A Review of Environmental Assessment and Carbon Management for Integrated Supply Chain Models

Muhammad Idham Sabtu
Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan

Hawa Hishamuddin
Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan

Saibani, Nizaroyani
Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan

Mohd Nizam Ab Rahman
Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan

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Muhammad Idham Sabtu*, Hawa Hishamuddin, Nizaroyani Saibani, Mohd Nizam Ab Rahman

Department of Mechanical & Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia

*Corresponding author E-mail: deham899@gmail.com

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Abstract: Through the potential possibilities of improving environmental criteria into the economic prospect, it is desirable to introduce the concept of green into business practices and associated perspectives. This article reviews the existing research on inventory problems in integrated or coordinated supply chains (SC) with consideration of environmental and carbon management. The study utilised the method of selection, practical criteria, screening, and synthesis, where a total of 35 articles were selected. An analysis of the papers has revealed that SC coordination problems that are often considered include order quantity, production quantity, delivery frequency and delivery quantity in minimising costs and carbon emissions (CO_2). It was discovered that 38% of the studies considered the model's problem of production or transportation with a majority of studies, 71% considered carbon management in SC models. It is anticipated that this review will be useful for researchers who are interested in inventory modelling in the economic and environmental context by highlighting gaps for future studies and useful insights into the existing literature.

Keywords: CO_2 emission, carbon management, integrated supply chain models, review.

1. Introduction

This study presents an extensive review of existing research which is highly relevant to environmental assessment and carbon management on different levels of manufacturer-retailer relationships for integrated inventory supply chain models. A total of 35 relevant main articles were screened and selected from[1-35]. In most cases, it was discovered that organisations working within or associated with supply chains (SC) often optimise their performance[19,36-38]. Moreover, they assume that by integrating the interests of other organisations in the market, globalisation will invariably increase the complexity of the decision-making process. As a result, this leads to a deterioration in the performance of the SC system's effectiveness and resulting in a negative impact on the costly operations of other organisations. This problem attracts the interest and attention that motivates academics to investigate the development of SC integration models.

Decision-making problems can mostly be addressed by incorporating operational and management sciences to coordinate various processes within the SC. Coordinated results among SC partners are a key approach in supply chain management (SCM) that is beneficial to improve SC performance[39]. Decisions are made to integrate SC partners with various processes within the SC, including procurement, production, inventory, and transportation activities to optimise SC performance. Based on such reasons, it is therefore important to identify the root causes of decision-making problems that make SC entities uncoordinated in certain parts of the process.

In this article, decision variables from integrated models were identified and categorised for SC coordination problems. The scope of this study was further narrowed by assuming the decision is related to inventory control measures in the SC, allowing the minimisation of SC costs and the environment. Therefore, the results of the review and analysis have been expected to identify the decision variables as the criteria of the coordination problems is presented in this study. The contributing factor of CO_2 emissions is fundamentally produced from manufacturing processes and transportation activities[12], since these operations require some form of energy for combustion or burning activities[40] to operate machines, equipment or vehicles in manufacturing or delivering products within the entire SC[41]. Previously, authors[42] investigated the calculation of carbon emissions from the transportation process in maritime ports, such as the transfer of goods from piers to stacking areas and stacking. Thus, CO_2 emissions are significantly associated with energy consumption [43]. From the SC perspective, it is essential to evaluate the effects of inventory management on limiting CO_2 emissions, particularly from the manufacturing and transportation processes within the SC. It has been reported by authors[34-35] that manufacturing and transportation activities are the primary sources of CO_2 emissions.

Another aspect that is related to environmental sustainability is carbon management, such as carbon policy. Many countries continue to implement various mechanisms to reduce CO_2 emissions, including establishing mandatory incentives or targets to reduce the effects of CO_2[44]. Hence, many researchers have endeavoured to develop models that may help achieve low-carbon economic objectives. These objectives follow international or national regulations, such as the Kyoto Protocol for certain countries[24]. Most often, carbon policies that are frequently considered in the model include carbon caps, carbon tax, carbon trading, carbon penalty and carbon offsets. Therefore, this paper aims to present the findings of existing and updated research on the coordination of inventory problems in SC models with consideration of an environmental assessment, exclusively on CO_2 emissions and carbon management. It is anticipated that this study will be beneficial for SC researchers by contributing useful insights, in addition to identifying the gaps for future research to expand the SC coordination research field.

1.1 Literature Review

a. Supply Chain Inventory Models

A model is a simple representation of a real system defined as a set of concepts that are appropriate to represent but not to describe the whole object or actual process [45]. Research on inventory decisions, particularly on lot-sizing decisions in the SC, begins with the classical model of the economic order quantity (EOQ)[46]. The model assists companies in managing the extent of inventory management to anticipate demand from customers. The purpose of this model is to determine the optimal order or production quantity by offsetting the cost of inventory and the cost of preparation or ordering, thus obtaining a minimum total system cost. As a consequence, a variety of inventory models have rapidly emerged in the literature that better reflect many of the real industrial problems and constraints. Based on a review reflected in a number of authors [47-49], the problems in inventory modelling are typically aspect that influences inventory management for the current demand and supply conditions. Most inventory management models tend to focus on improving economic performance, albeit cost or profit. This matter has been explained in detail through the literature reviews discussed in previous studies [47-54]. Subsequently, there are growing concerns over environmental issues that place increasing pressure on the need to manage inventory by considering economic and environmental objectives. Therefore, most recent inventory problems that consider environmental objective functions in addition to cost functions are emphasised. For example, CO_2 emissions are included in the inventory model to represent CO_2 emissions concerning ordering, inventory, production, and transportation processes [5,55,56]. However, it is challenging to alter the inventory process towards the green concept in any industry or SC. The increased interest among researchers has led to the integration of environmental aspects into the inventory model utilising the concept of green supply chain management (GSCM) [57-59].

In order to integrate CO_2 emissions into the inventory model, previous researchers have developed a model by compiling a set of economic and environmental parameters that form the function of cost and CO_2 emissions [3,5,56,60-69]. Based on the author's observations, many researchers also assume that the structure of the CO_2 emission function is similar to the cost function that needs to be jointly optimised. Thus, the common objective of the models was developed to address management issues that assist managers in making decisions to reduce costs and CO_2 emissions. However, based on some of these studies, when the environmental aspect is included in the inventory model, it can cause a discrepancy between the cost objective function and CO_2 emissions. Therefore, some of the articles propose model solutions such as order quantity, production quantity and delivery quantity that balance the cost performance and CO_2 emissions[3,56,60]. In addition, regulatory considerations of carbon management such as carbon limits, carbon tax, carbon penalties, carbon offsets and carbon trade into basic inventory models are included in the model solution simplification process[56].

b. Basic Inventory Models with CO_2 Emission

This section discusses the reviews of previous studies incorporating CO_2 emissions into basic inventory models. Table 1 categorises each study based on inventory problems in addition to how researchers developed inventory models by considering CO_2 emissions. As depicted in Table 1, the basic inventory model refers to the EOQ or EPQ model and dynamic lot-sizing[47,48]. The model is a representation of inventory problems by considering CO_2 emissions. The purpose of the inventory model is to optimise inventory decision variables to improve costs or profit performance and CO_2 emissions. Based on Table 1, the inventory model conventionally involves cost parameters to establish a cost function related to inventory results. However, in order to develop an inventory model with CO_2 emission considerations, previous researchers also considered a set of CO_2

Table 1. Basic inventory model with carbon emission and carbon management consideration

Inventory problems		Decisions				Carbon emission	Carbon management	Authors
EOQ	lot-size	Order quantity	Binary Order	Inventory level	others			
	√	√	√	√		√	√	71)
	√	√	√	√		√	√	72)
√		√				√		73)
√		√				√	√	61)
		√				√		60)
	√	√	√	√	√	√	√	5)
√		√				√		74)
√		√				√	√	3)
√		√				√		55)
√		√				√	√	62)
	√	√		√	√	√	√	75)
√		√				√	√	65)
	√					√	√	66)
√		√				√	√	67)
√		√				√	√	56)
√		√				√		68)
√		√				√	√	63)
√		√				√	√	76)
√		√				√	√	77)
	√	√	√	√		√	√	78)
√		√				√		79)
√		√				√	√	64)
√		√				√		69)

emission parameters that form the CO_2 emission function. In order to facilitate the search for multi-functional model solutions for cost and CO_2 emissions, the model is simplified by transforming two different functions into one function [70].

The model can be simplified by directly converting the CO_2 emission function unit into a cost function since there is a need to integrate CO_2 management for example carbon limit, carbon tax, carbon trade, carbon penalty and carbon offset[5,56]. This is because such regulation affects the budget in the form of incentives or taxes[5,56].

Based on Table 1, researchers' [60,61,68,69,74] constructed an EOQ model by considering CO_2 emissions as an additional source of economic costs, in order for the model to focus on cost reduction only. The authors[60] examined environmental costs referring to CO_2 emissions from transportation activities. At the same time, the authors [61] here assumed the cost of CO_2 emissions from production, transportation, and inventory processes considering carbon policies in the EOQ model. The authors[60] integrated the cost of CO_2 emissions from warehouse inventory into a basic EOQ model. Next, the authors [68] investigated the effect of CO_2 emission costs on order size and total customer profits in an imperfect supply process, where buyers received a group of product containing a percentage of defective items. While the authors in [69] investigated the cost-effectiveness of CO_2 emissions to production and location decisions for manufacturers.

Other examples of research studies include the integration of CO_2 emission function modelling into EOQ models to minimise CO_2 emissions jointly. Authors in [55] proposed a modified EOQ model by calculating the cost and CO_2 emissions. At the same time, other authors[73] adopted the EOQ model framework towards multi-objective optimisation problems where cost and CO_2 emissions functions were examined in combination, comparing transport sharing methods. The authors [79] here considered the environmental impact of a multi-level manufacturing system having demand and information uncertainty.

Most researchers listed in Table 1 discussed EOQ inventory problems or lot-sizing with CO_2 emission functions while considering that of carbon management. For instance, the authors[56] here investigated the approach that industry could adopt in managing CO_2 emissions in the process of controlling inventory based on EOQ models with carbon trade considerations. While the authors[3] here proposed the EOQ, in establishing multi-objectives by considering carbon trade and carbon tax. Next, the authors [62]) in another study examined the reduction of total costs, subject to carbon limits proving that carbon limits are effective when the setting value is low in triggering a change in the quantity ordered.

Authors[76] in these studies analysed the EOQ model by considering cost, transport capacity, and carbon limits by considering the characteristics of multi-truck emissions used for transport inclusion. Then, some authors[63] have investigated the impact of full truck transport, transport with less than truck capacity, and carbon policy on the optimum order quantity based on the EOQ model.

Meanwhile, the authors[65] here examined the size of production based on the EOQ model and optimal CO_2 emissions under carbon trading regulations. In another study, the authors[67] proposed a solution approach that considered the relationship between EOQ models, total CO_2 emissions, product prices and demand to increase profits and reduce CO_2 emissions. Here the authors[71] constructed a dynamic lot-sizing model by considering carbon limits, while in another study the authors[5] identified the impact of operational results on CO_2 emissions by incorporating CO_2 emission considerations into a dynamic lot scheduling inventory model. The study also considered carbon limits and carbon taxes in the model.

The authors[78] in this study examined a supply chain based on a dynamic lot filtering model where buyers have the option to obtain products from different suppliers. Each supplier is considered to use a specific mode of transportation, where the mode selected is assumed to depend on the distance between the buyer and the supplier. The purpose of the model is to study how different carbon management mechanisms, such as carbon limits or carbon taxes, affect inventory decisions, supplier selection and mode of transport within the SC. In other studies, the authors[66] developed a dynamic lot filtering model with carbon limit considerations, by examining CO_2 emissions during each defined carbon limit constraint period. Here, the authors[77] developed a classic EOQ model for uncertain market demand conditions by providing a simple solution for the optimal order quantity reproduced under any type of random distribution from market demand and carbon management. The purpose of the model was to maximise profits and reduce CO_2 emissions. Interestingly, most of the proposed models, as shown in Table 1, consider only one industry.

Although the development of the inventory models in Table 1 is greener than the basic inventory model which includes of environmental perspectives, the model solution is still unable to achieve an optimal outcome overall. Therefore, this study elaborated on the effectiveness of an integrated inventory model involving various industries involved in the SC by considering CO_2 emissions. In the process of reviewing these studies, an integrated inventory model, the basic inventory model was used as a reference. The analysis in Section 3 presents the results in reviewing integrated inventory models considering CO_2 emissions. Initially, the integrated inventory model can be described as a coordination process involving inventory problems in the SC. However, the dimension of an integrated SC requires two or more parties to cooperate toward a common objective in designing and implementing activities in the SC effectively [80,81]. The integrated decision-making process in the SC requires the interchange of information towards operational planning between SC members[22]. The purpose is to gain more productive decisions which are a flexible reaction to environmental changes and enhanced economic performance[82].

By attracting the attention of many academicians, research on integrated inventory models has moved forward. The majority of previous studies tend to concentrate more on solving coordination problems given the uncertainty of inventory decisions between manufacturers and retailers where both parties are independent in managing their activities[83-85]. However, existing review articles are limited in discussing the importance of an integrated inventory model to enhance environmental objectives. Nonetheless, more recent reviews undertaken by researchers on the integrated inventory decision model conducted by authors[47,84,86-90] does not report on any environmental aspects, in particular, CO_2 emissions.

2. Methodology

This section discusses the methodology associated with the inventory model integrated with CO_2 emission considerations. The methods of this study employed the approach proposed by the author[91], which applies four principal steps regarding the literature review method. Generally, this approach is begun by selecting the appropriate research questions, database, website, and search terms. Next, practical examination criteria are used to examine the relevant literature. The next step uses methodological screening criteria to assess the most accurate literature in terms of quality, and the final step is through the descriptive synthesis of search results. Fig. 1 illustrates the research flowchart to obtain the appropriate article according to the topic under study.

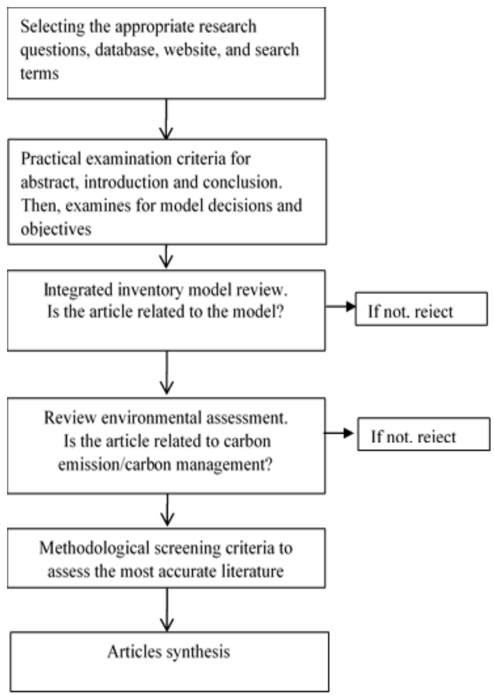

Fig. 1: Flowchart of literature review methodology

a. Selection of research questions, databases and websites, and appropriate search terms

This study has focused exclusively on CO_2 emissions and carbon management. For the first step in developing the research questions represent the problems affecting the integrated green inventory model and characteristics of the model itself. Furthermore, research questions such as the source of coordination problems, SC dimensions, environmental aspects and carbon management in the model were employed. Further to that, databases like Elsevier, Emerald, Springer, Taylor & Francis and Google Scholar and Wiley with particular on quality standard of paper indexed in Scopus and ISI and search terms were used to locate relevant literature. To search all green integrated inventory model studies, the search terms used were a combination of three categories, namely, integration, SC and the environment where each category has its own derivative terms related to the topic under study.

b. Practical examination criteria

The author[91] proposed two criteria in determining whether to include or exclude the criteria in the literature review and analysis. The first criteria focused on narrowing the search, including publication type, language, and publication date. According to these criteria, the selection included articles, journals, conference proceedings, books, and research reports. The second criterion was to find the article that was most relevant to this topic. Next, each article was manually reviewed by examining the title, abstract, introduction, and conclusion. For the content of the article(s), any article related to the study of integrated green inventory model was included in for further analysis.

c. Applying the Screening criteria

In this step, a research protocol was developed to assess the scientific quality of the article(s) in meeting the goals of this study. This tool was particularly useful where study protocols contained specific information on special research questions addressed in a systematic review[92]. The study protocol discussed the bibliography of each publication. This section analyses the relevant publication patterns of this study from year to year. The second part deals with the focus and content of the publication.

d. Synthesis of Articles

From the literature review, a total of 35 articles were considered suitable for further analysis by follows the sequence of procedure in section a to section c systematically. The articles were analysed for each period (i.e., year), as shown in Figure 2. The first article was for the year 2011 until the present time (2020) in which the study was undertaken. This indicated that the study of integrated green inventory models had been recent since conventional studies first emerged in 1976[38]. The pattern of green integrated inventory models examined indicated most were published in 2017. This shows that the topic was relevant and important for consideration in the business environment, especially for inventory decision-making. There were many articles related to carbon emissions and environmental assessment [93-108], following this approach.

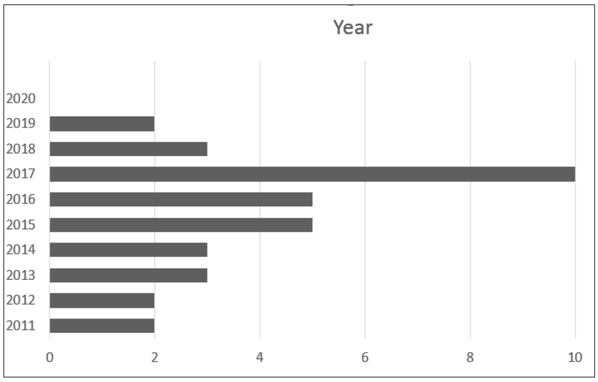

Fig. 2: Number of articles per year

3. Results and Discussion

In this section, the findings are separated into main sections in examining coordination problems, the SC dimension and analysis of environmental aspects and carbon management considered in the integrated inventory model.

a. Analysis of coordination problems and SC dimension considered in the integrated inventory model

Previous researchers tended to be motivated in developing a green integrated inventory model to address coordination problems in consideration of environmental aspects, especially identifying the effect of inventory changes on CO_2 emissions, as shown in Table 2.

The causes of coordination problems or model decision variables that researchers often considered included order quantity, production quantity, delivery frequency, and delivery quantity. However, each model that was studied had different decision variables, depending on the perspective and case study faced by the researcher in integrating the SC process.

The SC dimensions included the category of participants, the structure and process of the SC. The SC participants involved in the model are depicted in Table 3. The participants, however, could be extended to include other participants, such as third-party logistics, wholesalers and retailers [45].

The authors[38] here explained the focus of an integrated inventory model based on the SC structure, which is divided into two categories. The first category is a two-stage model consisting of two echelons with one or two participants at each level. Whereas the second category is a multi-level model that considers advanced echelons in analysis, such as raw material suppliers or logistics service providers.

Table 2. Coordination problems considered in the green integrated inventory model

Coordination problems	Model objectives	Authors
Delivery quantity and delivery frequency.	Maximise SC profits and minimise environmental quality-related costs.	[1]
Order quantity, production quantity, and delivery frequency.	Minimise SC costs and costs associated with CO_2 emissions.	[2]
Order quantity.	Minimise SC costs and CO_2 emissions.	[3]
Manufacturer order quantity, supplier and manufacturer production rate, product price, and number of investments.	Maximise profits and minimise CO_2 emissions.	[4]
Order quantity, order binary, inventory level, and order quantity.	Minimise SC costs and CO_2 emissions.	[5]
Production quantity, inventory level, and order quantity.	Minimise SC costs and CO_2 emissions.	[6]
Production rate and delivery quantity.	Minimise SC costs and CO_2 emissions.	[7]
Production quantity, delivery quantity, and delivery frequency.	Minimise SC costs and costs associated with CO_2 emissions.	[8]
Production quantity, delivery frequency, delivery quantity, selling price, and total investment to improve production process.	Maximise profits and minimise CO_2 emissions.	[9]
Order quantity, delivery frequency, and production rate.	Minimise SC costs and CO_2 emissions.	[10]
Production quantity.	Minimise SC costs and CO_2 emissions.	[11]
Production rate, and frequency of delivery.	Minimise SC costs and CO_2 emissions.	[12]
Cycle length, order quantity, delivery quantity, lot allocation ratio, transition plan, cumulative loading quantity, supplier selection plan, and vehicle selection plan.	Minimise SC costs and CO_2 emissions.	[13]
Order quantity	Minimise SC costs and CO_2 emissions.	[14]
Preparation cost, increase in delivery quantity rate, delivery frequency, and first delivery quantity	Minimise SC costs and CO_2 emissions.	[15]
Order quantity, production quantity, and delivery frequency	Minimise SC costs and CO_2 emissions.	[16]
Order quantity, production quantity, and delivery frequency	Minimise SC costs and CO_2 emissions in transportation and inventory.	[17]
Delivery quantity, frequency of delivery, and profit per unit of product for suppliers and customers.	Maximise SC profits and minimise CO_2 emissions costs.	[18]
Order quantity, production quantity, and delivery frequency.	Minimise SC costs and CO_2 emissions.	[19]
Supplier, manufacturer, and customer cycle times, and delivery frequency.	Minimise SC costs and CO_2 emissions related costs.	[20]
Order quantity, production quantity, and delivery frequency.	Minimise SC costs and CO_2 emissions.	[21]
Order quantity, delivery quantity, and delivery frequency.	Minimise SC costs and CO_2 emissions.	[22]
Shipment quantity, shipment quantity, number of reproduction generations.	Minimise SC costs and CO_2 emissions costs.	[23]
Delivery frequency, return order point, and order quantity.	Minimise SC costs and CO_2 emissions.	[24]
Order quantity, delivery quantity, delivery frequency, order time cycle, and number of trucks.	Minimise SC costs and CO_2 emissions.	[25]
Order quantity, safety factor, and delivery frequency	Minimise SC costs and CO_2 emissions costs.	[26]

Coordination problems	Model objectives	Authors
Order quantity, frequency of delivery, quantity of delivery, and rate of production.	Minimise SC costs and CO_2 emissions costs.	27)
Wholesale and retail price, breakdown time, cycle time, and excessive number of machines.	Maximise SC profits and minimise CO_2 emissions.	28)
Order quantity	Minimise SC costs and CO_2 emissions.	29)
Order quantity	Minimise SC costs and CO_2 emissions.	30)
Order quantity	Minimise SC costs and CO_2 emissions and carbon taxes	31)
Order quantity, production quantity, delivery frequency, defective product proportions, and time cycle	Minimise SC costs and CO_2 emissions.	32)
Order quantity	Minimise SC costs and CO_2 emissions.	33)
Order quantity, delivery frequency, production rate, safety factor, re-order point, and number of routes.	Minimise SC costs and CO_2 emissions.	34)
Order quantity, delivery frequency, and production rate.	Minimise SC costs and CO_2 emissions.	35)

Table 3. Results of the SC dimension analysis

SC dimension	Authors
Participants: Single Supplier-Single customer Structure: Two levels Process: Order-inventory	3,22)
Participants: Single Supplier-Single customer Structure: Two levels Process: Order-production-inventory	1,4,6,7,9,10,29,30,33)
Participants: Single Supplier-Single customer Structure: Two levels Process: Production-inventory-transportation	11)
Participants: Single Supplier-Single customer Structure: Two levels Process: Order-inventory-transportation	25)
Participants: Single Supplier-Single customer Structure: Two levels Process: Ordering-Production-Inventory-Transportation	2,8,12,14,15,16,17,18,19,21, 23,24,26,27,31,32,35)
Participants: Single Supplier-Multiple customers Structure: Two levels Process: Ordering-Production-Inventory-Transportation	28,34)
Participants: Multiple single-customer suppliers Structure: Two levels Process: Ordering-Production-Inventory-Transportation	13)
Participants: Single supplier-single Manufacturer-Single customer/Multiple customers Structure: Multi-level Process: Ordering-Production-Inventory-Transportation	5,20)

Next dimension of the SC process is the process consisting of the functions: order, production, inventory, and transportation. Each SC process function has its own cost component factored into the inventory decision-making process, such as order costs, preparation, production costs, inventory costs and transportation costs incurred in the ordering, production, inventory, and transportation processes, respectively. In this regard, each article has a different perspective when considering the function of the SC process and the costs associated with that process for the development of a green integrated inventory model. The SC dimension analysis for each relevant study is summarised in Table 3.

Table 3 is related to the analysis of SC participants. The

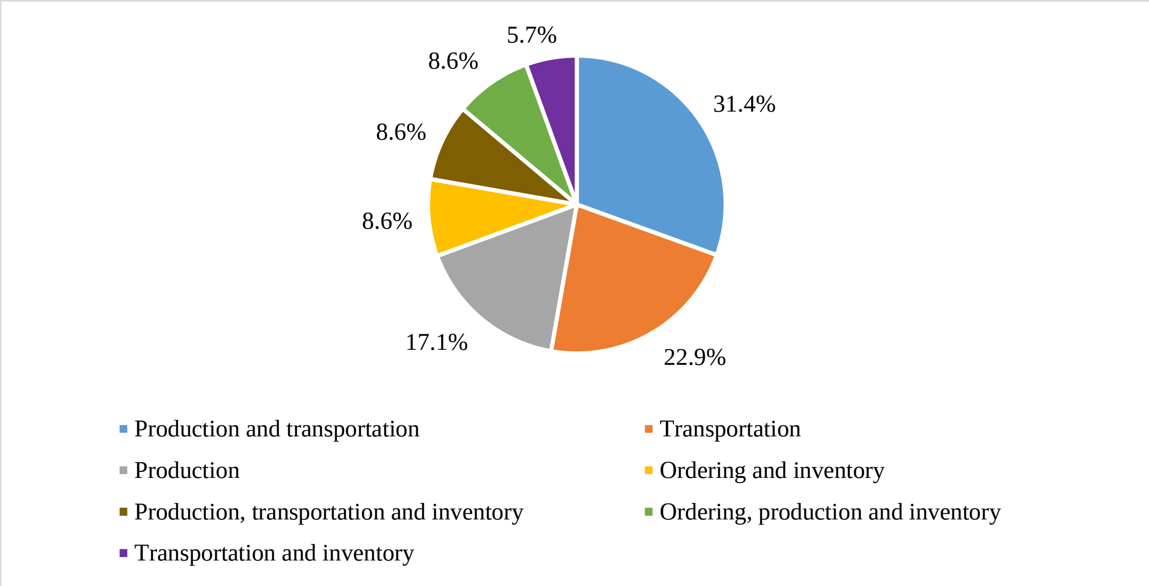

Fig. 3: Environmental assessment on the SC process

majority of research studies as highlighted the above table represent the SC integrated system with a 1:1 relationship based on two-stage considerations, for example, single supplier and single customer relationships. This relationship is considered the basic structure in representing dependence within the SC. Also, the 1:1 relationship is considered by most researchers as a preliminary test to develop a model that addresses two objectives in addition to being used for minimising SC cost and CO_2 emissions.

For a more complex relationship, researchers have previously considered a two-tier model consisting of two or more participants at each SC level. The authors[28,34] here considered single manufacturers and multiple customers in the model, while the authors[13] in this study analysed multiple single-customer suppliers. Here the authors[5,20] proposed a model having multi-level considerations.

In identifying the participants involved in the SC, it is important to understand the role of all participants and relationships [109-111]. This indicates that a green integrated inventory model can be developed if the business strategy and targets of all participants are clearly stated. Therefore, researchers can suggest integrated inventory results concerning models that bring economic benefits and having minimal impact on the environment within the SC. For this reason, researchers need to identify the process on which each SC participant is considered to be integrated. This is closely related to the key parameters in the SC process used for decision-making.

Moreover, the majority of researchers in previous studies considered the SC's overall process of ordering, production, inventory, and transportation. However, there are several studies in simplifying the model by considering two or three SC processes. Regarding Table 3, many researchers considered three SC processes, namely ordering, production and inventory process. Whereas the authors[11] here considered the production, inventory, and transportation processes. Some authors[25] developed a model considering the ordering process, inventory, and transportation, while other authors[3,22] only considered two processes for ordering and inventory.

b. Analysis of environmental aspects and carbon management

After identifying the SC's dimension that was considered in the model, not all SC processes were associated with CO_2 emissions. Therefore, the developer of the integrated green inventory model only involved the SC process, which is considered the most effective means in producing CO_2 emissions. Based on the results of the analysis presented in Fig. 3, it reveals that 31% from 11 articles consider production and transportation as the main cause of CO_2 emission problems[8,11, 12,15,18,21, 23, 26, 27,34,35]. This is because CO_2 emissions in the company are from burning activities to generate energy to produce products from raw materials[41] (UNDP 2014). While the source of CO_2 emissions in the transport process is related to each product delivery network from one location to another, thus requiring energy from the combustion of fossil fuels at a certain distance[33]. Subsequently, only eight articles (22.9%) examined the source of CO_2 emissions in the transportation sector[2,6,13,14,20,25,31,33] and six articles (17.1%) examined CO_2 emissions in production[1,4,7,9,10,21].

Some studies also allocated CO_2 emissions on the ordering process, but implicitly considered the process to be equated with CO_2 emissions on the transport process. Also, other studies considered CO_2 emissions derived from the inventory process as a result of storing products per unit time. For instance, a study involving CO_2

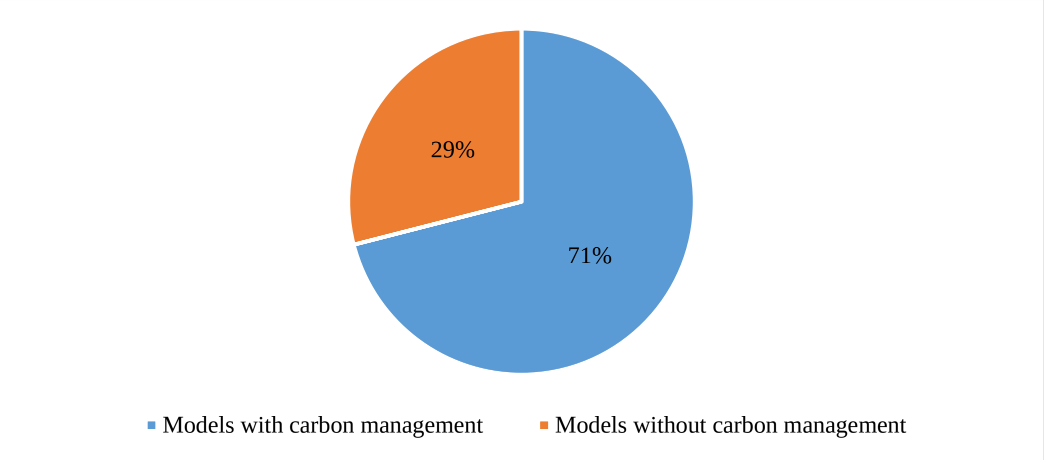

Fig.4. An integrated inventory model with environmental assessment and carbon management

emissions in the ordering and inventory process were evident in three articles (8.6%)[3,22]. Another study considered three processes concurrently for production, transportation, and inventory as three articles (8.6%)[3,22,29] and a combination of three other processes for order, production, and inventory in three articles (8.6%)[5,16,30], and two articles (5.7%) studied CO_2 emissions in transportation and inventory[17,32].

Another aspect related to the environment is carbon management. This is because many countries worldwide are now implementing various mechanisms to reduce CO_2 emissions, including mandatory incentives or targets to reduce the effects of carbon emissions[44]. Moreover, many researchers have endeavoured to develop models that can help meet low-carbon economies as a reference that follow international or national agreements, especially Kyoto Protocols[24]. Major carbon policies that are frequently considered in the model include carbon caps, carbon tax, carbon trading, carbon penalties, and carbon offset. Fig. 4. classifies the studies that analysed the integration of carbon management into a green integrated inventory model.

Based on Fig. 4, the majority of articles (25) signifying 71% considered carbon management, while only ten articles (29%), developed a model without involving a carbon policy. From the 25 articles, it was found that many studies integrated a carbon tax into the model. Generally, the regulation of carbon is determined by the government in the respective country[29]. A carbon tax is linear in nature with the number of carbon units emitted[5]. A total of seven articles only considered tax [13,14,18,19,23,25,32].

Nevertheless, several researchers developed models with other carbon management considerations such as carbon limits, carbon business, carbon penalties and carbon offsets. The carbon limit sets the policy by establishing the maximum allowable CO_2 emissions per unit of time[5]. In this literature review, only one article had considered carbon limits[24]. In addition, the carbon business policy occurs when companies produce more CO_2 emissions than the carbon limit. Accordingly, they need to buy the balance of their CO2 emissions in the carbon market. In this case, only one article examined a single carbon policy into a model[17]. For carbon penalties, this refers to penalties that are imposed for exceeding the carbon range limit or threshold[7]. Based on the literature, only one article examined a single carbon policy for carbon penalties included in the model[26]. Lastly, the carbon offset is almost identical to that of the carbon trading policy; however, the carbon offset is the investment charged for exceeding the carbon limit. These investments can be in various forms such as energy-efficient equipment and facilities, renewable energy sources and energy-saving programmes[61].

In addition, only the author[5] here considered a complete carbon policy. The study examined models with carbon policies, including carbon limits, carbon business, carbon offsets, and carbon penalties. A total of seven articles considered models with the carbon tax and carbon penalties[7,10,11,12,21,34,35]. Here, two articles proposed a model with the carbon tax and carbon penalty[27,29]; one article constructing a model with carbon limits and carbon business [3]; one article building a model with carbon limits and carbon tax [28], and one article that developed a model with carbon limits, carbon tax, and carbon business[16].

4. Conclusion

This article provides important findings on identifying environmental aspects in the SC process that are considered effective against CO_2 emissions in the integrated inventory model. The causes of integrated problems or model's decision variables that researchers have often considered include order quantity, production quantity, delivery frequency, and delivery quantity to minimise costs and minimise CO_2 emissions. However, each model has different decision variables and depends on the objectives as well as the case study in question. Thirty-eight per cent of articles considered production or transportation processes in integrated SC model. This demonstrates that there remain many researchers who have failed to consider the main source of emissions in the

SC from a holistic point of view. In addition, the majority of previous studies signify SC integrated systems with a simple 1:1 relationship ratio based on two-stage considerations, for example, single supplier and single customer relationships. Therefore, future studies should include at least two key processes, namely production and transportation, in various relationships such as (1: *n*). In the event that the model only considers one process, then it will generate biased decisions on the performance of CO_2 emissions on other processes.

Seventy-one per cent of articles considered the aspect of carbon management in the SC model. The integration of carbon management into a green integrated inventory model could attract the attention of future research. The effects of carbon management on companies may include supply chain decisions, selection of modes of transportation and effective logistics management. Therefore, by considering carbon emissions and carbon management in the model, it can help SC managers to make proper decisions in addressing the reduction of CO_2 emissions targets set by the company or via government regulation.

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