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Review

Recent Trends in Sustainable Inventory Models: A Literature Review

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Abstract: Greenhouse gas emissions are increasing global warming significantly, hence the need for manufacturing companies to include sustainability strategies in their supply chain to reduce emissions generated by their operations. This article aims to provide a systematic literature review on integrating sustainability issues into inventory management models to support scholars and practitioners in decision-making processes according to their market requirements. Thus, this paper discusses the most relevant papers published on inventory management topics that consider environmental criteria such as greenhouse gas emissions, ecological quality controls, unsold inventory, and fixed carbon costs. Therefore, we have extended the literature review to incorporate sustainability considerations in inventory models involving an industry's environmental and social effects. As a result, in this article, a detailed analysis of the existing literature and related weaknesses provide meaningful discussions on crucial issues for future field research avenues in the field.

Keywords: sustainability; inventory models; lot sizing; sustainable order quantity; carbon emissions; environmental factors

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1. Introduction

Due to long-term greenhouse gas (GHG) emissions, between 1990 and 2013, the World Meteorological Organization reported a global 34 per cent growth in radiative forcing, indicating increasing global warming [1]. Consequently, modern manufacturing companies, commonly recognized as the primary source of pollutants, need to consider sustainable development a key issue in their business models and supply chain [2,3]. Due to the increasing environmental concern, supply chain management has shifted to focus on environmental implications of manufacturing and the preservation of earth resources [4,5]. Even if the Paris Agreement's target of keeping global warming below 2 degrees is met [6], adaptation to climate change's effects will be needed to avoid catastrophic consequences for future generations [7]. Government regulatory pressures encourage businesses to implement practices to reduce the pollution they generate [6,8]. Several companies, for example, are devoted to recovering and remanufacturing damaged products rather than making new ones to cut carbon emissions since the carbon footprint of new goods is higher than that of remanufactured ones [9]. According to Tighazoui et al. [10], the remanufacturing process is extensively adopted in reverse logistics, whose goal is to manage the end life of used and discarded products, components, and materials. Moreover, the objectives of reducing fossil fuel consumption and GHG emissions contributed to significant policy support for increasing the use of bioenergy [11]. Several governments have also introduced carbon emission legislation, such as carbon taxes, mandated carbon emission capacity, and carbon emission cap and trade to limit GHG emissions [12]. The effects of global warming are becoming more evident in everyday life, with increasingly frequent incidents of flooding, drought, storms, and rising sea level [13]. Thus, this phenomenon is a significant source of

concern since it threatens community priorities such as air quality, water quality, public lands, wildlife, and human health [14], causing shortened life expectancy and significant health consequences [15], such as allergic diseases [16]. Furthermore, it is becoming increasingly evident that GHG emissions result in significant biodiversity loss [17]. Consequently, as public interest and regulatory oversight have grown, businesses have become more involved in environmental protection to boost their credibility and image [18]. Companies could adopt different intraorganizational sustainable practices to reduce their environmental impacts, such as using renewable energy sources, recyclable packaging, and eco-friendly raw materials [19]. Notably, recycling is widely regarded as one of the most important methods for addressing pressing environmental issues [20] since it has huge potential to enhance sustainability by reducing the disposal of end-of-life goods [21]. Indeed, most of the emissions produced by companies are associated with waste disposal. Besides this, according to Waxin et al. [22], adopting the environmental management system (EMS) certified ISO 14,001 could enhance companies' environmental performance by reducing the wasted resources' cost. Other supporting interorganizational practices strictly connected to the manufacturing processes, such as those addressing inventory management decisions, transport frequency and energy management policies, significantly influence emissions generated by transport and storage procedures. Therefore, in the green supply chain context, efficient production and inventory management are crucial to reduce carbon emissions [19].

The first category of inventory management models has been developed to evaluate the lot size quantity with the lowest possible costs to satisfy the requirements. Thus, these models are primarily focused on how much to order and when to place an order. However, these models, such as the economic order quantity (EOQ) model, which was first developed by Harris [23], only consider economic variables without considering environmental factors. Nowadays, in addition to concerns with economic spending, the industries face environmental challenges, a growing source of concern. Increasing interest has been shown in developing methodologies that support decision making in progress towards sustainable development [24], thus including into the decision process environmental and social factors [25]. This is challenging given the different social, political, environmental, and economic aspects [26]. To face these issues, conventional inventory models that only consider the three costs of keeping, ordering, and scarcity, are inadequate. A new period of responsible and creative inventory models that consider environmental costs (e.g., transport pollution costs, warehouse emission costs, and waste management emission costs) is needed to represent the real issues. Consequently, in recent years, researchers have developed sustainable inventory models that include environmental and social factors as well as economic ones, helping companies reduce environmental pollution and adverse social effects [3]. These models are therefore in line with the "Triple Bottom Line" (TBL) framework, which was coined by Elkington [27], according to which business performance should be measured considering three dimensions: economic, social, and environmental, placing equal significance on each of the three lines. Indeed, the concept of sustainability acknowledges that businesses should address social objectives such as environmental conservation, social justice, and economic development [28,29]. Thus, many industries are trying to determine the optimal ordering policies in demand instability and include corporate social responsibility (CSR) issues in their supply chain decisions [30].

A significant amount of research has been done in the field of sustainable inventory management. Economic inventory models are converted into environmentally friendly inventory models. In particular, in these models, a company's environmental costs refer to all the costs associated with environmental impact, safety, and pollution. For instance, Bonney & Jaber [31] proposed an EOQ model which considers waste disposal costs. A large part of the emissions abatement costs is associated with waste disposal in order to promote a pollution-free climate. The word "waste" has two connotations. It contains both marketable and non-marketable production. Non-marketable products are goods not used in the manufacturing process and products not repairable (or reparable). Solid waste, wastew-

ater, and air pollution are examples of non-product generation [32]. Several researchers developed inventory models that involved non-marketable chemical waste disposal [33]. Other sustainable inventory models include critical variables such as emissions linked to transport and warehouse activities [34]. Such costs are particularly relevant for cold items because, in the electric sector, refrigerants are the second most important source of GHG emissions [35].

Even if a growing number of inventory models and papers integrate sustainability issues in purchasing decisions, practices, and strategies, the literature is still fragmented, and a review study that systematizes the body of knowledge is still missing.

Based on the above premises, the objectives of this paper are (1) to provide a comprehensive analysis of the literature about incorporating sustainability factors into inventory models, and (2) to find gaps in the field that could lead to new future research suggestions. Notably, the future research avenues identified include a wide range of topics in inventory management that can help improve economic, environmental, and social sustainability. For example, future studies could focus on the role of the emerging digital technologies in improving inventory management, optimizing transport, reducing lead times, and making operations more sustainable overall.

Our literature review is composed of two main phases: papers selection, in which we defined the criteria used to collect the documents related to the research field, and descriptive and content analysis of the selected papers, within which we first provided descriptive statistics of the papers (e.g., distribution of papers over time) and then an in-depth analysis of their content.

The article is composed of six sections. After this introduction, the next section explains the review methodology. Section 3 contains methodological details related to the material collection and selection phases. Section 4 contains descriptive statistics of the selected articles. Section 5 is devoted to explaining and examining the contents of the papers chosen. Finally, Sections 6 and 7 present the discussions and conclusions, specifying the contributions to theory, and managerial practice, as well as the limitations of the study and future research directions.

2. Materials and Methods

In this article, a systematic literature review has been conducted according to the review approaches proposed by Centobelli et al. [36], Cerchione and Esposito [37], Bazan et al. [38], Hassini et al. [39], and Gaston et al. [40]. Considering these contributions, we recommend that the systematic analysis of the literature can be split into two key phases, that in turn are divided into two steps:

1. Papers selection phase:
    a. Comprehensive material research. This process entails finding keywords, creating search strings, and choosing the academic databases for data collection.
    b. Selection criteria. This step entails the determination of inclusion and exclusion criteria to identify relevant papers to be in-depth reviewed.
2. Descriptive and content analysis of the selected documents:
    a. Descriptive analysis. To have an overall mapping of the chosen articles, the papers are analyzed according to different perspectives (i.e., distribution of papers based on the year of publication, distribution of papers among journals, distribution of papers based on methods).
    b. Content analysis. The full text of the selected papers is thoroughly analyzed to identify the literature's strengths and weaknesses, research gaps, and relevant research issues to be further investigated.

3. Data Collection

This section is divided into two subsections: Extensive material analysis and selection criteria.

3.1. Phase of Material Search

This section's goal is to find relevant output on the subject of integrating sustainability into inventory models. The search was conducted using two databases, Scopus and Web of Science, as two of the most reliable databases to conduct literature reviews [37]. Further, we focused on the time range of 2010–2020, although a few papers published before 2010 and after 2021 were included for relevance in the field. Only papers published in peer-reviewed journals were considered, thus removing book chapters and conference proceedings. A focus group of four researchers and two senior inventory consultants from the logistics service business were involved in determining the search string of keywords. As a result, the following keywords were used in combination with inventory models: "environmental", "sustainability", "carbon footprint", "carbon cap-and- trade policies", "CO_2 pollution", and "Greenhouse Gas emission".

According to Centobelli et al. [36] and Cerchione and Esposito [37], two additional filters were used:

a. Only papers published in peer-reviewed journals were selected.
b. Articles from subject areas that were not related to the issue under investigation were excluded.

The material research began with the following topics in mind: inventory management, supply chain management, and operational research management science, as well as various environmental issues such as carbon emission costs from keeping, disposing, deteriorating products, transporting, and so on, as well as energy costs from manufacturing, production, repair, electricity, solar energy, gasoline, and diesel. As a result, Table 1 shows the search string used and the papers initially retrieved in the two databases.

Table 1. Material search.

Keywords Used	**("Inventory Models") and ("Environmental" or "Sustainability" or "Carbon Footprint" or "Carbon Cap-and-Trade Policies" or "CO_2 Pollution" or "Greenhouse Gas Emission")**
Scopus database	132 papers
Web of Science database	60 papers
Total papers retrieved in the two databases excluding duplications	165 papers

3.2. Paper Selection Process

Three criteria were used to select relevant articles. The first criterion allowed us to identify relevant articles reading their abstracts. To this end, two researchers examined the abstracts of the 165 papers, with a third researcher reading them if there was any doubt. As a result, the abstracts of the 165 articles identified were read and then divided into two groups (Table 2).

Table 2. First step selection.

List	**Description**	**Number of Papers**
A	Papers whose abstracts focus on sustainable inventory management	140
B	Papers whose abstracts do not focus on sustainable inventory management	25

According to the first exclusion criterion, the papers in list B (25 papers) were excluded because they were beyond the study's scope. Therefore, only the 140 articles in list A were thoroughly examined and subjected to the second criterion, which was based on a thorough examination of each article reading the full text. We excluded 84 papers that were not focused on the study subject during this reading process. Finally, we used the "snowball" approach as the third criterion, identifying and including the remaining possibly significant studies in our collection. A total of 27 additional articles on the topic investigated were

found and included in the analysis. As a result, we picked and considered 83 papers. In line with Mittal et al. [41], Figure 1 shows the flowchart of the literature search and screening process.

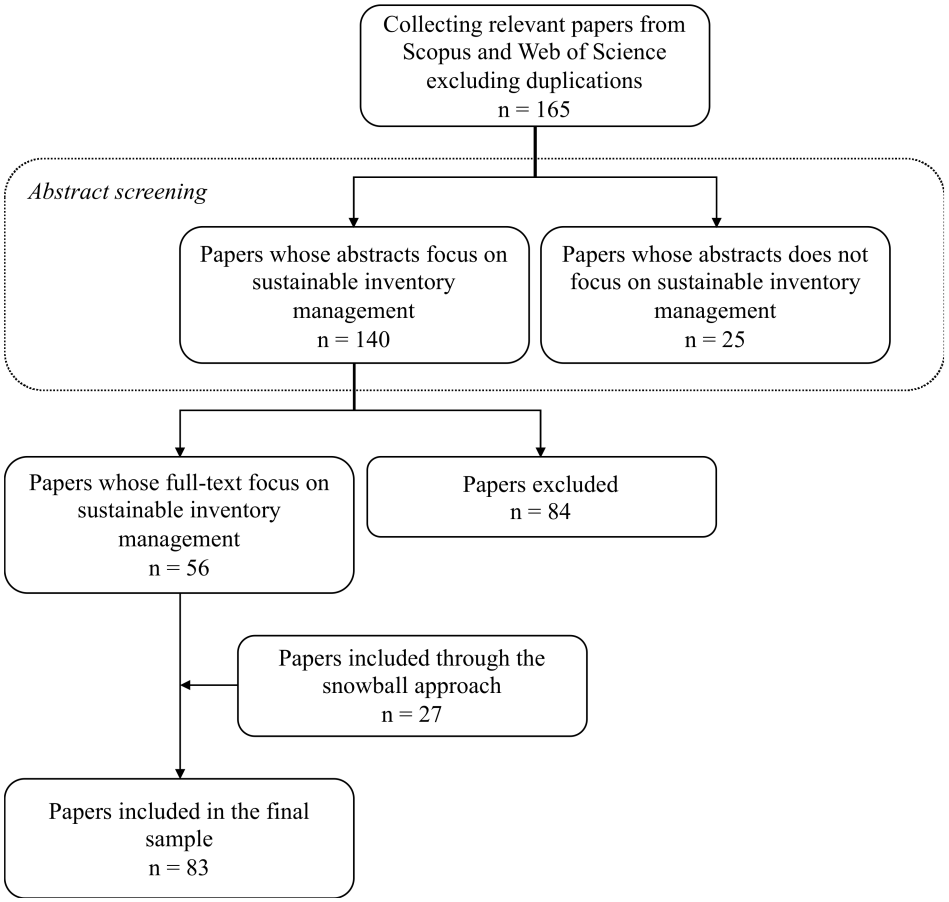

Figure 1. Literature selection process.

4. Descriptive Analysis

This section aims to provide an overview of the papers that deal with incorporating sustainability into the inventory problem. Three perspectives were considered for this purpose.

4.1. Distribution of Papers Based on the Publication Year

The timeline of paper distribution is shown in Figure 2. We have noticed that the number of publications on this subject has risen in recent years, with 50% of the articles written in the last four years.

4.2. Distribution of Papers among Journals

The dissemination of articles across journals reveals that there are 39 different journals incorporating sustainability into inventory management. Figure 3 shows all the journals with at least three papers published. There is the Journal of Cleaner Production at the top of the ranking, with 18 papers published out of the 83 articles, followed by the International Journal of Production Economics (11), and the European Journal of Operational Research (5). The SCImago classifications, proper to evaluate the scientific impact, include these three leading journals in Quartile 1 (Q1).

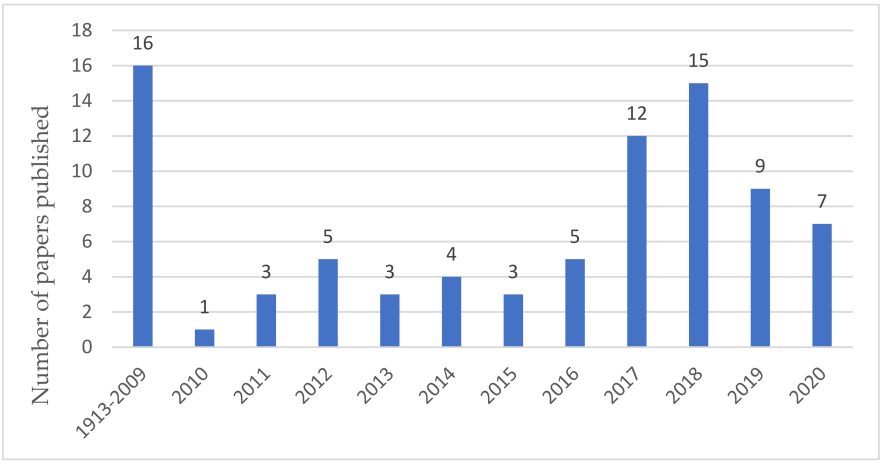

Figure 2. Distribution of articles based on the year of publication.

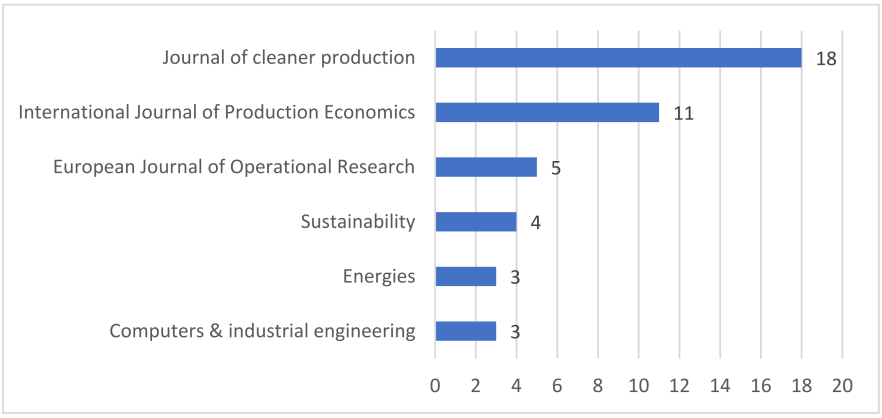

Figure 3. Top journals.

4.3. Distribution of Papers based on Methods

The distribution of papers by methodology displayed in Figure 4 shows that more than 80% of the articles are characterized by quantitative methods (i.e., surveys and mathematical models). In contrast, few articles adopted a case study methodology or other approaches (e.g., conceptual and mixed methods). Notably, the use of secondary data and knowledge rather than primary data is used in conceptual papers based on earlier theoretical approaches. Qualitative and quantitative research are combined in mixed methods studies.

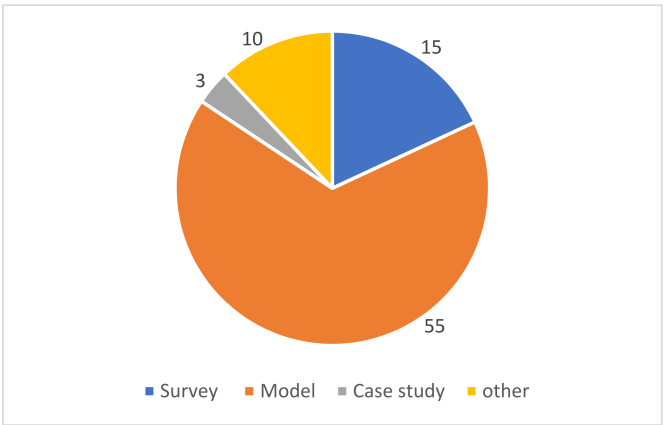

Figure 4. Distribution of the papers by methodology.

5. Content Analysis

This section aims to provide a comprehensive overview of the issues addressed in the literature on inventory management's environmental sustainability. The current state of the corporate climate is experiencing many shifts due to government legislation, environmental issues, and social consciousness, which enable industries to foster sustainability in their respective jurisdictions. Sustainability is described as a creation that meets current needs without jeopardizing future generations' ability to fulfill their own [42]. Due to natural resource depletion, all the companies are now focused on sustainability issues. This study aims to offer a comprehensive overview of the difficulties raised in the literature about the incorporation of sustainability criteria into inventory models. In particular, the full text of the selected 83 papers is thoroughly analyzed (Appendix A), following the procedure in Figure 5.

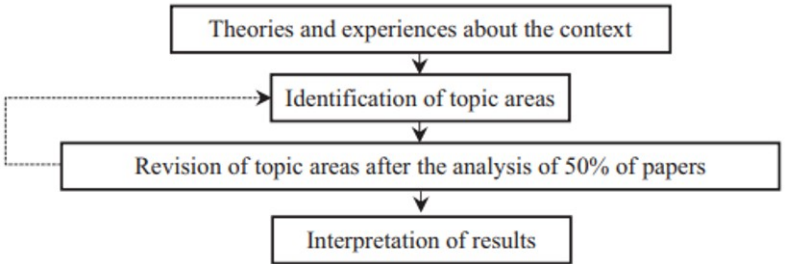

Figure 5. Content analysis procedure.

According to Centobelli et al. [36], we created an initial set of topic areas based on experiences with the context and theoretically based definitions of key literature categories before analyzing the 50% of selected publications (i.e., inventory model includes environmental and social factors). After analyzing half of the papers and applying inductive category creation techniques, we updated the initial set of subject areas and added an extra topic area covering the importance of customer perspective in the sustainable supply chain. As a result, the content analysis of the selected articles revealed two distinct issue areas: incorporating environmental and social factors into the Inventory system and Supply chain system.

Many studies from various fields have established long-term inventory models regarding economic and social problems, with significant manufacturing and output issues. Ambec [43] investigated the effect of sustainability on company financial results. Rădulescu et al. [44] used multi-objective programming to build an inventory development model that considered minimal emission risk and maximum potential return. El Saadany et al. [33] developed a two-echelon supply chain model of price-dependent demand and environmental efficiency goods, as well as pollution from production processes, including concerns related to the climate and social problems. Benjaafar [45] showed how the carbon footprint could be factored into organizational decision making. Plambeck [46] discussed how companies could reduce GHG pollution in their supply chains while making a profit. Hassini [39] offered a summary of the literature from 2000 to 2010 and case studies and models for sustainable supply chains from multiple perspectives.

Other research focused on the development of new EOQ models incorporating sustainability objectives and constraints. For example, a multi-objective EOQ model was reformulated by Bouchery et al. [47], while Tao et al. [48] developed an economic lot size and development model focused on the green cost principle. On another note, Chen [49] produced the carbon-constrained EOQ model, which was evaluated under various environmental regulations (for example, settings with a carbon tax, cap-and-offset, and cap and price). Andriolo et al. [50] addressed a systematic analysis of inventory replenishment issues for sustainable manufacturing and inventory models.

Other studies focused on the definition of sustainable order quantity (SOQ) models. Digiesi et al. [51] developed an empirical SOQ model that takes stochastic fluctuations of

supply lead time and uncertainty demand into account. Battini et al. [34] suggested the SOQ model that incorporates pollution from shipping and warehouses activities. Digiesi [52] developed the SOQ model for repairable spare parts based on uncertain demand. Toptal [53] built a sustainable EOQ model that considers carbon emissions reduction expenditure availability. Notably, the carbon pollution regulation of the inventory policy is considered. Hovelaque [54] introduced a demand model focused on price and environmental variables. Both exogenous and endogenous price results were clarified. Andriolo [55] built a new haulage-sharing lot size model that looked at both the expense and pollution functions. Soleymanfar [56] created a partly backlogged SOQ model that took output emissions, inventory keeping, and obsolescence into account. Hua [57] suggested an inventory model of freshness-dependent demand under a carbon pollution restriction. The carbon emissions in this model are caused by product rotting and inventory shipment and keeping. Furthermore, Andriolo et al. [58] suggested a modern multi-objective lot-sizing procedure for a single-product replenishment epidemic, with the social effect of inventory decisions quantified in terms of the ergonomics of managing operations. Khan [59] implemented the SOQ model's knowledge exchange and consistency in integrating socioeconomic and environmental sustainability criteria. Darom [60] examined the effect of environmental factors on supply chain organizational decision making. Considering both economic and social-environmental costs, Digiesi [61] estimated the optimum order quantity and the logistic cost function's minimization. Karmakar [62] developed a thick fuzzy production model with preservation technologies and a functional relationship between environmental emission and production rates. Lee [63] created the S-EOQ problem for multi-modal transportation solutions, assuming ambiguity lead time. Marklund & Berling [64] developed a model for inventory management that considers both economic (costs) and environmental (CO_2 emissions) variables.

On the influence of renewable investment and carbon taxes on a manufacturing process, Datta [65] invented a model in which the output rate is variable, and the sale price dictates demand. Shu et al. [66] used a cap-and-trade policy to integrate "manufacturing/remanufacturing" techniques into their model. Hariga et al. [67] combined economic and environmental models for a temperature-controlled and multi-stage cold supply chain under carbon tax regulation. Considering a fluctuating transportation rate, Sarkar et al. [68] developed a two-stage inspection model for an incomplete quality object. Bazan et al. [38] investigated a remanufactured closed-loop supply chain regarding the effect of electricity and carbon dioxide pollution. Wangsa [69] created an economic lot size model that considers the GHG penalty and incentive policies to reduce industrial and transportation emissions. Multi-objective optimization is used. The cost and carbon emissions of a non-coordinated and coordinated two-echelon supply chain were contrasted by Bouchery et al. [70]. Based on environmental emissions control and salvage benefit consideration for imperfect objects, Uthayakumar [71] built multiple development models.

Considering the most recent contributions (from 2018 to 2020), we report in Table 3. A detailed overview of the papers analyzed considering the first author's name, publishing year, journal name, sustainability parameters, types of models, intent, outcomes, and conclusions. In particular, most researchers developed a mathematical model using different assumptions, provided numerical examples, calculated sensitivity analysis, graphical representation, and given managerial insights. Using different methods, the researchers find the optimal solution, which is the optimal size of the lot that minimizes the economic, environmental, and social costs. As a result, this table includes 25 papers focusing on incorporating sustainability requirements into inventory models. Notably, the content analysis of these papers has shown three main research topics: sustainability into economic order quantity model (4 papers), sustainability into economic production model (12 papers), and sustainability into supply chain inventory system (9 papers).

Table 3. Relevant contributions (2018–2020).

Authors	Publication Year/Journal Name	GHG Emission and Their Cost	Models/Objective	Result and Finding
Kazemi et al. [72]	2018/International Journal of Systems Science	Carbon Emission cost from inventory holding and obsolescence disposal.	EOQ/Four defective quality models with carbon emission costs were produced.	Incorporation of carbon pollution prices into the buyer's strategy in order to reduce lot sizes and achieve minimal costs.
Tiwari et al. [19]	2018/Journal of Cleaner Production	Carbon emission cost from transporting, warehousing, and deteriorating item.	Single vendor single buyer IM/With carbon emissions in mind, a standard for imperfect, decaying objects was developed.	Due effect of carbon emission cost reducing the delivery frequency and increasing the delivery quantity to minimize both the total inventory and carbon emission costs.
Taleizadeh et al. [73]	2018/Journal of cleaner production	Environmental concern from production.	S-EPQ/by considering different shortage situation developed four SEPQ models.	To assess the optimal value of the decision element, various scarcity conditions such as missed revenue, full backordering, and partly backordering were used.
Daryanto et al. [74]	2018/Journal of Advanced Management Science	Carbon emission cost from production, warehousing, and waste disposal.	S-EPQ/They designed their models with carbon pollution costs factored into the overall cost function to approach cleaner production.	Carbon emissions from the EPQ model was minimized in order to create a cleaner manufacturing environment.
Sarkar et al. [75]	2018/Applied Sciences	Carbon emission cost and source of energy cost from electricity, solar energy, diesel fuel, and gasoline.	EPQ/Generated a multi-objective manufacturing model that takes into account long-term supply chain management.	Minimize overall cost of production, carbon footprint reduction, and electricity cost.
Wu et al. [76]	2018/International Conference on Management Science and Engineering Management	Carbon emission cost.	EPQ/Provide the right production lot models for products with perfect and faulty product quality, as well as pollution restrictions.	To assess the relationship between the ideal quality product's predicted rate and the right output lot.
Gautam et al. [77]	2018/Uncertain Supply Chain Management,	Carbon emission cost from transportation.	EPQ/In order to minimize costs, an incomplete production was created that took into account transportation pollution.	The model is ideally tailored to real-time inventory situations because it decreases the total expense of the device.
Lin et al. [78]	2018/Journal of Applied Science and Engineering	Carbon emission cost from holding inventory, transporting, and disposing.	S-EOQ/Incorporate sustainability concept in the traditional inventory system by integrating economic and environmental perspectives.	Integrate economic and environmental viewpoints into the conventional inventory structure to integrate the sustainability concept.
Zadjafar & Gholamian [3]	2018/Journal of cleaner production	Emission of Sulfur dioxide, Nitrogen oxide gases, was BOD, COD from wastewater. (Biochemical oxygen demand (BOD) and chemical oxygen demand (COD))	GEOQ/Considering simultaneously effects of environmental and social factor developed a sustainable model.	Optimized the cost function along with reduction of gases and water pollutants.
Yassine [79]	2018/Annals of Operations Research	Transport emission cost and tax.	SEPQ/Along with emission tax from transportation and effects of different quality of raw materials they developed production model.	Reducing environmental and social impacts to optimize lot size and total production cost.
Wangsa et al. [80]	2018/Energies	Consumption of electrical energy cost from holding, transmission, distribution, and power generation.	SESCE/Considering four type of customer price dependent demand such as increasing linearly, quadratically, and multiplicatively and decrease multiplicatively developed their model.	Parameters like price of electricity and elasticity coefficient, production cost, scaling factor and rate of power supply affect optimal decision variable and total profit.
Daryanto et al. [81]	2019/International Journal of Industrial Engineering and Engineering Management	Carbon emission cost from electric consumption during production and inventory storage and waste disposing.	CEPQ/Deteriorating imperfect quality items model developed with considering environmental concept and carbon tax regulation.	To minimize carbon emission cost, total operation, and production quantity.

Table 3. *Cont.*

Authors	Publication Year/Journal Name	GHG Emission and Their Cost	Models/Objective	Result and Finding
Lee [82]	2019/Journal of the Operational Research Society	Carbon emission due to replenishment and production.	EOQ/With cap and price regulation policy developed classical EOQ model.	Investment optimal lot size and carbon emission reduction in model with cap-and-price regulation policy.
Gautam et al. [83]	2019/Journal of cleaner production	Carbon emission cost are due to transportation and waste disposal).	Vendor-buyer inventory Model/considering carbon emissions and strategies of defect management developed a model.	To maximize the total profit with management of defectives and reducing carbon emission.
Shen et al. [84]	2019/Sustainability	Carbon emission cost due to inventory producing, purchasing, holding.	EPQ/Under carbon tax policy and preservation technology formulated a model for deteriorating items.	For buyer and vendor to find maximum profit and optimal production, delivery, ordering.
Asghar et al. [85]	2019/Energies	Energy consumption cost due to manufacturing, producing, repairing, storing.	EPQ/stochastic production and inventory system under variable energy consumption costs.	Optimize production lot size, production rate, and readability parameters.
Sarkar et al. [86]	2019/International Journal of Production Economics	Carbon footprint cost for setup and labor and carbon emission cost per quantity.	EPQ/Under advance logistics management formulated a model with carbon emission and footprint.	Control carbon footprint and optimum cash-flow within a smart production system such as manufacturing, distribution, consumption, and remanufacturing.
Zavanella et al. [87]	2019/Journal of Business Economics	Energy cost.	EPQ & JELS/Based on both economic and environmental concern extending the economic production quantity and joint economic lot size models.	Energy cost directly impact in total cost and its environmental linkage.
Choi et al. [88]	2019/Sustainability	Emission cost due to production.	Stochastic model/By using cap and trade regulation designed two inventory optimization models.	Approaching PTR (pollution base regulation) and BCR (Baseline credit regulation) to analyze stochastic optimization problem.
Mishra et al. [89]	2019/Energies	Carbon emission cost of energy holding of transmission, power generation.	SEESCIM/Effect of carbon emission they formulated an inventory model with linear price dependent demand under set up cost.	Affected total profit and all decision variable due to impact of key parameters such as demand, production, and reduction of set-up cost, ordering cost, loss factor, and carbon emission.
Kamna et al. [90]	2020/International Journal of System Assurance Engineering and Management	Carbon emission cost and energy cost.	SPIM/Effect of carbon emission during production, storage of good as well as energy consumption discussion in this model.	To maximize the overall inventory turnover by conjointly optimize selling price as well as production rate and time.
Wangsa et al. [91]	2020/Journal of cleaner production	Carbon emission cost.	IIM/Considering environmental and economic issue, developed an integrated inventory model.	Find minimum total cost to optimize the decision variables such as order quantity, total emission, safety time, lead time, and number of shipments.
Mishra et al. [92]	2020/Journal of cleaner production	Carbon tax and cap.	SEPQ/Under carbon tax and cap policy developed three SEPQ Model with and without shortage.	This model gives better justifiable profit with highest cycle time, lowest value of fractional length period, as well as lower green technology investment cost.
Biuki et al. [93]	2020/Journal of cleaner production	Sustainable level growth.	ILRIM/Developed a multi objective mixed integer programming model based on the sustainability issue.	By using GA and PSO to find the optimal solution of the problem.
Tang et al. [94]	2020/Mathematical problems in engineering	Carbon Tax.	IOSIM/Under the carbon tax policy to optimize the sustainable transportation and inventory.	The results indicate that a carbon tax policy can improve social welfare and the sustainability of transportation and inventory but could hinder corporate profits.

6. Discussion of the Results and Research Agenda

Classic inventory models cannot monitor emerging issues in the industrial sectors such as managing inventory overage, product marketing, growing consumer consumption, inefficient manufacturing processes, GHG emissions related to inventory management, and logistics and transportation operations. Inventory planning and management should be analyzed from a financial, environmental, and social perspective to solve these concerns. The development of sustainable inventory models, including environmental and social issues, should solve these problems. GHG emissions, especially CO_2 emissions, were frequently chosen as the environmental factor to be integrated into decision-making models in most studies since climate change and global warming represent a problem that must be resolved. Transportation, power generation, warehousing, and other fields were given special consideration to satisfy the CO_2 emission standards. Various new costs criteria are integrated into traditional inventory models to devise sustainable inventory models. Besides this, it was possible to identify literature gaps based on the material analysis performed starting from the findings of the publications examined. Furthermore, great attention was paid to develop an inventory model which includes GHG emissions, especially carbon dioxide (CO_2) emissions, using different carbon pricing methods. Since environmental sustainability is a critical focal point in today's market, a supply chain based on a sustainable model provides more collaboration opportunities. Identifying the strengths and weaknesses of sustainable inventory model implementation leads us to identify the following research gaps and the consequent research questions.

First, there is a lack of studies in the scientific literature that consider the influence of different factors (e.g., carbon regulatory policy, transportation distance, lead time, etc.) on the design of the sustainable supply chain and inventory management. Hence, the following research questions:

RQ1: How does the role of carbon regulatory policies affect sustainable inventory management?
RQ2: What factors can influence the design of a supply chain that considers economic, environmental, and social costs in inventory management?

Furthermore, in the scientific literature, most studies have developed mathematical inventory models that assume a deterministic demand and constant lead time. As a result, future studies could use a probabilistic demand, a variable lead time, and other sustainability issues to make the scenario more realistic, obtaining more precise results, as the following research question suggests:

RQ3: What is the impact of probabilistic demand and variable lead time on the accuracy and efficiency of a sustainable inventory model?

Another research gap concerns comparing a sustainable inventory model and a conventional one in terms of economic, environmental, and social impact to understand how high the trade-off between these three dimensions is. Hence, the following research questions:

RQ4: What is the difference in terms of economic, environmental, and social impact between a sustainable inventory model and a conventional inventory model?

Moreover, qualitative research could be conducted to investigate how and if the new digital technologies improve sustainable inventory management and people's perception of human health due to the implementation of more sustainable operations in supply chains. Hence, the following research questions:

RQ5: What is the role of the new digital technologies in improving sustainable inventory management?
RQ6: What is the impact on human health of using sustainable inventory models?

These six research questions describe several potential topic areas in the field of inventory management to enhance economic, environmental, and social sustainability. Sustainability makes a vital contribution nowadays, adopting and incorporating a long-term supply chain management system makes a difference. For companies in the transportation and logistics service sector, environmental protection has become a key criterion for obtaining various business benefits.

7. Conclusions and Implications

7.1. Contribution to Theory

This paper presents different theoretical contributions in the research field. It proposes a comprehensive literature review on integrating sustainability into inventory management, highlighting specific literature gaps, and providing a research agenda for future studies. The detailed review offers a high-level outline of the articles selected. This step illustrates a positive pattern in recent years. The content analysis allows the identification of specific issues. Many studies that incorporate environmental factors into traditional inventory models were identified and discussed with particular attention. Therefore, these articles go beyond the traditional inventory model. These criteria aim to formally analyze logistics chains to aid in the production of economically and environmentally sustainable decisions while still fulfilling service level requirements. Finally, this paper aims to serve as a reference point for both quantitative and qualitative modeling researchers. For example, this study could support scholars by highlighting a significant number of economic, environmental, and social parameters that could be included and integrated into the mathematical inventory models to develop new ones. Moreover, qualitative researchers could conduct multiple case studies in order to investigate the role of digital technologies (e.g., Blockchain) in improving inventory management and the decision-making process, as well as the effects on human health of using sustainable inventory models.

7.2. Contribution to Managerial Practice and Policymakers

This paper intends to make a substantial contribution concerning the managerial implications, supporting industry experts in linking the sustainability movement with inventory control processes. This study's findings would benefit the decision-making process by examining and identifying different environmental and social factors that can be included in inventory models to promote sustainable development. Consequently, by incorporating several control variables of asset management, sustainable inventories allow the manufacturing industries to develop a greener climate. The use of environmentally sustainable performance metrics in model formulation encourages environmental protection and helps companies create a complex, robust inventory structure. Therefore, this research helps maintain a scalable manufacturing system that can react to developments in an environmentally friendly manner, making it possible for new product control programs to produce higher-quality products. Furthermore, due to the increasing focus on the Agenda 2030 for Sustainable Development, policymakers and governments should use the results of our study to encourage companies to implement sustainable supply chain management practices to reduce environmental pollution and promote the welfare of society.

7.3. Limitations of the Study

Even though great care has been taken to ensure the validity and findings of the study technique, some limitations must be acknowledged. First, we searched documents in the Scopus and Web of Science databases, ignoring data from other sources like Google Scholar and Business Source Complete. Furthermore, we only examined articles and reviews published in double-blind peer-reviewed journals, excluding conference proceedings, book chapters, and reports. As a result, future research could compare the results of other databases to those presented in this paper, also considering other types of publications.

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Appendix A

Table A1. Comprehensive Analysis of Papers Selected.

Authors	Publication Year/Journal Name	Research Objective
Ambec et al.	2008/Academy of Management Perspectives	Does It Pay to be Green? A Systematic Overview
Andriolo et al.	2015/International Journal of Production Economics	Haulage sharing approach to achieve sustainability in material purchasing: New method and numerical applications
Andriolo et al.	2016/International Journal of Production Research	A new bi-objective approach for including ergonomic principles into EOQ model
Asghar et al.	2019/Energies	Optimize production lot size, production rate and readability parameters
Bai et al.	2019/Environmental Science and Technology	Further Improvement of Air Quality in China Needs Clear Ammonia Mitigation Target
Battini et al.	2014/International Journal of Production Economics	A sustainable EOQ model: Theoretical formulation and applications
Bazan et al.	2017/International Journal of Production Economics	Carbon emissions and energy effects on a two-level manufacturer-retailer closed-loop supply chain model with remanufacturing subject to different coordination mechanisms
Benjaafar et al.	2012/IEEE transactions on automation science and engineering	Carbon footprint and the management of supply chains: Insights from simple models
Biuki et al.	2020/Journal of cleaner production	By using GA and PSO to find the optimal solution to the problem
Bonney et al.	2011/International Journal of Production Economics	Environmentally responsible inventory models: Non-classical models for a non-classical era
Bouchery et al.	2012/European Journal of Operational Research	Including sustainability criteria into inventory models
Bozorgi et al.	2014/International Journal of Production Economics	A new inventory model for cold items that considers costs and emissions
Centobelli et al.	2017/Transport and Environment	Environmental sustainability in the service industry of transportation and logistics service providers: Systematic literature review and research directions
Cerchione et al.	2016/International Journal of Production Economics	A systematic review of Supply Chain knowledge management research: State of the art and research opportunities
Chen et al.	2013/Operations Research Letters	The carbon-constrained EOQ
Choi et al.	2019/Sustainability	Approaching PTR (pollution base regulation) and BCR (Baseline credit regulation) to analyze stochastic optimization of the problem
Daryanto et al.	2018/Journal of Advanced Management Science	Carbon emissions from the EPQ model was minimized in order to create a cleaner manufacturing environment
Daryanto et al.	2019/International Journal of Industrial Engineering and Engineering Management	To minimize carbon emission cost, total operation, and production quantity
Datta et al.	2017/Advances in Operations Research	Effect of Green Technology Investment on a Production-Inventory System with Carbon Tax
Digiesi et al.	2013/Management and Production Engineering Review	Supply lead time uncertainty in a sustainable order quantity inventory model
Digiesi et al.	2014/IMA Journal of Management Mathematics	A sustainable EOQ model for repairable spare parts under uncertain demand

Table A1. *Cont.*

Authors	Publication Year/Journal Name	Research Objective
Digiesi et al.	2016/In New Models for Sustainable Logistics	Sustainable Inventory Management
Elkington et al.	1998/Environmental Quality Management	Partnerships from cannibals with forks: The triple bottom line of 21st-century business
Gaston et al.	2019/Environmental Science and Technology	Prioritization Approaches for Substances of Emerging Concern in Groundwater: A Critical Review
Gautam et al.	2018/Uncertain Supply Chain Management,	The model is ideally tailored to real-time inventory situations because it decreases the total expense of the device
Gautam et al.	2019/Journal of cleaner production	To maximize the total profit with management of defectives and reducing carbon emission
Hariga et al.	2017/Journal of Cleaner Production	Integrated economic and environmental models for a multi-stage cold supply chain under carbon tax regulation
Harris et al.	1913/Production Engineer	Development of the EOQ model
Hassini et al.	2012/International Journal of Production Economics	A literature review and a case study of sustainable supply chains with a focus on metrics
Hovelaque et al.	2015/International Journal of Production Economics	The carbon-constrained EOQ model with carbon emission dependent demand
Hua et al.	2016/International Journal of Simulation Modelling	Carbon-constrained perishable inventory management with freshness-dependent demand
Jasch et al.	2003/Journal of Cleaner production	The use of Environmental Management Accounting (EMA) for identifying environmental costs
Jena et al.	2018/Journal of the Operational Research Society	Managing channel profit and total surplus in a closed-loop supply chain network
Jokar et al.	2020/Journal of the Operational Research Society	Simultaneous coordination of order quantity and corporate social responsibility in a two-Echelon supply chain: A combined contract approach
Kamna et al.	2020/International Journal of System Assurance Engineering and Management	To maximize the overall inventory turnover by conjointly optimize selling price as well as production rate and time
Karmakar et al.	2017/Journal of cleaner production	A pollution-sensitive dense fuzzy economic production quantity model with cycle time dependent production rate
Kazemi et al.	2018/International Journal of Systems Science	Incorporation of carbon pollution prices into the buyer's strategy in order to reduce lot sizes and achieve minimal costs
Khan et al.	2016/International Journal of Production Economics	Information sharing in a sustainable supply chain
Kumar et al.	2021/Journal of Environmental Planning and Management	Static and dynamic regression models are used to gauge the impact of environmental management practices on firm profitability
Law et al.	2010/Asia Pacific Management Review,	Factors affecting sustainability development: High-tech manufacturing firms in Taiwan
Lee	2019/Journal of the Operational Research Society	Investment optimal lot size and carbon emission reduction in model with cap-and-price regulation policy
Lee et al.	2017/Sustainability	Sustainable EOQ under lead-time uncertainty and multi-modal transport
Lin et al.	2018/Journal of Applied Science and Engineering	Integrate economic and environmental viewpoints into the conventional inventory structure to integrate the sustainability concept
Marklund et al.	2017/Sustainable supply chains	Green inventory management

Table A1. *Cont.*

Authors	Publication Year/Journal Name	Research Objective
Mishra et al.	2021/Journal of Cleaner Production	Development of a carbon cap and tax-regulated sustainable inventory management for a buyer utilizing a linear and non-linear price-dependent demand
Mishra et al.	2019/Energies	Affected total profit and all decision variable due to impact of key parameters such as demand, production, and reduction of set-up cost, ordering cost, loss factor, and carbon emission
Mishra et al.	2020/Journal of cleaner production	This model gives better justifiable profit with highest cycle time, lowest value of fractional length period, as well as lower green technology investment cost
Modak et al.	2021/Journal of the Operational Research Society	Mathematical models are proposed for expected profit maximization under a carbon emissions tax
Mukhopadhyay et al.	2014/Systems Science & Control Engineering	Economic production quantity models for imperfect items with pollution costs
Plambeck et al.	2012/Energy Economics	Reducing greenhouse gas emissions through operations and supply chain management
Poplawska et al.	2017/Journal of the Operational Research Society	From vicious to virtuous circles: Problem structuring for quantified decision making in operationalization of corporate social responsibility
Rădulescu et al.	2009/European Journal of Operational Research	Sustainable production technologies which take into account environmental constraints
Reinmuth et al.	2017/Environmental Science and Technology	Air Pollution and Climate Change Effects on Allergies in the Anthropocene: Abundance, Interaction, and Modification of Allergens and Adjuvants
Reyes et al.	2018/International Journal of Environmental Sustainability	Corporate social initiatives of top oil players in the Philippines
Robinson et al.	2019/Environmental Management	Integration of social and ecological sciences for natural resource decision making: Challenges and opportunities
Saadany et al.	2011/Management Research Review	Environmental performance measures for supply chains
Sarkar et al.	2017/Journal of Industrial & Management Optimization	An integrated inventory model with variable transportation cost, two-stage inspection, and defective items
Sarkar et al.	2018/Applied Sciences	Minimize overall cost of production, carbon footprint reduction, and electricity cost
Sarkar et al.	2019/International Journal of Production Economics	Control carbon footprint and optimum cash-flow within a smart production system such as manufacturing, distribution, consumption, and remanufacturing
Shen et al.	2019/Sustainability	For buyer and vendor to find maximum profit and optimal production, delivery, ordering
Shu et al.	2017/Journal of cleaner production	Manufacturers'/remanufacturers' inventory control strategies with cap-and-trade regulation
Soleymanfar et al.	2015/Journal of Industrial and Systems Engineering	Economic manufacturing model under partial backordering and sustainability considerations
Suprayoga et al.	2020/Journal of Environmental Planning and Management	Identifying barriers to implementing a sustainability assessment tool for road project planning: an institutional perspective from practitioners in Indonesia
Taleizadeh et al.	2018/Journal of cleaner production	To assess the optimal value of the decision element, various scarcity conditions such as missed revenue, full backordering, and partly backordering were used
Tang et al.	2020/Mathematical problems in engineering	The results indicate that a carbon tax policy can improve social welfare and the sustainability of transportation and inventory but could hinder corporate profits

Table A1. *Cont.*

Authors	Publication Year/Journal Name	Research Objective
Tao et al.	2010/Annual Kent State International Symposium on Green Supply Chains	A green cost based economic production/order quantity model
Tenggren et al.	2020/Journal of Environmental Planning and Management	Climate risk in a globalized world: Empirical findings from supply chains in the Swedish manufacturing sector
Tiwari et al.	2018/Journal of Cleaner Production	Due effect of carbon emission cost reducing the delivery frequency and increasing the delivery quantity to minimize both the total inventory and carbon emission costs
Tiwari, et al.	2018/Journal of Cleaner Production	Sustainable inventory management with deteriorating and imperfect quality items considering carbon emission
Toptal et al.	2014/International Journal of Production Research	Joint decisions on inventory replenishment and emission reduction investment under different emission regulations
Wangsa et al.	2017/International Journal of Industrial Engineering Computations	Greenhouse gas penalty and incentive policies for a joint economic lot size model with industrial and transport emissions
Wangsa et al.	2018/Energies	The parameters like price of electricity and elasticity coefficient, production cost, scaling factor, and rate of power supply affect optimal decision variable and total profit
Wangsa et al.	2020/Journal of cleaner production	Find minimum total cost to optimize the decision variables such as order quantity, total emission, safety time, lead time, and number of shipments
Waxin et al.	2019/Environmental Management	Drivers and challenges for implementing ISO 14001 environmental management systems in an emerging Gulf Arab country
Weaver, et al.	2019/Environmental Management	A Framework for Climate Change-Related Research to Inform Environmental Protection
Wilting et al.	2017/Environmental Science and Technology	Quantifying Biodiversity Losses Due to Human Consumption: A Global-Scale Footprint Analysis
Wu et al.	2018/International Conference on Management Science and Engineering Management	To assess the relationship between the ideal quality product's predicted rate and the right output lot
Xiao et al.	2016/International Journal of Environmental Sustainability	Public design and household participation in recycling for sustainability: A case study in Hong Kong
Yassine	2018/Annals of Operations Research	Reducing environmental and social impacts to optimize lot size and total production cost
Yıldızbaşı et al.	2021/Environment, Development and Sustainability	Development of a Multi-Criteria Decision-Making (MCDM) method to identify the situation in terms of the social sustainability of the automotive industry companies in Turkey
Zadjafa et al.	2018/Journal of cleaner production	A sustainable inventory model by considering environmental ergonomics and environmental pollution, case study: Pulp and paper mills
Zadjafar & Gholamian	2018/Journal of cleaner production	Optimized the cost function along with reduction of gases and water pollutants
Zavanella et al.	2019/Journal of Business Economics	Energy cost directly impact in total cost and its environmental linkage

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