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Towards Energy Efficiency in Integrated Inventory Supply Chain Models: A Review

(Ke Arah Kecekapan Tenaga dalam Model Rantaian Bekalan Inventori Bersepadu: Ulasan)

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ABSTRACT

Amidst the sustainability concerns of the industrial sector to fulfil the increase in customer demands, this study emphasizes on the characteristics of integrated inventory supply chains that is closely related to energy efficiency. Environmental and economic perspectives must be given equal consideration to ensure a competitive supply chain (SC). In response to global calls for sustainable energy and lower carbon emissions, the Malaysian government currently provides tax exemptions and allowances for the provision of green technology services and the acquisition of green technology assets. Furthermore, as sources of electricity are highly variable, efficient SC activities can feasibly minimise the cost of energy. Therefore, multiple studies have integrated the green concepts in SCs to develop energy efficient integrated inventory SC models. This present review examined 42 articles that assessed the environmental impact of integrated inventory SC models with a focus on energy efficiency and energy-related issues. A systematic literature review (SLR) was conducted to identify gaps in the existing literature and offer directions for future studies. The articles were categorised according to the SC dimensions of an integrated inventory model; such as categories of SC participants, structures, processes, and decision-making variables. Of the reviewed articles, only 35% examined energy efficiency or energy-related issues in integrated inventory models. Therefore, future studies should examine the energy efficiency or energy-related issues that integrated inventory SCs face.

Keywords: Integrated inventory model; supply chain; energy; review

INTRODUCTION

Increased energy usage and demand is currently a major global concern. The manufacturing sector faces tremendous environmental and economic concerns (Mokhtari & Hasani, 2017). It is estimated that approximately 20% of the total manufacturing cost is spent on energy and emissions (Marchi et al. 2019a). Therefore, the industry needs to strengthen its competitive position in the global market by ensuring that all supply chain (SC) members work together, towards the same goal, as well as use the same SC network and integrated SC management models to meet customer demands (Glock 2012a). Energy management can be used to reduce the amount of energy that the manufacturing industry uses (May et al. 2013). As such, the industry should seriously consider increasing energy efficiency using integrated inventory models.

This study discusses the evolution of the integrated inventory model to the extended integrated inventory model; which focuses on environmental impacts and carbon dioxide (CO_2) emissions. Inventory management is a key component of product supply chain coordination as it is a material flow system that connects supply chain partners (Bushuev et al. 2015). SC participants use inventory integration models; that integrate and coordinate material, information, and cost; to manage and replenish inventory between suppliers-manufacturers and suppliers-customers. The model also uses management decisions to streamline various SC processes; such as purchasing, production, inventory, and transportation; to boost SC performance (Glock 2012b; Bahinipati et al. 2013; Glock et al. 2014).

According to Glock (2012a), the integrated inventory model was developed using two inventory models; economic order quantity or economic production quantity and lot sizing. Basic integrated inventory models can consist of only two stages or multiple stages. A two-stage model consists of two echelons with one or more participants at every stage while a multi-stage model consists of additional echelons; such as material suppliers or third party-logistics. These models were then extended to take into consideration stochastic demand, stochastic lead time, order or setup cost-lead time reduction, and product quality to name a few (Glock 2012a).

Most basic integrated inventory models only consider costs; such as set-up inventory, ordering, and logistics; during model development. Therefore, they do not take environmental impacts into consideration. This was evident in the single supplier-single customer model (Roy et al. 2012) and single supplier- multiple customer model (Hoque, 2011) that extant articles have developed. However, other articles have extended these models to take additional costs; such as delivery time, degradation, and product quality; into consideration (Moon et al. 2011; Lee & Fu 2013). Other SC dimensions; such as participants, structures, and processes; must be taken into consideration when developing models (Glock 2012a). Therefore, this present review identified SC dimensions to determine the extent to which integrated inventory models take environmental impacts into consideration during inventory decision-making.

At present, only a handful of articles have developed integrated inventory models that assess environmental impacts; specifically, the effect of inventory decisions on CO_2 emissions; while trying to overcome coordination problems (Li et al. 2017; Tiwari et al. 2018; Castellano et al. 2019; Marchi et al. 2019). Most of the articles only identified order quantity, production quantity, delivery frequency, and delivery quantity as the causes of coordination issues (Bouchery et al. 2012; Bouchery et al. 2017; Glock et al. 2012b; Jaber et al. 2013; Ghosh et al. 2016; Jiang et al. 2016; Toptal & Cetinkaya, 2017; Tiwari et al. 2018; Zissis et al. 2018; Tiwari et al. 2018; Castellano et al. 2019; Huang et al. 2020; Jauhari & Wangsa, 2022). However, the model that each of these articles developed used different sets of decision-making variables according to the perspective of the researcher as well as the case study in question. Apart from managing CO_2 emissions, there is also a need to develop energy-saving measures. Multiple articles have identified problems with the inventory decisions that SC participants make to streamline processes in order to enhance economic performance while reducing environmental impacts, energy consumption, and CO_2 emissions (Chan et al. 2013; Bazan et al. 2015a; Bazan et al. 2015b; Hariga et al. 2017; Paul et al. 2014; Bazan et al. 2017; Dwicahyani et al. 2017; Darma 2017; Li et al. 2017; Marchi et al. 2019; Hasanov et al. 2019; Wangsa et al. 2020; Gautam et al. 2021; Jauhari et al. 2022; Singh & Mishra 2022).

As various operations require energy for execution, therefore, the energy required to execute an entire production should be taken into consideration when discussing production systems. Energy consumption must be taken into consideration and minimised to meet sustainability objectives (Gautam, 2021). The production processes of energy-intensive industries require massive amounts of electrical energy (Marchi et al. 2019). As the costs of energy and emissions are expected to rise, these factors are far too pertinent to be ignored. Bazan et al. (2015) and Marchi et al. (2019) have extensively studied the energy consumption process of integrated inventory models and concluded that energy cost affects inventory holding cost. Examples of energy costs include material handling, or the energy used to maintain the temperature of a warehouse where inventory is stored (Paul et al. 2014). Additionally, as seen in Figure 1, energy efficiency can be generally considered throughout the supply chain. However, energy efficiency is typically measured in areas like production and logistics, which substantially contribute to energy consumption.

This present review examined existing literature that assessed the environmental impacts of energy efficiency in an integrated inventory SC. The purpose of this present review was to identify articles that could provide insights on integrated inventory SC models as well as identify gaps in existing energy-related studies. Extant studies have extensively examined integrated inventory problems in SC models (Glock 2012a; Bushuev et al. 2015). However, very few studies have holistically reviewed integrated inventory models that assess energy. Therefore, the purpose of this present review was to classify and contextualise the SC dimensions of existing studies on integrated inventory models that assess environmental impacts and energy efficiency. The evolution of issues in integrated inventory SC in terms of assessing environmental impacts were also examined. The overall structure of the present review takes the form of four main sections, including an introduction, methodology, results and discussion and conclusion.

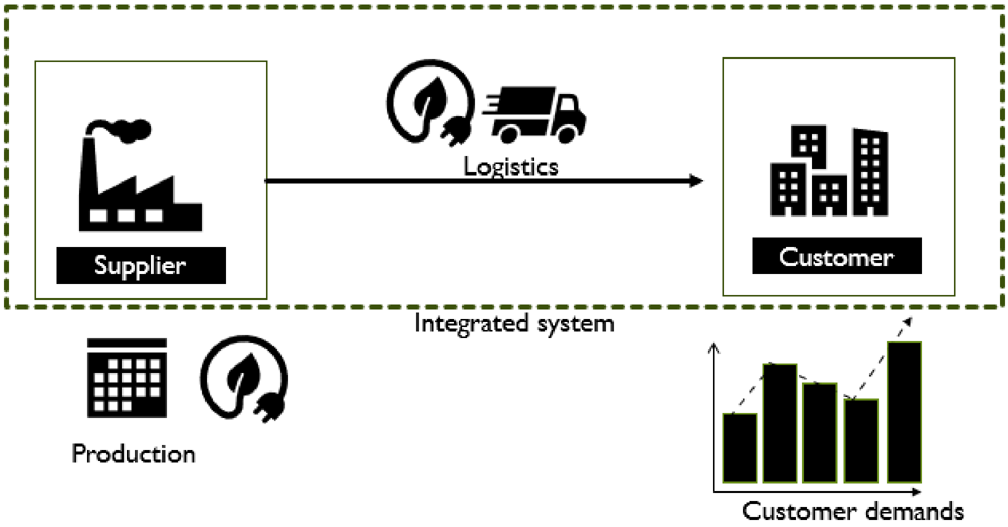

FIGURE 1. Integrated supply chain with energy efficiency consideration

METHODOLOGY

A systematic literature review (SLR) was conducted according to the methodologies outlined by Fink (2014), Pattnaik et al. (2021), and Govindan et al. (2022). According to Govindan et al. (2022), an SLR is a type of literature review that identifies essential information and provides manageable results for additional investigation and final conclusions regarding the purpose of the study. It also attempts to reduce bias by documenting the review techniques, decisions, and conclusions based on an extensive search of both published and unpublished studies. The SLR of this present review was conducted in four major steps as shown in Figure 2: 1) selecting the research questions, database, and comprehensive search parameters, 2) outlining the screening criteria, 3) qualitatively evaluating the relevant literature, and 4) forming a descriptive synthesis.

The SLR method was used to investigate integrated inventory models and their environmental impacts. The primary purpose of the SLRs was to identify research gaps in the selected articles. Therefore, the research questions were developed to achieve the purpose of the SLR. The research questions focused on the problems affecting integrated inventory models that take environmental impacts into considerations and the characteristics of the model. These questions included integrated decision-making problems, SC dimensions, and environmental impacts. Advanced searches were conducted on databases; such as Elsevier, Wiley, Emerald, Google Scholar, and Taylor & Francis; while the search terms included integrated supply chain inventory, supply chain management, environmental, energy, and carbon emission.

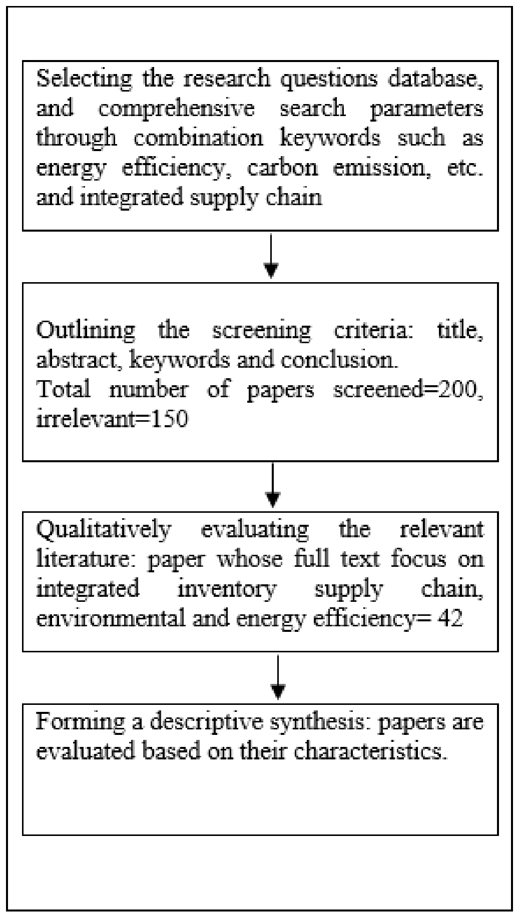

FIGURE 2. Literature selection procedure

Screening criteria were then used to identify the most relevant articles before they were filtered according to type and year of publication. Only technical and empirical publications, articles, and research books were included in this present review. The quality of the shortlisted articles was then examined by skimming the title, abstract, introduction, and conclusion. A descriptive synthesis, which is the results of the main findings and research gaps, was then descriptively presented. As seen in Figure 3, a total of 42 articles that assessed the environmental impact of integrated inventory models were published between 2011 to 2022. The descriptive analysis of these shortlisted articles was then used to identify gaps in the dimensions of models that assess energy performance.

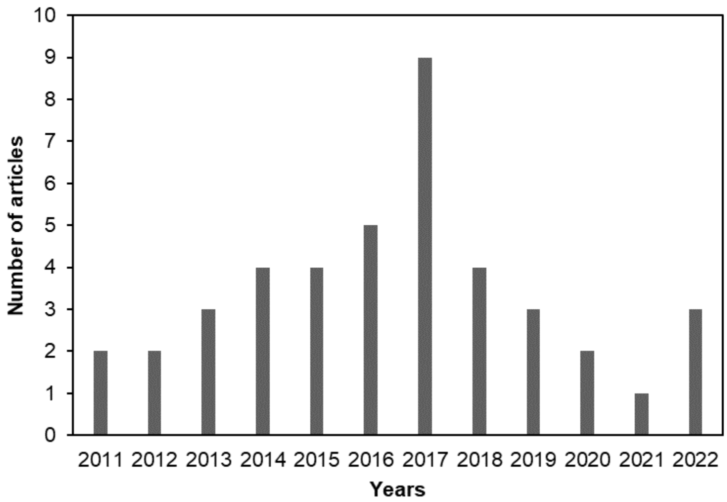

FIGURE 3. Quantity of articles on integrated inventory models

RESULTS AND DISCUSSION

SC DIMENSIONS OF INTEGRATED INVENTORY MODELS WITH ENVIRONMENTAL IMPACTS

The results of analysing the supply chain (SC) dimensions of integrated inventory models that assess environmental impacts are discussed in this section. The SC dimensions include SC participants, structures, and processes as well as environmental impacts, which was categorised under energy consumption and carbon emissions. SC participants come in a variety of forms; such as suppliers, customers, and extended participants, such as third-party logistics providers. Coordinated inventory models were then examined with a focus on SC structure, which include two-level and multi-level structures.

The SC process includes ordering, production, inventory, and transportation. The dimension of the process is a cost element that models must take into consideration as it is important for the construction of the model. An inventory model that assesses environmental impacts can be constructed using the various components of the SC processes involved. Therefore, this present review identified SC dimensions that generally relate to environmental impacts with a focus on energy, specifically in relation to the energy models that have been developed by extant studies (Table 1).

TABLE 1. SC dimensions of integrated inventory models that assess environmental impacts

Participants (P1-P4)				Structure (S5-S6)		Process (P7-P10)				Environmental Performances		Authors
P1	P2	P3	P4	S5	S6	P7	P8	P9	P10	Energy Efficiency- & Energy-Related	Carbon Emissions & Carbon Management	
✓				✓		✓					✓	Bouchery et al. 2012
✓				✓		✓					✓	Bouchery et al. 2017
✓				✓			✓				✓	Saadany et al. 2011

continue ...

... cont.

✓				✓		✓				✓	Glock et al.2012
✓				✓		✓			✓	✓	Chan et al. 2013
✓				✓		✓			✓	✓	Hariga et al. 2017
✓				✓		✓				✓	Jaber et al. 2013
✓				✓		✓				✓	Zanoni et al. 2014 a
✓				✓		✓				✓	Zanoni et al. 2014 b
✓				✓		✓				✓	Tao et al. 2018
✓				✓		✓				✓	Toptal & Çetinkaya, 2017
✓				✓		✓				✓	Zissis et al. 2018
✓				✓			✓		✓	✓	Bazan et al. 2015a
✓				✓			✓		✓	✓	Bazan et al. 2015b
✓				✓				✓		✓	Wahab et al. 2011
✓				✓				✓	✓	✓	Paul et al. 2014
✓				✓				✓	✓	✓	Bazan et al. 2017
✓				✓				✓		✓	Gurtu et al. 2015
✓				✓				✓		✓	Sarkar et al. 2015
✓				✓				✓		✓	Ghosh et al. 2016
✓				✓				✓		✓	Jiang et al. 2016
✓				✓				✓		✓	Khan et al. 2016
✓				✓				✓		✓	Yang et al. 2016
✓				✓				✓		✓	Ghosh et al. 2017
✓				✓				✓		✓	Darom et al. 2018
✓				✓				✓		✓	Tiwari et al. 2018
✓				✓				✓		✓	Jauhari & Wangsa, 2022
✓				✓				✓	✓	✓	Dwicahyani et al. 2017
✓				✓				✓	✓	✓	Darma, 2017
✓				✓				✓	✓	✓	Li et al. 2017
✓				✓				✓	✓	✓	Marchi et al. 2019
✓				✓				✓	✓	✓	Gautam et al. 2021
✓				✓				✓	✓	✓	Jauhari et al. 2022
✓				✓				✓	✓	✓	Singh & Mishra, 2022
	✓			✓				✓		✓	Karimi & Niknamfar, 2017
	✓			✓				✓		✓	Castellano et al. 2019
		✓		✓				✓		✓	Glock & Kim, 2014
			✓		✓			✓		✓	Benjaafar et al. 2013
			✓		✓			✓		✓	Sarkar et al. 2016

continue ...

	✓		✓	✓	✓	✓	Hasanov et al. 2019
✓		✓		✓		✓	Huang et al. 2020
	✓	✓		✓	✓	✓	Wangsa et al. 2020

Legends:

P1. Single supplier-single customer
P2. Single supplier-multiple customers
P3. Multiple supplier-single customer
P4. Single supplier-single manufacturer-single customer/multiple customers
S5. Two-level
S6. Multi-level
P7. Order-inventory
P8. Order-production-inventory
P9. Order-inventory-transportation
P10. Ordering-Production-Inventory-Transportation

Table 1 depicts the 42 articles that were shortlisted in this present review. An analysis of the SC participants revealed that most of the articles developed integrated SC models with single supplier-single customer participation as the fundamental SC parts. Furthermore, 35 articles used this correlation to develop models whose primary goal was minimum cost and environmental impacts. Most of these articles focused on carbon emissions and carbon management instead of energy efficiency, energy consumption, and energy-related aspects which frequently correlates with production rate in the manufacturing and transportation industry (Li et al. 2017, Bazan et al. 2015a, Marchi et al. 2019).

Karimi & Niknamfar (2017) and Castellano et al. (2019) constructed two-level models that took CO_2 emissions into consideration while Wangsa (2020) constructed a two-level model that took CO_2 emissions and energy into consideration in more complex relationships; such as single supplier-multiple customers. While developing the two-level model, all three studies considered two or more participants at each stage of the SC. Meanwhile, other articles created models that examined CO_2 emissions using wider relationships and diverse participants (Benjaafar et al. 2013; Glock & Kim, 2015; Sarkar et al. 2016). It is crucial to analyse each participant in a SC as each participant must play their part well. This is because integrated inventory models that assess environmental impacts are developed to reap the economic and environmental benefits of an SC. Therefore, such models must incorporate the SC process as it closely correlates to important model parameters that are used to make decisions.

Most of the 42 articles took all SC processes into account. This included ordering, production, inventory, and transportation (Paul et al. 2014; Ghosh et al. 2016; Castellano et al. 2019; Gautam et al. 2021; Jauhari et al. 2022). Bazan et al. (2015a) and Bazan et al. (2015b) proposed different processes that simplified the model by taking three SC processes; ordering, inventory, and transportation; into consideration. Meanwhile, other articles took ordering, production, and transportation into account (Hariga et al. 2017; Tao et al. 2018; Zissis et al. 2018). Some articles only took two SC processes; ordering and inventory; into account while developing a model that assesses environmental impacts (Bouchery et al. 2012; Bouchery et al. 2017).

As seen in Table 1, most of the integrated inventory models that were developed to assess environmental impacts examined single suppliers and single customers, two-level structures, and all SC process, including ordering, production, inventory, and transportation. These models were developed to take CO_2 emissions and CO_2 management; such as carbon taxes, carbon trading, and carbon policies that are still applicable; into consideration. Meanwhile, other articles incorporated energy formulas; such as energy efficiency and energy utilisation; into integrated mathematical inventory models to simplify them (Chan et al. 2013; Bazan et al. 2015a; Bazan et al. 2015b; Dwicahyani et al. 2017; Darma, 2017; Li et al. 2017; Marchi et al. 2019; Gautam et al. 2021; Singh & Mishra, 2022).

Paul et al. (2014) investigated a scenario in which holding and ordering costs are influenced by energy utilisation. For example, ordering costs could be a part of energy costs; such as the logistics cost of the supplier; and inventory holding costs could include the use of energy for material handling or to maintain the temperature at a warehouse for inventory storage. For two-level models, Bazan (2015) analysed the energy consumption of production and transportation operations as well as the joint energy cost of an integrated SC. Meanwhile, Marchi et al. (2019) addressed the energy consumption of an integrated inventory model in which the energy requirements of the manufacturing and rework operations were modelled as a function of production rate. Hasanov et al. (2019) investigated the correlation between energy utilisation and CO_2 emissions in a multi-echelon system.

Some articles addressed energy consumption even though their research objective was to reduce CO_2 emissions (Gautam et al. 2021). Most of the articles developed theoretical methods and validated them with numerical examples instead of examining actual case studies. Meanwhile, other articles combined theoretical and empirical methods (Wahab et al. 2011; Chan et al. 2013; Bazan et al. 2015a; Bouchery et al. 2017). Some recent articles, on the other hand, continue to develop theoretical methods and validate them with numerical examples (Jauhari et al. 2022; Singh & Mishra, 2022).

Based on the findings, majority of the 15 articles that focusing on energy efficiency discussed energy consumption in production and logistics. Energy efficiency in the perspectives of production and logistics includes various aspects of energy consideration across different stages of the process. The various of energy efficiency aspects addressed in these articles can be explained as follows. Chan et al. (2013) addresses the energy efficiency for initial setup and production quantity. In this article emphasizes the importance of minimizing energy waste during the initial setup of machines and the impact of production quantity on energy efficiency. Through efficient machine setup and optimal production quantities may result in reduced energy waste. Hariga et al. (2017) discuss energy efficiency through effective temperature control. This article explores the subject of energy efficiency to maintaining products at predetermined temperatures. This may result in reduced energy usage and enhanced operational efficiency.

Bazan et al. (2015a) discuss energy consumption for Production. This article addresses on the energy consumption during the production process, including energy required to remove materials and operate machine tools. While Bazan et al. (2015b); Bazan et al. (2017) and Hasanov et al. (2019) discuss energy efficiency through manufacturing and remanufacturing. These articles analyse the amount of energy is used during the production and remanufacturing processes. They evaluate factors such as machine tools, energy consumption coefficients and idle machine conditions to improve these processes towards energy efficient. Meanwhile, energy consumption considerations are integrated into the holistic manufacturing process (Gautam et al. 2021).

Bazan et al. (2015b) and Hasanov et al. (2019) incorporate the aspect of emissions penalty tax and coefficients an idle machine related to energy consumption during manufacturing and remanufacturing. This implies that regulations and the environment may be affected by energy efficiency initiatives. Moreover, energy efficiency is discussed in the context of maintaining ideal temperature conditions in warehouses and determining order sizes that reduce overall energy consumption. Energy savings may result from effective warehouse management and optimal order size (Paul et al.2014). Furthermore, Li et al. (2017) considers energy consumption in logistics. It focuses on optimizing freight volume based on energy consumption for different modes of transportation that indicates the significance of effective logistics. Based on Darma (2017); Singh & Mishra, (2022) and Wangsa et al. (2020) emphasize the significance of optimizing energy consumption in several forms, including electricity, heating, steam, cooling, and energy losses. This broader perspective recognizes various sources of energy consumption. Meanwhile, Jauhari et al. (2022) incorporated electricity and solar electricity consideration to evaluate the green production's total costs.

DECISION VARIABLES OF INTEGRATED INVENTORY SC MODELS WITH ENVIRONMENTAL IMPACTS

This present review also identified problems in inventory decisions that coordinate processes between SC participants to enhance both economic and environmental performance. As seen in Table 2, some studies consider the order quantity to make single inventory decisions with which to coordinate processes between SC participants (Bouchery et al. 2012; Bazan et al. 2015a; Gurtu et al. 2015; Bouchery et al. 2017; Tao et al. 2017; Toptal & Cetinkaya, 2017; Zissis et al. (2018). These articles take order quantities into consideration to minimise system costs as well as CO_2 emissions. Meanwhile, other articles make order quantity-based single inventory decisions that prioritise energy performances. For instance, one of the models that Hasanov et al. (2019) proposed took into consideration emissions from production and transportation as well as accounted for energy usage.

Only a handful of articles have considered two inventory decisions for production rates and delivery frequency. Chan et al. (2013) and Huang et al (2020) aimed to minimise system costs and CO_2 emissions while Bazan et al. (2015b) and Darma (2017) took energy performance into consideration using the two inventory results. Some of the other articles, however, took three inventory decisions; order quantity, production quantity, and delivery frequency; into consideration to reduce system costs (Bazan et al. 2017; Castellano et al. 2019). However, only a handful of articles considered three inventory decisions to improve energy performance and reduce CO_2 emissions (Hariga et al. 2017; Wangsa et al. 2020; Gautam et al. 2020; Singh & Mishra, 2022).

TABLE 2. Decision variables of inventory integration problems in models that examine the environmental impacts of energy consumption and CO_2 emission

Decision Variables (D1-D4)				Model Performance (M5-M8)				Authors
D1	D2	D3	D4	M5	M6	M7	M8	
√				√			√	Bouchery et al. 2012
√				√			√	Bouchery et al. 2017
		√	√		√		√	Saadany et al. 2011
√	√		√		√		√	Glock et al. 2012
√	√			√		√	√	Chan et al. 2013
√	√			√			√	Jaber et al. 2013
√	√	√		√			√	Zanoni et al. 2014a
√	√	√	√	√	√		√	Zanoni et al. 2014b
√				√			√	Tao et al. 2017
√				√			√	Toptal & Çetinkaya, 2018
√				√			√	Zissis et al. 2018
	√			√		√	√	Bazan et al. 2015a
	√	√		√		√	√	Bazan et al. 2015b
√		√	√	√		√	√	Hariga et al. 2017
√	√	√	√	√			√	Wahab et al. 2011
√	√	√	√	√		√	√	Paul et al. 2014
√		√	√	√		√	√	Bazan et al. 2017
√				√			√	Gurtu et al. 2015
√		√	√	√			√	Sarkar et al. 2015
√	√	√		√			√	Ghosh et al. 2016
√	√	√		√			√	Jiang et al. 2016
√		√	√		√		√	Khan et al. 2016
√	√	√		√			√	Yang et al. 2016
√		√		√		√	√	Dwicahyani et al. 2017
√		√	√	√			√	Ghosh et al. 2017
√		√		√		√	√	Darma, 2017
√	√	√	√	√		√	√	Li et al. 2017
√	√		√	√			√	Darom et al. 2018
√	√	√	√	√			√	Tiwari et al. 2018
√	√	√		√		√	√	Marchi et al. 2019
			√		√		√	Karimi & Niknamfar, 2017
√		√	√	√			√	Castellano et al. 2019
√		√	√	√			√	Glock & Kim, 2015
√			√	√			√	Benjaafar et al. 2013
		√	√	√			√	Sarkar et al. 2016
√				√		√	√	Hasanov et al. 2019
	√	√		√			√	Huang et al. 2020

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√		√	√	√		√	√	Wangsa et al. 2020
√		√	√		√	√	√	Gautam et al. 2021
		√	√	√			√	Jauhari & Wangsa, 2021
√	√	√	√	√		√	√	Jauhari et al. 2022
√		√	√	√		√	√	Singh & Mishra, 2022

Legends:
D1. Order quantity
D2. Production rate
D3. Frequency of delivery
D4. Other decisions
M5. Minimise cost
M6. Maximise profits
M7. Energy-related
M8. CO2 emissions-related

A total of 23 articles were found to examine non-general inventory decisions; such as order quantity, production quantity, and delivery frequency. The decision variables were based on the most recent SC theory and scenarios. For instance, Khan et al. (2016) examined profit per product unit while Tiwari et al. (2018) examined the proportion of defective products and cycle time. Castellano et al. (2019) examined safety, reorder point, and the number of routes while both Wangsa et al. (2020) and Jauhari et al. (2022) examined safety. Jauhari and Wangsa (2021) examined green investment decisions.

Based on the findings, order quantity, production rate, and delivery frequency are the most frequently examined aspects of the integrated problem (Table 2). Considering various decision variables can provide a more complete picture of the SC scenario. However, according to Pyke and Cohen (1993), improper decision variable selection drives up cost and lowers service delivery.

As this present review focused on energy performances, only 14 articles considered the use of order quantity decisions to reduce system costs, energy consumption, and CO_2 emissions. Meanwhile, only six articles considered using the results of order quantity, production rate, and delivery frequency as well as performance to reduce system cost, energy consumption, and CO_2 emissions (Hariga et al. 2017; Paul et al. 2014; Ghosh et al. 2016; Li et al. 2017; Marchi et al. 2019; Jauhari et al. 2022). However, each article used different decision variables that were based on the observations of the researchers and the SC process integrating case study. This poses a challenge to optimising the results to improve the performance integrated SCs.

CONCLUSION

The findings of this present review suggest that future integrated inventory models may be extended to examine the environmental impacts of energy consumption or energy management; such as energy policy, energy tariffs, energy investment, and energy regulation; in bringing about changes in areas other than CO_2 emissions. The importance of integrating energy into a model is to ensure that economic and environmental advantages are obtained in equal measure. Furthermore, few extant articles have examined the inclusion of energy factors. For instance, only 15 articles (35%) examined the energy-related issues of integrated inventory models. Researchers could also explore broader SC dimensions; such as single supplier-multiple customers; while taking into consideration the holistic process of ordering, production, inventory, and transportation. Moreover, most of the articles used a theoretical approach and only a few articles used a combination of theoretical methods and empirical case studies in real-life industry problems, which is more practical when describing real-life industry problems. The findings of this present review provide insights that future studies can use to develop integrated inventory models that include various participants, two- or multi-level structures as well as an energy parameter as a performance model. It could also be used to determine the best decision variables with which to solve the complexity of SC problems and describe a real-life SC scenario.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Bahinipati, B. K., Kanda, A. & Deshmukh, S. G. 2013. Coordinated supply management: Review, insights, and limitations. *International Journal of Logistics Research and Applications* 12: 37–41.

Bazan, E., Jaber, M. Y. & Saadany, E. A. M. A. 2015. Carbon emissions and energy effects on manufacturing-remanufacturing inventory models. *Computers & Industrial Engineering* 88: 307–316.

Bazan, E., Jaber, M. Y. & Zanoni, S. 2015. Supply chain models with greenhouse gases emissions, energy usage and different coordination decisions. *Applied Mathematical Modelling* 39(17): 5131–5151.

Bazan, E., Jaber, M. Y. & Zanoni, S. 2017. Carbon emissions and energy effects on a two-level manufacturer-retailer closed-loop supply chain model with remanufacturing subject to different coordination mechanisms. *International Journal of Production Economics* 183: 394–408.

Benjaafar, S., Li, Y. & Daskin, M. 2013. Carbon footprint and the management of supply chains: Insights from simple models. *IEEE Transactions on Automation Science and Engineering*, 10(1), 99–116.

Bouchery, Y., Ghaffari, A., Jemai, Z. & Dallery, Y. 2012. Including sustainability criteria into inventory models. *European Journal of Operational Research* 222(2): 229–240.

Bouchery, Y., Ghaffari, A., Jemai, Z. & Tan, T. 2017. Impact of coordination on costs and carbon emissions for a two-echelon serial economic order quantity problem. *European Journal of Operational Research* 260(2): 520–533.

Bushuev, M. A., Guiffrida, A., Jaber, M. Y. & Khan, M. 2015. A review of inventory lot sizing review papers. *Management Research Review*, 38(3): 283–298.

Castellano, D., Grassi, A., Santillo, L. C., Grassi, A. & Santillo, L. C. 2019. The effect of GHG emissions on production, inventory replenishment and routing decisions in a single vendor-multiple buyers supply chain. *International Journal of Production Economics* 218: 30–42.

Chan, C. K., Lee, Y. C. E. & Campbell, J. F. 2013. Environmental performance - Impacts of vendor-buyer coordination. *International Journal of Production Economics* 145(2): 683–695.

Darma, I. 2017. Greenhouse gas penalty and incentive policies for a joint economic lot size model with industrial and transport emissions. *International Journal of Industrial Engineering Computations* 8: 453–480.

Darom, N. A., Hishamuddin, H., Ramli, R. & Mat Nopiah, Z. 2018. An inventory model of supply chain disruption recovery with safety stock and carbon emission consideration. *Journal of Cleaner Production* 197: 1011–1021.

Dwicahyani, A. R., Jauhari, W. A., Rosyidi, C. N. & Laksono, P. W. 2017. Inventory decisions in a two-echelon system with remanufacturing, carbon emission, and energy effects. *Cogent Engineering* 4(1): 1–17.

Fink, A. 2014. *Conducting Research Literature Reviews*. Edisi ke-4. Thousand Oaks: Sage Publication, Inc.

Gautam, P., Khanna, A., & Jaggi, C. K. 2021. An integrated green supply chain model with product recovery management towards a cleaner system. *Journal of Cleaner Production* 320.

Ghosh, A., Jha, J. K. & Sarmah, S. P. 2016. Optimizing a two-echelon serial supply chain with different carbon policies. *International Journal of Sustainable Engineering* 9(6): 363–377.

Ghosh, A., Jha, J. K. & Sarmah, S. P. 2017. Optimal lot-sizing under strict carbon cap policy considering stochastic demand. *Applied Mathematical Modelling* 44.

Glock, C. H. 2012a. The joint economic lot size problem: A review. *International Journal of Production Economics* 135(2): 671–686.

Glock, C. H., Jaber, M. Y. & Searcy, C. 2012b. Sustainability strategies in an EPQ model with price- and quality-sensitive demand. *International Journal of Logistics Management* 23(3): 340–359.

Glock, C. H. & Kim, T. 2014. Shipment consolidation in a multiple-vendor-single-buyer integrated inventory model. *Computers and Industrial Engineering* 70(1): 31–42.

Govindan, K., Kannan, D., Ballegård, T. & Straarup, T. 2022. Supply Chain 4.0 performance measurement: A systematic literature review, framework development, and empirical evidence. *Transportation Research Part E* 164.

Gurtu, A., Jaber, M. Y. & Searcy, C. 2015. Impact of fuel price and emissions on inventory policies. *Applied Mathematical Modelling* 39(3–4):1202–1216.

Hariga, M., As'ad, R. & Shamayleh, A. 2017. Integrated economic and environmental models for a multi stage cold supply chain under carbon tax regulation. *Journal of Cleaner Production* 166: 1357–1371.

Hasanov, P., Jaber, M. Y., & Tahirov, N. 2019. Four-level closed loop supply chain with remanufacturing. *Applied Mathematical Modelling* 66: 141–155.

Hoque, M. A. 2011. An optimal solution technique to the single-vendor multi-buyer integrated inventory supply chain by incorporating some realistic factors. *European Journal of Operational Research* 215(1): 80–88.

Huang, Y. S., Fang, C. C., & Lin, Y. A. 2020. Inventory management in supply chains with consideration of Logistics, green investment, and different carbon emissions policies. *Computers and Industrial Engineering*, 139: 106207.

Jaber, M. Y., Glock, C. H., & Saadany, E. A. M. A. 2013. Supply chain coordination with emissions reduction incentives. *International Journal of Production Research* 51(1): 69–82.

Jauhari, W. A. & Wangsa, I. D. 2022. A Manufacturer-Retailer Inventory Model with Remanufacturing, Stochastic Demand, and Green Investments. *Process Integration and Optimization for Sustainability* 6(2): 253–273.

Jauhari, W. A., Pujawan, I. N., Suef, M. & Govindan, K. 2022. Low carbon inventory model for vendor–buyer system with hybrid production and adjustable production rate under stochastic demand. *Applied Mathematical Modelling* 108:840–868.

Jiang, Y., Li, B., Qu, X., & Cheng, Y. 2016. A green vendor-managed inventory analysis in supply chains under carbon emissions trading mechanism. *Clean Technologies and Environmental Policy* 18(5): 1369–1380.

Karimi, M., & Niknamfar, A. H. 2017. A vendor-managed inventory system considering the redundancy allocation problem and carbon emissions. *International Journal of Management Science and Engineering Management* 12(4):269–279.

Khan, M., Hussain, M., & Saber, H. M. 2016. Information sharing in a sustainable supply chain. *International Journal of Production Economics* 181(2007): 208–214.

Lee, S.-D. & Fu, Y.C. 2013. Joint production and shipment lot sizing for a delivery price-based production facility. *International Journal of Production Research* 51(20): 6152–6162.

Li, J., Su, Q. & Ma, L. 2017. Production and transportation outsourcing decisions in the supply chain under single and multiple carbon policies. *Journal of Cleaner Production* 141: 1109–1122.

Malaysian Investment Development Authority 2020. Green Technology Incentives: Towards Achieving Sustainable Development in Malaysia. https://www.mida.gov.my/green-technology-incentives-towards-achieving-sustainable-development-in-malaysia/

Moon, I. K., Cha, B. C. & Lee, C. U. 2011. The joint replenishment and freight consolidation of a warehouse in a supply chain. *International Journal of Production Economics* 133(1): 344–350.

Marchi, B., Zanoni, S., Zavanella, L. E., & Jaber, M. Y. 2019. Supply chain models with greenhouse gases emissions, energy usage, imperfect process under different coordination decisions. *International Journal of Production Economics* 211:145–153.

May, G., Taisch M., Stahl B., & V. Sadr. 2013. Toward Energy Efficient Industrial: A Study on Practices and Viewpoint of the Industry. Advances in Production Management Systems. *Competitive Industrial for Innovative Products and Services, IFIP Advances in Information and Communication Technology* 397: 1– 8.

Mokhtari, H., & Hasani, A. 2017. An energy-efficient multi-objective optimization for flexible job-shop scheduling problem. *Computers and Chemical Engineering* 104: 339–352.

Pattnaik, S., Nayak, M. M., Abbate, S. & Centobelli, P. 2021. Recent trends in sustainable inventory models: A literature review. *Sustainability* 13(21): 1–20.

Paul, S., Wahab, M. I. M., & Cao, X. F. 2014. Supply chain coordination with energy price uncertainty, carbon emission cost, and product return. *Handbook of EOQ Inventory Problems*, *Springer*.179–199.

Pyke, D.F. & Cohen M.A. 1993. Performance characteristics of stochastic integrated production-distribution systems. *Eur. J. Oper. Res* 68: 23–48.

Roy, M. Das, Sana, S. S. & Chaudhuri, K. 2012. An integrated producer–buyer relationship in the environment of EMQ and JIT production systems. *International Journal of Production Research* 50(19): 5597–5614.

Saadany, E. A. M. A., Jaber, M. Y., & Saadany, E. A. M. A., Jaber, M. Y., & Bonney, M. 2011. Environmental performance measures for supply chains. Management Research Review 34(11): 1202–1221.

Sarkar, B., Saren, S., Sinha, D. & Hur, S. 2015. Effect of unequal lot sizes, variable setup cost, and carbon emission cost in a supply chain model. *Mathematical Problems in Engineering*.

Sarkar, B., Ganguly, B., Sarkar, M., & Pareek, S. 2016. Effect of variable transportation and carbon emission in a three-echelon supply chain model. *Transportation Research Part E: Logistics and Transportation Review* 91: 112–128.

Singh, R., & Mishra, V. K. 2022. *Sustainable Integrated Inventory Model for Substitutable Deteriorating Items Considering Both Transport and Industry* 31(3): 267–287.

Tao, F., Fan, T. & Lai, K. K. 2018. Optimal inventory control policy and supply chain coordination problem with carbon footprint constraints. *International Transactions in Operational Research* 25(6): 1831–1853.

Toptal, A. & Çetinkaya, B. 2017. How supply chain coordination affects the environment: a carbon footprint perspective. *Annals of Operations Research* 250(2): 487–519.

Tiwari, S., Daryanto, Y. & Wee, H. M. 2018. Sustainable inventory management with deteriorating and imperfect quality items considering carbon emission. *Journal of Cleaner Production* 192: 281–292.

Wahab, M. I. M., Mamun, S. M. H., & Ongkunaruk, P. 2011. EOQ models for a coordinated two-level international supply chain considering imperfect items and environmental impact. *International Journal of Production Economics* 134(1): 151–158.

Wangsa, I. D., Tiwari, S., Wee, H. M., & Reong, S. 2020. A sustainable vendor-buyer inventory system considering transportation, loading, and unloading activities. *Journal of Cleaner Production* 271: 122120.

Yang, M. F., Zou, Y. Y., Lo, M. C. & Chao, Y. T. 2016. Integrated supply chain inventory model with progressive carbon taxation. *Lecture Notes in Engineering and Computer Science*, *2*, 926–930.

Zanoni, S., Mazzoldi, L., Zavanella, L. E. & Jaber, M. Y. 2014. A joint economic lot size model with price and environmentally sensitive demand. *Production and Manufacturing Research* 2(1): 341–354.

Zanoni, S., Mazzoldi, L., & Jaber, M. Y. 2014. Vendor-managed inventory with consignment stock agreement for single vendor-single buyer under the emission-trading scheme. *International Journal of Production Research* 52(1): 20–31.

Zissis, D., Saharidis, G. K. D., Aktas, E. & Ioannou, G. 2018. Emission reduction via supply chain coordination. *Transportation Research Part D: Transport and Environment* 62: 36–46.