources	Low Carbon Economy (LCE)
García-Orozco, S., Vargas-Gutiérrez, G., Ordóñez-Sánchez, S., & Silva, R.	Using Multi-Criteria Decision Making in Quality Function Deployment for Offshore Renewable Energies	Integrates Multi-Criteria Decision Making (MCDM) methods such as AHP, TOPSIS, and DEMATEL with Quality Function Deployment (QFD) to evaluate and prioritize customer and technical requirements for offshore renewable energy technologies.	The integration of MCDM methods in QFD improves decision-making in the offshore renewable energy sector by accurately ranking customer needs and technical specifications.	Innovation (INN)
Attia, A. M.	A multi-objective robust optimization model for upstream hydrocarbon supply chain	Uses a multi-objective robust optimization model to manage the upstream hydrocarbon supply chain under market uncertainties.	The model provides a robust plan that maximizes cash inflow and minimizes total costs while managing the depletion rate of resources. The robust approach outperforms deterministic, stochastic, and risk-based models, showing better adaptability to market volatility	Low Carbon Economy (LCE)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Biswal, J. N., Muduli, K., Satapathy, S., & Yadav, D. K.	A TISM based study of SSCM enablers: an Indian coal- fired thermal power plant perspective	Uses Total Interpretive Structural Modeling (TISM) to identify and analyze enablers for Sustainable Supply Chain Management (SSCM) in Indian coal-fired thermal power plants.	Key enablers such as "Government policies," "Corporate social responsibilities," "Resource scarcity," and "Avoiding negative media attention" drive SSCM adoption. Factors such as "Establishment of green image" have less influence. The model helps decision-makers prioritize actions to enhance sustainability	Environmental Management (EM)
Smith, A. D.	Alternative energy supply chain management issues: Wind generation considerations in Ohio	The study uses a qualitative case study approach to examine supply chain management (SCM) issues related to wind power generation	The study finds that supportive policies, a strong manufacturing base, and strategic investments are crucial for developing Ohio's wind energy supply chain.	Environmental Management (EM)
Muduli, K., Kusi-Sarpong, S., Yadav, D. K., Gupta, H., & Jabbour, C. J. C.	An original assessment of the influence of soft dimensions on implementation of sustainability practices: implications for the thermal energy sector in fast growing economies	Uses Interpretive Structural Modeling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL) to analyze the influence of soft dimensions (such as management commitment) on sustainability practices	The study identifies "Commitment to SSCM" and "Inclusion in Vision and Mission" as the most influential factors for implementing sustainable practices. Understanding these soft dimensions helps improve decision-making sustainability performance	Social Responsibility (SR)
Gamarra, A. R., Lechón, Y., Escribano, G., Lilliestam, J., Lázaro, L., & Caldés, N.	Assessing dependence and governance as value chain risks: Natural Gas versus Concentrated Solar power plants in Mexico	Extends the Multi-Regional Input-Output (MRIO) model to assess import dependence and governance risks in the value chains of natural gas (NG) and concentrated solar power (CSP) plants in Mexico.	The CSP plant supply chain is more diversified and includes countries with better governance than the NG plant, implying lower geopolitical risks. However, sensitivity analysis shows that if CSP components are sourced from China, governance risks may exceed those of the NG plant.	Low Carbon Economy (LCE)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Aziz, N. I. H. A., Hanafiah, M. M., Gheewala, S. H., & Ismail, H.	Bioenergy for a cleaner future: A case study of sustainable biogas supply chain in the Malaysian Energy Sector	Uses a Life Cycle Assessment (LCA) framework to evaluate the environmental sustainability of biogas production	The study finds that biogas production with zero discharge treatment is environmentally sustainable, utilizing organic waste efficiently and achieving zero effluent discharge.	Innovation (INN)
Duggal, K., Rangachari, R., & Gupta, K.	Consequences of crisis and the great re-think: COVID-19's impact on energy investment sustainability and the future of international investment agreements	Reviews the impact of the COVID-19 pandemic on energy investments, sustainability, and international investment agreements (IIAs). It analyzes recent IIAs from 2019–202	The pandemic caused significant disruptions in the energy sector, leading to reduced energy demand, investment decline, and regulatory challenges. It highlighted the need for reforming IIAs to incorporate sustainable development and human rights principles	Low Carbon Economy (LCE)
Masoomi, B., Sahebi, I. G., Ghobakhloo, M., & Mosayebi, A.	Do industry 5.0 advantages address the sustainable development challenges of the renewable energy supply chain?	Uses a hybrid Fuzzy Best-Worst Method (FBWM) and Fuzzy Weighted Aggregated Sum Product Assessment (FWASPAS) technique to evaluate the advantages of Industry 5.0 in addressing sustainability challenges	The study finds that the most critical challenges are "non-consideration of human factors," "inadequate regulation," and "management's lack of commitment to sustainability." Key Industry 5.0 advantages include "supply chain modularity," "research and innovation in social and human problems," and "hyper-connected networks,".	Innovation (INN)
Sun, I., & Kim, S. Y.	Energy R & D towards sustainability: A panel analysis of government budget for energy R & D in OECD countries (1974-2012)	Uses panel data analysis to examine government budgets for energy R&D in 34 OECD countries from 1974 to 2012	Higher overall R&D spending and right-leaning governments increase energy R&D budgets, while refinery output increases general energy R&D but decreases renewable energy R&D.	Low Carbon Economy (LCE)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Halldorsson, A., & Svanberg, M.	Energy resources: Trajectories for supply chain management	Uses a conceptual framework to understand how SCM principles can enhance the use and accessibility of energy resources, especially in transitioning to renewable energy	Effective SCM can improve energy efficiency and reduce carbon emissions by optimizing the supply chain from raw material sourcing to end-user delivery	Environmental Management (EM)
Efthymiopoulos, N., Makris, P., Tsaousoglou, G., Steriotis, K., Vergados, D. J., Khaksari, A., & Varvarigos, E.	FLEXGRID – A novel smart grid architecture that facilitates high-RES penetration through innovative flexibility markets towards efficient stakeholder interaction	Uses a novel smart grid architecture with innovative flexibility markets to enable high penetration of renewable energy sources	Demonstrates that the new architecture improves market efficiency and stakeholder coordination. It enhances the flexibility of market operations, and reduces grid management costs, thereby facilitating a sustainable, competitive, and secure energy ecosystem	Innovation (INN)
Lundie, S., Wiedmann, T., Welzel, M., & Busch, T.	Global supply chains hotspots of a wind energy company	Uses a multi-regional input-output (MRIO) analysis to assess the global supply chain impacts of a wind energy company.	The analysis reveals that the majority of greenhouse gas emissions come from suppliers in sectors such as electricity, metal, and concrete. The study shows that focusing on these supply chain tiers can significantly reduce the overall carbon footprint and improve sustainability performance for wind energy projects	Environmental Management (EM)
Annunziata, E., Rizzi, F., & Frey, M.	How do firms interpret extended responsibilities for a sustainable supply chain management of innovative technologies? An analysis of corporate sustainability reports in the energy sector	The study uses content analysis of 172 corporate sustainability reports from 16 European energy utilities to examine how companies interpret extended responsibilities for sustainable supply chain management,	The analysis reveals that while some companies mention initiatives for LIBs management, most are not committed to comprehensive end-of-life practices. There is a lack of long-term strategies and stable partnerships, indicating that LIBs end-of-life management is not yet a priority in their sustainability efforts	Closed Loop Supply Chains (CLSC)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Balaman, Ş. Y., Scott, J., Matopoulos, A., & Wright, D. G.	Incentivizing bio-energy production: Economic and environmental insights from a regional optimization methodology	The study uses a fuzzy multi-objective optimization model to analyze the economic and environmental impacts of different incentive schemes for bio-energy production.	Changes in incentive schemes significantly affect the profitability of the bio-energy supply chain, with RoC (Renewables Obligation Certificate) having the largest impact. Environmental performance, measured by GHG emissions, is least affected by incentive changes	Low Carbon Economy (LCE)
Balaman, Ş. Y.	Investment planning and strategic management of sustainable systems for clean power generation: An ϵ-constraint based multi objective modeling approach	Uses an ϵ-constraint based multi-objective modeling approach combined with fuzzy decision-making to optimize investment planning and strategic management for clean power generation systems.	The model identifies optimal supply chain configurations that balance costs and greenhouse gas emissions. It demonstrates that strategic decisions on location, capacity, and technology significantly impact both economic and environmental performance	Environmental Management (EM)
Yassin, A. M. M., Hassan, M. A., & Elmesmary, H. M.	Key elements of green supply chain management drivers and barriers empirical study of solar energy companies in South Egypt	Uses a mixed-method approach combining qualitative and quantitative research strategies.	The most significant drivers for Green Supply Chain Management are normative drivers such as stakeholder pressure, while the major barriers include lack of government regulations, poor supplier commitment, and lack of awareness of sustainable products.	Low Carbon Economy (LCE)
Matos, S., & Silvestre, B. S.	Managing stakeholder relations when developing sustainable business models: The case of the Brazilian energy sector	Uses case studies. It includes interviews with informants and a review of relevant literature on sustainable supply chains, and stakeholder theory.	Effective stakeholder management requires diverse local stakeholder engagement, fostering learning and capability building, and encouraging stakeholders to shift from single to multiple objectives. Combining these strategies helps overcome challenges of conflicting stakeholder interests and promotes sustainable practices	Environmental Management (EM)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Attia, A. M., Ghaithan, A. M., & Duffuaa, S. O.	Multi-Objective optimization of the Hydrocarbon supply chain under price and demand uncertainty	Develops a stochastic multi-objective optimization model for the hydrocarbon supply chain under price and demand uncertainty. It uses a two-stage stochastic programming approach to optimize cost	The model helps decision-makers balance production levels to meet demand while maintaining reserves. Sensitivity analysis shows that production can be reduced during high-demand periods to conserve reserves, with excess demand met through external contracts.	Low Carbon Economy (LCE)
Hecht, A. D., & Miller, C. A.	Perspectives on achieving sustainable energy production and use	The study reviews policies, strategies, and practices needed to achieve sustainable energy production and use.	The research highlights that achieving sustainable energy production requires coordinated efforts across government, industry, and science. Key areas such as biofuel production demonstrate how integrated approaches combining policy, technology, and business strategies can lead to more sustainable energy systems	Low Carbon Economy (LCE)
Rehme, J., Nordigården, D., & Chicksand, D.	Public policy and electrical-grid sector innovation	The study uses in-depth multiple case studies of grid companies, suppliers, and other actors in the business network. It is based on 55 interviews across different companies and sectors.	Initially, collaborative innovation led to strong technological advancements focused on product quality. However, deregulation shifted the focus to cost efficiency, reducing innovation. The study suggests that policymakers need to foster collaboration and incorporate sustainability into grid development to enhance innovation and meet future energy demands.	Low Carbon Economy (LCE)
Nair, P. U., & Thankamony, P.	Social issues in supply chain sustainability – focus areas for energy and manufacturing sectors in India and USA	The study uses a systematic literature review (SLR) and a questionnaire survey to identify social issues in the supply chains of the energy and manufacturing sectors in India and the USA.	The study finds that social sustainability is less researched compared to economic and environmental dimensions. Key social issues identified include child labor, gender discrimination, and worker rights.	Social Responsibility (SR)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Chen, H. H., Lee, A. H., & Chen, S.	Strategic policy to select suitable intermediaries for innovation to promote PV solar energy industry in China	The study employs a mixed-method approach involving hypothesis development, data collection through questionnaires, and multivariate analysis (factor analysis and cluster analysis)	The study identifies different intermediaries for each supply chain stage: systemic instruments for higher-level support at the conceptual stage, brokerage organizations for peer networks at the development stage, and innovation consultants for collectives of entrepreneurs at the production stage.	Innovation (INN)
Dudin, M. N., Frolova, E. E., Protopopova, O. V., Mamedov, O., & Odintsov, S. V.	Study of innovative technologies in the energy industry: Nontraditional and renewable energy sources	Uses content, analytical, statistical, and functional research methods to explore trends and issues in the global energy market	Innovative technologies and a shift toward renewable energy sources will lead to an increase in energy efficiency and sustainability. However, a complete transition will take decades, requiring significant investment in infrastructure and technological advancements, particularly in smart grid technologies	Innovation (INN)
Medina-González, S., Graells, M., Guillén-Gosálbez, G., Espuña, A., & Puigjaner, L.	Systematic approach for the design of sustainable supply chains under quality uncertainty	Uses a multi-objective optimization model based on a State Task Network (STN) formulation under uncertainty to design sustainable supply chains. It employs the Sample Average Approximation (SAA) algorithm for optimization and the ELECTRE-IV method for solution selection.	The model helps in optimizing supply chains by balancing economic, environmental, and social objectives. It shows that accounting for material quality variability and uncertainty leads to more robust and sustainable supply chain designs, effectively reducing costs and environmental impacts while enhancing social benefits	Environmental Management (EM)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Ahmad, W. N. K. W., Rezaei, J., de Brito, M. P., & Tavasszy, L. A.	The influence of external factors on supply chain sustainability goals of the oil and gas industry	The study uses multiple regression analysis to explore the relationship between six external factors (political stability, economic stability, stakeholder pressure, competition, energy transition, and regulations) and supply chain sustainability goals in the oil and gas industry.	Stakeholder pressure and economic stability are the most influential factors affecting sustainability goals. While competition within the oil and gas industry positively impacts operational goals, competition from the broader energy sector negatively affects strategic sustainability goals.	Low Carbon Economy (LCE)
Okongwu, U., Morimoto, R., & Lauras, M.	The maturity of supply chain sustainability disclosure from a continuous improvement perspective	Uses content analysis and principal component analysis (PCA) to assess the maturity levels of supply chain sustainability (SCS) disclosure across different industries.	The study finds that business-to-consumer industries have higher disclosure maturity in social and environmental dimensions than business-to-business industries. The energy sector shows the lowest maturity in SCS disclosure.	Environmental Management (EM)
Annunziata, E., Rizzi, F., & Frey, M.	The supporting role of business models in the promotion of sustainable innovations in the energy sector: an explorative study in the Italian SMEs	Uses an exploratory multiple case study of 8 SMEs in the Italian geothermal heat pump (GHP) market. Data were collected through semi-structured interviews and document analysis.	Sustainable business models help SMEs to support sustainable innovation by providing ongoing customer support, promoting environmental benefits, and leveraging strong stakeholder relationship	Innovation (INN)
Hmouda, A. M., Orzes, G., & Sauer, P. C.	Sustainable supply chain management in energy production: A literature review	The study uses a systematic literature review and content analysis	The review highlights a bias towards biomass in SSCM research and a lack of studies on other energy sources. Key gaps include the under-representation of inter-organizational coordination and social sustainability.	Social Responsibility (SR)

Table A2. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Ibn-Mohammed, T., Koh, S. C. L., Reaney, I. M., Acquaye, A., Schileo, G., Mustapha, K. B., & Greenough, R.	Perovskite solar cells: An integrated hybrid lifecycle assessment and review in comparison with other photovoltaic technologies	Uses an integrated hybrid Life Cycle Assessment (LCA) to evaluate the environmental impact of Perovskite solar cells (PSCs) compared to other photovoltaic (PV) technologies.	The analysis shows that PSCs have a lower energy payback period and offer a more sustainable option compared to other PV technologies. However, the presence of toxic lead compounds in PSCs raises significant environmental concerns, particularly in terms of end-of-life management and potential hazards during production	Innovation (INN)
Afshari, H., Agnihotri, S., Searcy, C., & Jaber, M. Y.	Social sustainability indicators: A comprehensive review with application in the energy sector	The study conducts a comprehensive review of social sustainability indicators (SSIs) from various sectors and categorizes them for application in the energy sector. It uses a structured review approach to analyze and classify SSIs.	The study finds that most SSIs focus on the "production" and "demand" stages of the energy supply chain. Indicators related to employees are common, emphasizing the importance of internal stakeholders. It reveals a lack of consensus on SSI definitions and measurements, highlighting challenges in implementation and the need for standardized approaches in energy	Social Responsibility (SR)
Wu, Y., Wu, Y., Cimen, H., Vasquez, J. C., & Guerrero, J. M.	Towards collective energy Community: Potential roles of microgrid and blockchain to go beyond P2P energy trading	It employs a comprehensive review of research, applications, and pilot projects to analyze the integration of microgrid control systems with blockchain-based communication frameworks.	The combination of microgrid and blockchain enhances the flexibility, resilience, and scalability of decentralized energy systems. Microgrids provide local control and energy optimization, while blockchain facilitates secure, transparent, and automated energy transactions across communities.	Innovation (INN)

Table A3. Papers selected for the literature review, Part 3.

Authors	Title	Methodology	Findings	Clusters
Generalov, O.	Analysis of modern trends and opportunities in the logistics channels of energy products producers	Uses a comprehensive review of current literature, industry reports, and case studies to analyze the trends and opportunities in logistics for energy producers.	The research highlights the shift towards sustainable and diversified energy supply chains, driven by digitalization and green logistics. It emphasizes the need for strategic international cooperation, investment in technology, and sustainable practices	Environmental Management (EM)
Krishankumar, R.; Ramanujam, N.; Gandomi, A.H.	Ranking Barriers Impeding Sustainability Adoption in Clean Energy Supply Chains: A Hybrid Framework With Fermatean Fuzzy Data	Employs a hybrid framework integrating Fermatean fuzzy sets, the CRITIC method, and COPRAS for prioritizing barriers to sustainability. It uses variance-based criteria importance to determine weights and applies a complex proportional assessment-Copeland method for ranking barriers.	The top criteria influencing sustainability are wastage/pollution reduction and profit from green production. The major barriers identified are limited governmental policies, monitoring/control issues, and expertise mismatch, which significantly impede sustainability adoption.	Low Carbon Economy (LCE)
AlKhars, M., Masoud, M., AlNasser, A., Alsubaie, M.	Sustainable practices and firm competitiveness: an empirical analysis of the Saudi Arabian energy sector	Uses Structural Equation Modeling (SEM) to analyze the impact of sustainable supply chain management (SSCM) practices on the competitiveness.	It reveals that social practices for employees (SPE), social practices for the community (SPC), and operational practices (OP) significantly enhance firm competitiveness. However, environmental management practices (EMP) and supply chain integration (SCI) do not show a significant impact on competitiveness in this context	Social Responsibility (SR)

Table A3. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Goodwin, D.,Gale, F., Lovell, H.,Murphy, H., Schoen, M.	Sustainability certification for renewable hydrogen: An international survey of energy professionals	Uses an international survey of professionals. It employs mixed methods, combining quantitative data analysis (non-parametric statistics) with qualitative insights from open-text responses.	The study identifies broad agreement on including diverse sustainability criteria in certification schemes, with variations in perceived essentiality among different stakeholders. Respondents favor harmonization of certification standards but are concerned about risks of duplication and complex procedures.	Environmental Management (EM)
Li, B.	Leading role of natural resources, eco-efficiency assessment, and energy transition in environmental sustainability: A depth of digital transformation	Uses panel data analysis of 15 G-15 economies from 1995 to 2022. It employs econometric techniques such as unit root tests, cointegration tests, and panel quantile regression for robustness.	Digital transformation and eco-efficiency are critical for reducing carbon emissions and achieving carbon neutrality. However, natural resource exploitation and energy transition in some economies worsen environmental quality and increase CO_2 emissions.	Innovation (INN)
Pender, K.,Romoli, F.,Fuller, J.	Lifecycle Assessment of Strategies for Decarbonising Wind Blade Recycling toward Net Zero 2050 †	Uses a Lifecycle Assessment (LCA) approach to evaluate the carbon footprint of various recycling strategies for wind turbine blade	Mechanical recycling of WTB waste is most effective in minimizing Global Warming Potential (GWP) in the short to medium term. Beyond 2040, carbon fiber recycling becomes critical to reduce GWP as the composition of WTB waste evolves.	Closed Loop Supply Chains (CLSC)
Yu, J.	Factors Affecting Return on Assets in the Renewable Energy Sector during Supply Chain Disruptions	Uses a within-between random model to examine the impact of financial ratios on Return on Assets (ROA) in the renewable energy sector	Higher R&D expenses positively affect ROA during disruptions, while higher current ratios, fixed assets to total assets ratios, and growth negatively impact ROA. The study suggests renewable energy firms should focus on R&D and be cautious with expansion during supply chain disruptions to maintain profitability	Environmental Management (EM)

Table A3. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Giri, B. K., & Roy, S. K.	Fuzzy-random robust flexible programming on sustainable closed-loop renewable energy supply chain	Proposes a multi-objective mixed-integer programming (MOMIP) model using fuzzy-random robust flexible programming to design a sustainable closed-loop renewable energy supply chain.	The model optimizes the supply chain network by selecting suitable locations for solar production facilities and power plants in India. Sensitivity analysis shows that reducing air pollution constraints increases aggregate costs, highlighting the trade-offs between economic and environmental goals in renewable energy supply chains	Closed Loop Supply Chains (CLSC)
Le Luu, Q., Longo, S., Cellura, M., Sanseverino, E. R., Cusenza, M. A., & Franzitta, V.	A Conceptual Review on Using Consequential Life Cycle Assessment Methodology for the Energy Sector	The study conducts a conceptual review of the Consequential Life Cycle Assessment (CLCA) methodology for the energy sector.	Identifies that combining economic models (especially equilibrium models) with environmental data is effective for CLCA in the energy sector	Closed Loop Supply Chains (CLSC)
Ghazanfari, A.	An Analysis of Circular Economy Literature at the Macro Level, with a Particular Focus on Energy Markets	Conducts a systematic literature review to analyze the adoption of Circular Economy (CE) strategies in global energy markets.	The study finds that CE is essential for achieving sustainable development in energy markets by reducing waste and maximizing resource efficiency. It identifies economic, technical, and regulatory barriers to CE adoption and recommends policy frameworks, financial incentives, and technological advancements to overcome these challenges	Closed Loop Supply Chains (CLSC)
Labaran, M. J., & Masood, T.	Industry 4.0 Driven Green Supply Chain Management in Renewable Energy Sector: A Critical Systematic Literature Review	Conducts a critical systematic literature review of 215 papers from 2004 to 2023	The study emphasizes the need for integrating digital technologies to enhance Green Supply Chain Management practices in renewable energy	Innovation (INN)

Table A3. *Cont.*

Authors	Title	Methodology	Findings	Clusters
Sueyoshi, T., & Wang, D.	Radial and non-radial approaches for environmental assessment by Data Envelopment Analysis: Corporate sustainability and effective investment for technology innovation	Employs Data Envelopment Analysis (DEA) with radial and non-radial approaches to assess environmental and operational performance in the energy sector.	The analysis shows that green investments in the U.S. energy sector enhance unified performance when measured by operational metrics such as ROA (Return on Assets) and CO_2 emission reductions. However, the impact on corporate value, such as stock price, is limited, indicating that green investments improve operational performance more than market valuation	Environmental Management (EM)
Ma, J., Yuan, Y., Zhao, S., & Wu, W.	Research on Sustainability Evaluation of China's Coal Supply Chain from the Perspective of Dual Circulation New Development Pattern	Uses multi-granularity unbalanced decision-making and the TOPSIS method to develop a sustainability evaluation	The research identifies innovation and economic development as the most critical dimensions for enhancing the sustainability of China's coal supply chain.	Environmental Management (EM)
Yudha, S. W., Tjahjono, B., & Longhurst, P.	Sustainable Transition from Fossil Fuel to Geothermal Energy: A Multi-Level Perspective Approach	Employs a Multi-Level Perspective (MLP) framework combined with qualitative data collection	Identifies key factors driving the energy transition, such as energy demand, environmental awareness, energy regulations, and supply chain considerations. It emphasizes the need for government intervention, financial incentives, regulatory support, and technological innovation	Low Carbon Economy (LCE)
Nassani, A. A., Hussain, H., Condrea, E., Grigorescu, A., Yousaf, Z., & Haffar, M.	Zero Waste Management: Investigation of Green Technology, the Green Supply Chain, and the Moderating Role of CSR Intentions	Uses a quantitative research design involving regression analysis, correlation, and structural equation modeling (SEM) to examine the relationships between green technology, green supply chain, CSR intentions, and zero waste management.	The results indicate that green technology positively impacts zero waste management. The green supply chain mediates the relationship between green technology and zero waste management, while CSR intentions positively moderate this relationship.	Innovation (INN)

References

1. Bettley, A.; Burnley, S. Towards sustainable operations management integrating sustainability management into operations management strategies and practices. In *Handbook of Performability Engineering*; Springer: London, UK, 2008; pp. 875–904.
2. Gunasekaran, A.; Irani, Z. Sustainable operations management: Design, modelling and analysis. *J. Oper. Res. Soc.* **2014**, *65*, 801–805. [CrossRef]
3. Kleindorfer, P.R.; Singhal, K.; Van Wassenhove, L.N. Sustainable operations management. *Prod. Oper. Manag.* **2005**, *14*, 482–492. [CrossRef]
4. Solomon, B.D.; Krishna, K. The coming sustainable energy transition: History, strategies, and outlook. *Energy Policy* **2011**, *39*, 7422–7431. [CrossRef]
5. Environmental Protection Agency. Global Greenhouse Gas Overview. 2023. Available online: https://www.epa.gov/ghgemissions/global-greenhouse-gas-overview (accessed on 25 July 2024).
6. Intergovernmental Panel on Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Mitigation of Climate Change, Chapter 2; IPCC, 2022. Data from IPCC (2022); Based on Global Emissions from 2019, Details on the Sectors and Individual Contributing Sources. Available online: https://www.ipcc.ch/report/ar6/wg3/ (accessed on 25 July 2024).
7. Fouquet, R. The slow search for solutions: Lessons from historical energy transitions by sector and service. *Energy Policy* **2010**, *38*, 6586–6596. [CrossRef]
8. Kuzemko, C.; Lockwood, M.; Mitchell, C.; Hoggett, R. Governing for sustainable energy system change: Politics, contexts and contingency. *Energy Res. Soc. Sci.* **2016**, *12*, 96–105. [CrossRef]
9. Atasu, A.; Corbett, C.J.; Huang, X.; Toktay, L.B. Sustainable operations management through the perspective of manufacturing & service operations management. *Manuf. Serv. Oper. Manag.* **2020**, *22*, 146–157.
10. Seuring, S.; Müller, M. Core issues in sustainable supply chain management–a Delphi study. *Bus. Strategy Environ.* **2008**, *17*, 455–466. [CrossRef]
11. Rajeev, A.; Pati, R.K.; Padhi, S.S.; Govindan, K. Evolution of sustainability in supply chain management: A literature review. *J. Clean. Prod.* **2017**, *162*, 299–314. [CrossRef]
12. Touboulic, A.; Walker, H. Theories in sustainable supply chain management: A structured literature review. *Int. J. Phys. Distrib. Logist. Manag.* **2015**, *45*, 16–42. [CrossRef]
13. Kraus, S.; Breier, M.; Lim, W.M.; Dabić, M.; Kumar, S.; Kanbach, D.; Mukherjee, D.; Corvello, V.; Piñeiro-Chousa, J.; Liguori, E.; et al. Literature reviews as independent studies: Guidelines for academic practice. *Rev. Manag. Sci.* **2022**, *16*, 2577–2595. [CrossRef]
14. Dabić, M.; Vlačić, B.; Kiessling, T.; Caputo, A.; Pellegrini, M. Serial entrepreneurs: A review of literature and guidance for future research. *J. Small Bus. Manag.* **2023**, *61*, 1107–1142. [CrossRef]
15. Ghazanfari, A. An analysis of circular economy literature at the macro level, with a particular focus on energy markets. *Energies* **2023**, *16*, 1779. [CrossRef]
16. Giri, B.K.; Roy, S.K. Fuzzy-random robust flexible programming on sustainable closed-loop renewable energy supply chain. *Appl. Energy* **2024**, *363*, 123044. [CrossRef]
17. Annunziata, E.; Rizzi, F.; Frey, M. How do firms interpret extended responsibilities for a sustainable supply chain management of innovative technologies? An analysis of corporate sustainability reports in the energy sector. *Sinergie Ital. J. Manag.* **2019**, *37*, 57–74. [CrossRef]
18. Le Luu, Q.; Longo, S.; Cellura, M.; Riva Sanseverino, E.; Cusenza, M.A.; Franzitta, V. A conceptual review on using consequential life cycle assessment methodology for the energy sector. *Energies* **2020**, *13*, 3076. [CrossRef]
19. Pender, K.; Romoli, F.; Fuller, J. Lifecycle assessment of strategies for decarbonising wind blade recycling toward net zero 2050. *Energies* **2024**, *17*, 3008. [CrossRef]
20. Yudha, S.W.; Tjahjono, B. Stakeholder mapping and analysis of the renewable energy industry in Indonesia. *Energies* **2019**, *12*, 602. [CrossRef]
21. Yudha, S.W.; Tjahjono, B.; Longhurst, P. Sustainable transition from fossil fuel to geothermal energy: A multi-level perspective approach. *Energies* **2022**, *15*, 7435. [CrossRef]
22. Ahmad, W.; Rezaei, J.; de Brito, M.P.; Tavasszy, L.A. The influence of external factors on supply chain sustainability goals of the oil and gas industry. *Resour. Policy* **2016**, *49*, 302–314. [CrossRef]
23. Barton, J.; Davies, L.; Dooley, B.; Foxon, T.J.; Galloway, S.; Hammond, G.P.; O'Grady, A.; Robertson, E.; Thomson, M. Transition pathways for a UK low-carbon electricity system: Comparing scenarios and technology implications. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2779–2790. [CrossRef]
24. Subtil Lacerda, J.; Van den Bergh, J.C. International diffusion of renewable energy innovations: Lessons from the lead markets for wind power in China, Germany and USA. *Energies* **2014**, *7*, 8236–8263. [CrossRef]
25. Krishankumar, R.; Ramanujam, N.; Zavadskas, E.K.; Ravichandran, K.S.; Gandomi, A.H. Ranking barriers impeding sustainability adoption in clean energy supply chains: A hybrid framework with Fermatean fuzzy data. *IEEE Trans. Eng. Manag.* **2024**, *71*, 5506–5522. [CrossRef]
26. Hecht, A.D.; Miller, C.A. Perspectives on achieving sustainable energy production and use. *J. Renew. Sustain. Energy* **2010**, *2*, 031002. [CrossRef]

27. Yassin, A.M.M.; Hassan, M.A.; Elmesmary, H.M. Key elements of green supply chain management drivers and barriers empirical study of solar energy companies in South Egypt. *Int. J. Energy Sect. Manag.* **2022**, *16*, 564–584. [CrossRef]
28. Duggal, K.; Rangachari, R.; Gupta, K. Consequences of crisis and the great re-think: COVID-19's impact on energy investment, sustainability and the future of international investment agreements. *J. World Energy Law Bus.* **2021**, *14*, 133–146. [CrossRef]
29. Rehme, J.; Nordigården, D.; Chicksand, D. Public policy and electrical-grid sector innovation. *Int. J. Energy Sect. Manag.* **2015**, *9*, 565–592. [CrossRef]
30. Vavatsikos, A.P.; Tsesmetzis, E.; Koulinas, G.; Koulouriotis, D. A robust group decision making framework using fuzzy TOPSIS and Monte Carlo simulation for wind energy projects multicriteria evaluation. *Oper. Res.* **2022**, *22*, 6055–6073. [CrossRef]
31. Attia, A.M. A multi-objective robust optimization model for upstream hydrocarbon supply chain. *Alex. Eng. J.* **2021**, *60*, 5115–5127. [CrossRef]
32. Ziolo, M.; Bak, I.; Spoz, A. Incorporating ESG risk in companies' business models: State of research and energy sector case studies. *Energies* **2023**, *16*, 1809. [CrossRef]
33. Gamarra, A.R.; Lechón, Y.; Escribano, G.; Lilliestam, J.; Lázaro, L.; Caldés, N. Assessing dependence and governance as value chain risks: Natural gas versus concentrated solar power plants in Mexico. *Environ. Impact Assess. Rev.* **2022**, *93*, 106708. [CrossRef]
34. Balaman, S.Y.; Scott, J.; Matopoulos, A.; Wright, D.G. Incentivising bioenergy production: Economic and environmental insights from a regional optimization methodology. *Renew. Energy* **2019**, *130*, 867–880. [CrossRef]
35. Sun, I.; Kim, S.Y. Energy R&D towards sustainability: A panel analysis of government budget for energy R&D in OECD countries (1974–2012). *Sustainability* **2017**, *9*, 617. [CrossRef]
36. Papageorgiou, K.; Carvalho, G.; Papageorgiou, E.I.; Bochtis, D.; Stamoulis, G. Decision-making process for photovoltaic solar energy sector development using fuzzy cognitive map technique. *Energies* **2020**, *13*, 1427. [CrossRef]
37. Subramanian, A.S.R.; Gundersen, T.; Adams, T.A. Modeling and simulation of energy systems: A review. *Processes* **2018**, *6*, 238. [CrossRef]
38. Jelti, F.; Allouhi, A.; Buker, M.S.; Saadani, R.; Jamil, A. Renewable power generation: A supply chain perspective. *Sustainability* **2021**, *13*, 1271. [CrossRef]
39. Generalov, O. Analysis of modern trends and opportunities in the logistics channels of energy products producers. *Balt. J. Econ. Stud.* **2024**, *10*, 39–43. [CrossRef]
40. Halldórsson, A.; Svanberg, M. Energy resources: Trajectories for supply chain management. *Supply Chain.-Manag.- Int. J.* **2013**, *18*, 66–73. [CrossRef]
41. Goodwin, D.; Gale, F.; Lovell, H.; Beasy, K.; Murphy, H.; Schoen, M. Sustainability certification for renewable hydrogen: An international survey of energy professionals. *Energy Policy* **2024**, *192*, 114231. [CrossRef]
42. Hasheminasab, H.; Gholipour, Y.; Kharrazi, M.; Streimikiene, D. Life cycle approach in sustainability assessment for petroleum refinery projects with fuzzy-AHP. *Energy Environ.* **2018**, *29*, 1208–1223. [CrossRef]
43. Sueyoshi, T.; Wang, D. Radial and non-radial approaches for environmental assessment by data envelopment analysis: Corporate sustainability and effective investment for technology innovation. *Energy Econ.* **2014**, *45*, 537–551. [CrossRef]
44. Balaman, S.Y. Investment planning and strategic management of sustainable systems for clean power generation: An ϵ-constraint based multi objective modelling approach. *J. Clean. Prod.* **2016**, *137*, 1179–1190. [CrossRef]
45. Yu, J. Factors affecting return on assets in the renewable energy sector during supply chain disruptions. *J. Risk Financ. Manag.* **2024**, *17*, 253. [CrossRef]
46. Mastrocinque, E.; Ramírez, F.J.; Honrubia-Escribano, A.; Pham, D.T. Industry 4.0 enabling sustainable supply chain development in the renewable energy sector: A multi-criteria intelligent approach. *Technol. Forecast. Soc. Chang.* **2022**, *182*, 121813. [CrossRef]
47. Ma, J.Q.; Yuan, Y.; Zhao, S.N.; Wu, W. Research on sustainability evaluation of China's coal supply chain from the perspective of dual circulation new development pattern. *Sustainability* **2022**, *14*, 9129. [CrossRef]
48. Smith, A.D. Alternative energy supply chain management issues: Wind generation considerations in Ohio. *Int. J. Serv. Oper. Manag.* **2015**, *21*, 200–216. [CrossRef]
49. Lundie, S.; Wiedmann, T.; Welzel, M.; Busch, T. Global supply chains hotspots of a wind energy company. *J. Clean. Prod.* **2019**, *210*, 1042–1050. [CrossRef]
50. Vilkaite-Vaitone, N.; Skackauskiene, I.; Diaz-Meneses, G. Measuring green marketing: Scale development and validation. *Energies* **2022**, *15*, 718. [CrossRef]
51. Biswal, J.N.; Muduli, K.; Satapathy, S.; Yadav, D.K. A TISM based study of SSCM enablers: An Indian coal- fired thermal power plant perspective. *Int. J. Syst. Assur. Eng. Manag.* **2019**, *10*, 126–141. [CrossRef]
52. Xu, X.L.; Chen, H.H. Exploring the relationships between environmental management and financial sustainability in the energy industry: Linear and nonlinear effects. *Energy Environ.* **2020**, *31*, 1281–1300. [CrossRef]
53. Matos, S.; Silvestre, B.S. Managing stakeholder relations when developing sustainable business models: The case of the Brazilian energy sector. *J. Clean. Prod.* **2013**, *45*, 61–73. [CrossRef]
54. Okongwu, U.; Morimoto, R.; Lauras, M. The maturity of supply chain sustainability disclosure from a continuous improvement perspective. *INternational J. Product. Perform. Manag.* **2013**, *62*, 827–855. [CrossRef]
55. Ghobakhloo, M.; Fathi, M. Industry 4.0 and opportunities for energy sustainability. *J. Clean. Prod.* **2021**, *295*, 126427. [CrossRef]

56. Labaran, M.J.; Masood, T. Industry 4.0 driven green supply chain management in renewable energy sector: A critical systematic literature review. *Energies* **2023**, *16*, 6977. [CrossRef]
57. Dudin, M.N.; Frolova, E.E.; Protopopova, O.V.; Mamedov, A.A.; Odintsov, S.V. Study of innovative technologies in the energy industry: nontraditional and renewable energy sources. *Entrep. Sustain. Issues* **2019**, *6*, 1704–1713. [CrossRef]
58. Li, B. Leading role of natural resources, eco-efficiency assessment, and energy transition in environmental sustainability: A depth of digital transformation. *Resour. Policy* **2024**, *94*, 105145. [CrossRef]
59. Chen, H.H.; Lee, A.H.; Chen, S. Strategic policy to select suitable intermediaries for innovation to promote PV solar energy industry in China. *Appl. Energy* **2014**, *115*, 429–437. [CrossRef]
60. Annunziata, E.; Rizzi, F.; Frey, M. The supporting role of business models in the promotion of sustainable innovations in the energy sector: An explorative study in the Italian SMEs. *Sinergie Ital. J. Manag.* **2020**, *38*, 131–146. [CrossRef]
61. Haiyun, C.; Zhixiong, H.; Yüksel, S.; Dinçer, H. Analysis of the innovation strategies for green supply chain management in the energy industry using the QFD-based hybrid interval valued intuitionistic fuzzy decision approach. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110844. [CrossRef]
62. García-Orozco, S.; Vargas-Gutiérrez, G.; Ordóñez-Sánchez, S.; Silva, R. Using multi-criteria decision making in quality function deployment for offshore renewable energies. *Energies* **2023**, *16*, 6533. [CrossRef]
63. Masoomi, B.; Sahebi, I.G.; Ghobakhloo, M.; Mosayebi, A. Do industry 5.0 advantages address the sustainable development challenges of the renewable energy supply chain? *Sustain. Prod. Consum.* **2023**, *43*, 94–112. [CrossRef]
64. Nassani, A.A.; Hussain, H.; Condrea, E.; Grigorescu, A.; Yousaf, Z.; Haffar, M. Zero waste management: Investigation of green technology, the green supply chain, and the moderating role of CSR intentions. *Sustainability* **2023**, *15*, 4169. [CrossRef]
65. Efthymiopoulos, N.; Makris, P.; Tsaousoglou, G.; Steriotis, K.; Vergados, D.J.; Khaksari, A.; Herre, L.; Lacort, V.; Martinez, G.; Lorente, E.L.; et al. FLEXGRID–a novel smart grid architecture that facilitates high-RES penetration through innovative flexibility markets towards efficient stakeholder interaction. *Open Res. Eur.* **2021**, *1*, 128. [CrossRef] [PubMed]
66. Aziz, N.; Hanafiah, M.M.; Gheewala, S.H.; Ismail, H. Bioenergy for a cleaner future: A case study of sustainable biogas supply chain in the Malaysian energy sector. *Sustainability* **2020**, *12*, 3213. [CrossRef]
67. Ibn-Mohammed, T.; Koh, S.C.L.; Reaney, I.M.; Acquaye, A.; Schileo, G.; Mustapha, K.B.; Greenough, R. Perovskite solar cells: An integrated hybrid lifecycle assessment and review in comparison with other photovoltaic technologies. *Renew. Sustain. Energy Rev.* **2017**, *80*, 1321–1344. [CrossRef]
68. Dobrowolski, Z. Internet of things and other e-solutions in supply chain management may generate threats in the energy sector—The quest for preventive measures. *Energies* **2021**, *14*, 5381. [CrossRef]
69. Wu, Y.; Wu, Y.; Cimen, H.; Vasquez, J.C.; Guerrero, J.M. Towards collective energy community: Potential roles of microgrid and blockchain to go beyond P2P energy trading. *Appl. Energy* **2022**, *314*, 119003. [CrossRef]
70. Cader, J.; Koneczna, R.; Smol, M. Corporate social responsibility as a significant factor of competitive advantage-a case study of energy companies in Poland. *Energy Rep.* **2022**, *8*, 7989–8001. [CrossRef]
71. Hmouda, A.M.O.; Orzes, G.; Sauer, P.C. Sustainable supply chain management in energy production: A literature review. *Renew. Sustain. Energy Rev.* **2024**, *191*, 114085. [CrossRef]
72. Nair, P.U.; Thankamony, P. Social issues in supply chain sustainability–focus areas for energy and manufacturing sectors in India and USA. *Eur. J. Sustain. Dev.* **2021**, *10*, 495. [CrossRef]
73. AlKhars, M.; Masoud, M.; AlNasser, A.; Alsubaie, M. Sustainable practices and firm competitiveness: An empirical analysis of the Saudi Arabian energy sector. *Discov. Sustain.* **2024**, *5*, 146. [CrossRef]
74. Gardas, B.B.; Mangla, S.K.; Raut, R.D.; Narkhede, B.; Luthra, S. Green talent management to unlock sustainability in the oil and gas sector. *J. Clean. Prod.* **2019**, *229*, 850–862. [CrossRef]
75. Afshari, H.; Agnihotri, S.; Searcy, C.; Jaber, M.Y. Social sustainability indicators: A comprehensive review with application in the energy sector. *Sustain. Prod. Consum.* **2022**, *31*, 263–286. [CrossRef]
76. Muduli, K.; Kusi-Sarpong, S.; Yadav, D.K.; Gupta, H.; Jabbour, C.J.C. An original assessment of the influence of soft dimensions on implementation of sustainability practices: Implications for the thermal energy sector in fast growing economies. *Oper. Manag. Res.* **2021**, *14*, 337–358. [CrossRef]
77. Botnar, W.L.; Frederico, G.F. Industry 4.0 in the electric sector: Findings from a systematic review of the literature. *Electr. J.* **2023**, *36*, 107337. [CrossRef]