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A Systematic Literature Review of Sustainable Probabilistic Inventory Models

Khimya Tinani and Anuja Sarangale
P. G. Department of Statistics, Sardar Patel University, Vallabh Vidyanagar, Gujarat, 388120, India.

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Abstract

Incorporation of changing environmental needs in the daily businesses of the life are becoming the essential element for the long-term sustenance of the humanity considering the degrading natural environment. Brundtland report by the United Nations signifies the inclusion of sustainable practices to fulfil the needs of the present generation at the same time preserving resources for the future generations. Realizing the presence of number of polluting factors in the inventory management practices, this research attempts to give extensive systematic review of the available literature which is also incorporating the uncertainty of the components by considering their stochastic or probabilistic behaviour. This review assessed 32 research articles to write a comprehensive review where all the articles have incorporated at least one probability distribution. This study identifies that transportation, storage and production are the main contributors of carbon emissions and normal distribution is the most preferred probability distribution and hence future research can be extended by incorporation of other probability distributions in the model building of sustainable inventory management.

Key words: Carbon emission; Sustainable inventory management; Probability distributions; Demand; Normal distribution; Lead time.

1. Introduction

Sustainable inventory management has become an increasingly important topic in recent years, as businesses look to minimize their environmental footprint and promote social responsibility. One of the key benefits of sustainable inventory management is the potential for cost savings. By reducing waste and increasing efficiency, businesses can lower their costs and improve their bottom line. In addition to cost savings, sustainable inventory management also has the potential to improve a company's reputation and increase customer loyalty. As consumers become more environmentally conscious, they are increasingly looking for companies that are committed to sustainability. However, implementing sustainable inventory management can also present challenges. One of the main challenges is the lack of clear and consistent definitions and metrics for sustainability. This can make it difficult for businesses to know exactly what they need to do in order to be considered sustainable.

Corresponding Author: Khimya Tinani
Email: khimya27@yahoo.coml

Additionally, sustainable inventory management can require a significant investment in new technologies and processes, which can be a barrier for small and medium-sized businesses. To overcome these challenges, researchers have proposed a number of different methods and technologies that can be used to achieve sustainability goals in inventory management. One approach is the use of green supply chain management, which involves integrating environmental considerations into all aspects of the supply chain, including inventory management.

A systematic literature review of sustainable inventory management reveals a growing body of research that explores the various aspects of this topic including the benefits and challenges of implementing sustainable practices as well as the various methods and technologies that can be used to achieve sustainability goals. However, it also points to the challenges that businesses may face in implementing sustainable inventory management, and the importance of clear definitions and metrics, as well as the use of advanced technologies.

Variability in demand, lead time or any other component of inventory problems navigates the entire procedure of decision making of the practitioner and hence inclusion of it will help to understand more diverse and realistic scenarios of the inventory problem. There is enough literature where probabilistic nature of the demand or lead time has benefitted to develop inventory models for real life scenarios. Among which research work on normal distribution and gamma distribution is available for past many decades. Such as Burgin and Wild (1967) developed a procedure to obtain the reorder level and reorder quantity when lead time demand have probabilistic nature and obtained numerical expressions to particular case for gamma distribution. In another study by Burgin (1972) where demand is normal and lead times is gamma distributed exact expressions for reorder level and lost sales was obtained. Another interesting use of probability distributions can be found in the study by Lee *et al.* (2007) where mixture of two normal distributions is considered to obtain the order quantity.

Examining such diverse applications of probability distributions in inventory management this paper aims: (i) to lay out extensive analysis of the sustainable inventory management problems which include probabilistic nature of components. (ii) to discover different probability distributions used in the inventory management. (iii) to find the future research directions with incorporation of various probability distributions in inventory management.

The research paper further subdivided into four sections where Section 2 provides the review methodology followed for the inclusion of the articles for systematic literature review which itself divided into different subsections based on analysis techniques used. Section 3 concludes on the overall study and Section 4 ends the research paper by giving limitations and possible future research direction to the study.

2. Review methodology

For conducting systematic literature review, a review methods proposed by Becerra *et al.* (2021, 2022), Pattnaik *et al.* (2021), Tinani and Kandpal (2017) based on which this study can be broadly divided into two phases as articles selection phase and analysis phase. Articles selection phase involves identification of keywords, searching through database, abstract screening and full article screening based on the objectives. Whereas analysis phase involves thorough examination of articles to provide valuable insights.

2.1. Article selection phase

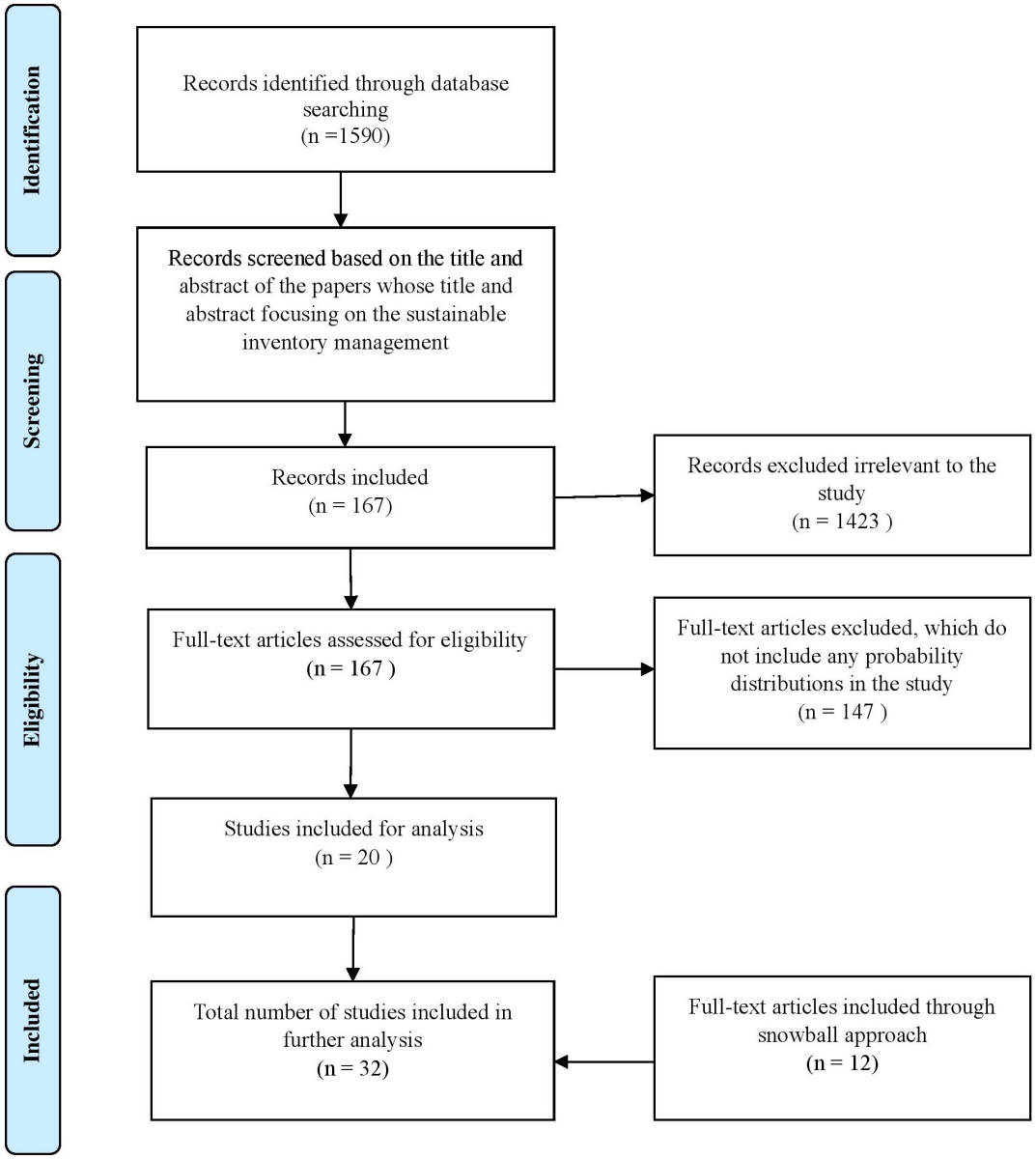

Figure 1: Flowchart of literature review

The search for the articles was conducted using Web of Science database for which initially keywords were identified such as “sustainability”, “environment”, “carbon emission”, “carbon tax”, “carbon footprint” and “carbon cap and trade” which were then combined with the inventory management to prepare a search string as TS=(sustainab* OR green OR environment* OR carbon OR ”carbon tax” OR ”carbon emission” OR “carbon footprint” OR “carbon cap and trade”) AND TS= (”inventory management” OR ”inventory model*”

OR "inventory control"). According to Andriolo *et al.* (2014) significant number of papers in sustainable inventory management are published after 2011, hence for this study articles published before 2011 were filtered out. Further articles published in peer-reviewed journals and available in English language are only considered. The above provided string displays 1590 publications carried out in March 2023 whose titles and abstracts were screened further to identify the relevant articles based on the objectives, which were trimmed down to 20 articles. To make the review more comprehensive and inclusion of more papers into the review as through the database only 20 research articles were shortlisted, therefore snowball approach is adopted where references of the 20 articles were extensively explored which helped to include 12 more relevant publications as per previously described criteria. Figure 1 depicts the flowchart of the literature review.

2.2. Analysis phase

2.2.1. Descriptive analysis of selected papers

(a) Distribution of articles based on Journal

Figure 2: Distribution of reviewed articles based on Journal

From the Figure 2 it can be observed that around 34% of the articles are published in

the journals like 'Journal of Cleaner Production', 'Computers & Industrial Engineering', 'International Journal of Logistics Systems and Management' and 'European Journal of Operational Research'. Other articles are distributed in other journals and one conference proceeding each having one article.

(b) Distribution of articles based on publication year

Figure 3: Distribution of articles based on publication year

From the Figure 3 though there are articles publishing year on year from the inception of the topic, approximately 70% are published during 2018-2023 which depicts the importance of the topic in recent years.

2.2.2. Bibliographic coupling

When two research publications have a common third publication in their reference lists, they are said to be bibliographically coupled. Third common publication is considered as a coupling unit between the two (Kessler, 1963). The bibliographic method helps to create the cluster of articles with common thread between them and further helped to identify the major areas of study.

Figure 4 depicts the bibliographic network for the finally included 30 publications excluding other unrelated publications. The Figure 4 provided below was created using the VOSviewer software. In the following Figure 4 each circle presents the research publication and the line between two publications indicates the number of common references. Publications having higher number of citations are shown by large circles and publications with smaller circles have relatively less number of citations. Bibliographic coupling helps to assigning different publications to different clusters based on important attributes. From the Figure 4 generated using bibliographic technique where 30 publications can be grouped into 4 clusters. These 4 clusters can be summarized as provided below. The 4 different clusters can be identified by observing their colours in the bibliometric network.

Cluster 1: Transportation and perishability inventory models

This is the largest cluster in the network with 12 documents depicted with red colour

in the figure provided below. Primary focus of the articles from this cluster is to develop inventory models considering the environmental considerations but the prominent components included are perishability of products, deteriorating items, costs and emissions related to transportation, carbon emission policies, *etc.*

Cluster 2: Imperfect quality items inventory models

This cluster consists of 7 articles including the earliest article published which is Wahab *et al.*(2011) which tried to provide optimum inventory policies for international supply chain for both vendor and buyer while taking into account imperfect quality of items and impact on the environment. Overall articles from this clusters attempted to incorporate the imperfect products and production processes for inventory management. Articles of this are represented with the blue colour in the bibliometric network.

Cluster 3: Hybrid production process inventory models

The cluster shown with the green colour in the figure, consisting of 7 articles this cluster is dominated by the author Wakhid Jauhari having 4 articles. Articles from this cluster focused on the inclusion of hybrid production processes while considering the range of other scenarios which include imperfect production, multiple retailers, single manufacturer, energy usage, *etc.*

Cluster 4: Demand and lead time uncertainty inventory models

This is the smallest cluster in the network consisting only 4 articles represented by the yellow colour. Digiesi *et al.* (2013a, 2013b) proposed the order quantity models for uncertain demand and lead time where as other two articles Kaur *et al.* (2020) and Kaur and Singh (2018) attempted to assimilate linear programming approach to get the better managerial insights.

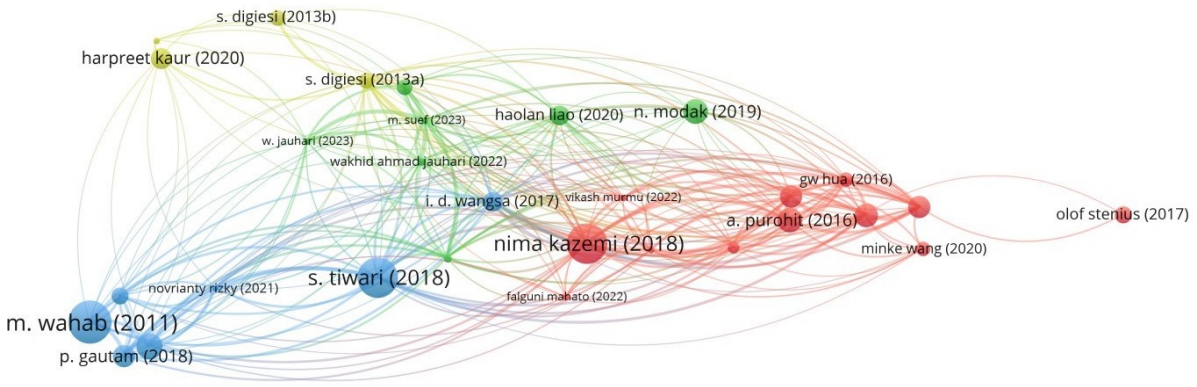

Figure 4: Bibliographic network of selected articles

2.2.3. Classification of articles based on probability distributions of different components

In a review conducted by Tinani and Kandpal (2017) , articles were classified based on two types of uncertainty problems namely yield uncertainty and random yield diversifica-

tion. Using the similar approach reviewed articles can be classified based on the probability distributions for demand being the crucial component and other components of inventory models as provided below.

(a) Probability distributions for demand component

The very first study in the reviewed articles where demand is considered uncertain with some probability distribution *i.e.* Digiesi *et al.* (2013a), where demand for the product is considered a stochastic independent variable which follows normal probability distribution with some mean and standard deviation. Proceeding further it can be observed that Purohit *et al.* (2016) also considered stochastic demand to formulate lot-sizing model using the inverse cumulative distribution function assuming the normal distribution for the demand. Further review of the articles also suggests that the choice of the normal distribution for the demand is more frequent than any other probability distributions. Also other studies such as Ahmad Jauhari (2022), Darma Wangsa (2017), Jauhari (2018), Jauhari *et al.* (2021), Jauhari *et al.* (2023), Jauhari *et al.* (2023), Kaur *et al.* (2020), Kaur and Singh (2018), Liao and Li (2021), Manupati *et al.* (2019), Modak and Kelle (2021), Rizky *et al.* (2021), Suef *et al.* (2023), Tang *et al.* (2018) have all preferred demand to be normally distributed. Interestingly, some studies have also incorporated other scenarios or probability distributions like Ghosh *et al.*(2017) assumed normal distribution jointly for lead time and demand termed as a lead time demand distribution. Further Stenius *et al.* (2018) developed a model where demand follows Poisson distribution whereas Wang *et al.* (2020) assumed that each demand zone has Poisson-normal compound demand during particular time period. Therefore, it can be concluded that the normal distribution is the most popular choice among the authors for formulation of inventory problems.

(b) Probability distributions for other components

Though demand is very decisive component of the inventory modelling, authors are also interested to incorporate uncertainty in the inventory problems by considering them as a random variable with some probability distributions. Among which contemplation of fractions or percentage of defectives or imperfect items is very often. For instance Gautam and Khanna (2018) and Kazemi *et al.* (2018) incorporated rate of defective items in the model without specifying any probability distribution for the same. However, Gautam *et al.* (2019), Mishra and Mishra (2022), Rizky *et al.* (2021) and Tiwari *et al.* (2018) preferred Uniform distribution for the same in the prescribed inventory problem. De-la-Cruz-Márquez *et al.* (2022) initially did not specify any probability distribution for imperfect items percentage at model development stage but for numerical example, author assumed it has Uniform Distribution. It is also worthwhile to notice that many of the studies does not specify any probability distributions while developing the theory. For example Lee *et al.* (2017) embodied unspecified distribution for lead time, Tang *et al.* (2018) for inventory level, Gautam *et al.* (2019) for number of items like scrap, repairable and non-repairable proportion of items, Mahato *et al.* (2023) for time between process to go out of control which shows that this component can also be expanded with experimenting with different probability distributions. Further for inclusion of deterioration concept Hua *et al.* (2016) considered Exponential distribution of time to deterioration where as Murmu *et al.* (2023) considered two parameter Weibull distributed deterioration rate. There are many such other components which have assumed different probability distributions which are summarized in the table.

2.2.4. Detailed analysis of the selected papers

This section aims to provide in depth analysis of selected papers by providing the overview, sustainability factors incorporated, other factors considered for model building with probability distribution and proposed future directions. Limited number of articles in the final inclusion stage of this study allows starting the review and analysis procedure from the earliest article published and going till the recent one. Considering the significance of EOQ models at the international level Wahab *et al.* (2011) developed a model for vendor and buyer when they are located in different countries while incorporating imperfect quality items in terms of percentage of defective items in three different scenarios also rate of exchange between two countries follows stochastic behaviour and to cater the needs of sustainability, carbon emission costs are considered. This model can be further extended as given by author by the inclusion of uncertainty in demand, lead time, credit, *etc.* and other environmental factors such as green packaging, remanufacturing, cleaner production, recycling, *etc.* Digiesi *et al.* (2013a) proposed the sustainable order quantity model when the product demand is uncertain jointly considering logistic costs like safety stock, shortage cost and environmental cost of transportation. Demand at the particular period is considered as independent stochastic variable with equal expected demand and standard deviation. The model building started with stating cost function adding associated costs. Further the loss factor component was considered which was only related to the technological advancement related to the energy sector in transportation. Lastly the cost function was optimised to obtain the order quantity levels and optimal safety stock. Proposed model then applied to automotive case study to obtain the insights on optimal solution.

On the similar lines Digiesi *et al.*(2013b) developed another sustainable order quantity models when lead time is uncertain and demand is deterministic in nature following the same approach as the previous article including logistic and environmental transportation cost and developed model applied to real industrial case. Jauhari *et al.* (2014) arrived at a model for vendor and buyer by integrating defective items produced in the production process and unequal size of the shipment with the environmental carbon emission cost for both vendor and buyer. The papers considered the probability distribution of defect rate and further model building was formulated. They further analyzed that if the probability of defects increases then it also increases the carbon emission cost. Authors also suggested that the proposed model can be further extended by incorporating of defective raw material, inspection and rework process for raw material, inspection error and application of other distribution models of defective rate on vendor-buyer problem.

Purohit *et al.* (2016) studied the lot sizing inventory problem using mixed integer linear programming approach with constraints on emission and service levels when demand from the buyer is uncertain and dynamic which is normally distributed. This model considered wide ranging emissions generated during ordering, storage and purchasing and their corresponding costs. The objective function for the proposed problem is to minimise the total cost for the prescribed time period consisting of the four components. Additionally various constraints such as cycle service level, identification of the optimum replenishment schedule and emission constraints are incorporated. This study analysed the impact of various emission factors and features related to product and system under the carbon cap-and-trade policy assuming constant carbon price. This study can be extended by considering variable carbon price, applying to real life cases and different supply structures. A detailed overview

of the remaining articles is summarized in the Table 1 provided below mentioning the authors, name of the publishing journal, probabilistic components used, sustainability factors and proposed future research.

3. Conclusion and future research direction

This paper attempts to provide the comprehensive review of the inventory models which included sustainability criteria where probability distributions are taken into consideration for at least one of the components of inventory management. This study tries to provide the detailed analysis of selected papers with sustainability criteria included, incorporated probability distributions and possible future prospects proposed by the reviewed articles. It can be observed that carbon emissions due to transportation and costs associated with it are the frequent components enclosed in the articles reviewed. Other emission factors such as emissions due to production and storage are also the prominent one. Therefore incorporation of investments made to reduce emissions from the transportation, production and storage could be exhaustive topic to move towards sustainability. Also it would be great extension to consider the other carbon regulations more than carbon tax like cross border adjustment mechanism, carbon penalty, *etc.* Another important concept identified that is incorporation of uncertainty in demand where Normal distribution is the very much preferred distribution. As normal distribution has some limitations such as it is symmetric in nature and assumes negative values as well. Hence consideration of other possible probability distributions for demand as well as other components of the inventory model can provide enormous and varied opportunities for the extension of the sustainable inventory models.

4. Limitations of study

This review can be extended by the considering the papers from the other databases like Scopus and Google Scholar. Major focus of this research paper is on the order quantity models and relevant studies with few papers with production inventory models. Hence the present study can be explored with inclusion of more production problems and other supply chain scenario models. This study does not focus much on the various quantitative and qualitative methods employed in the prescribed paper. Though the database was thoroughly examined there might be some possibility that some articles may have slipped and further excluded from the process. Inclusion of such articles will help to broaden all the horizons of study.

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Table 1: Summary of the articles

Authors	Journal Name	Sustainability Factors	Inventory components with their Probability Distributions	Proposed Future research work
Hua *et al.* (2016)	International Journal of Simulation Modelling	Carbon cap and trade mechanism, emission cost	Time to deterioration – Exponential Distribution	Incorporation of partial backlogging, lost sales, freshness having deterioration rate
Darma Wangsa (2017)	International Journal of Industrial Engineering Computations	Direct and indirect emissions from transport and industry sector, carbon emission tax	Demand – Normal Distribution	Consideration of multi-manufacturer and multi-buyer system, other indirect emissions like waste disposal, cleaner production. Green manufacturing, remanufacturing, recycling, emission reduction investment costs
Ghosh *et al.* (2017)	Applied Mathematical Modelling	Carbon emissions from production, inventory, transportation	Lead time demand – Normal Distribution	Model can be extended to multi-echelon or reverse supply chain with defective and waste item, inclusion of perishable products,
Lee *et al.* (2017)	Sustainability	Carbon emission cost of warehouse, collection and disposal of inventory waste	Lead time – Unspecified probability distribution	Extension can be done considering processing time at custom, waiting time at border and terminal handling activities
Kazemi *et al.* (2018)	International Journal of Systems Science: Operations & Logistics	Carbon emission cost and tax of holding inventory, warehousing, obsolete items	Fraction of imperfect items - Unspecified	Consideration of multiple manufacturer and supplier scenario, emissions from transportations or energy usage, imperfect supply process
Stenius *et al.* (2018)	European Journal of Operational Research	Emission cost of transportation	Demand – Poisson Distribution Shipment quantity to each retailer group – Binomial Distribution	Generalization of model by considering other demand distributions like compound Poisson
Tang *et al.* (2018)	European Journal of Operational Research	Emissions from storage and transportation	Demand – Normal Distribution Inventory level – Unspecified Distribution	Carbon reduction consideration, other sources of operational emissions

Kaur and Singh (2018)	Management of Environmental Quality: An International Journal	Carbon emission and its price and quota	Demand, Supplier capacity, Carrier capacity – Normal Distribution	Study can be extended by considering uncertain lead time, purchasing and transportation cost, other qualitative factors
Jauhari (2018)	International Journal of Logistics Systems and Management	Carbon emission cost due to transportation and production	Demand – Normal Distribution	Inclusion of inspection process, consideration of different supply chain structures, periodic review policy
Gautam and Khanna (2018)	Uncertain Supply Chain Management	Fixed and variable cost of carbon emissions at vendor	Defective rate – Unspecified Distribution	Further extended for the case of multiple buyer and items, also considering partial backordering, pricing discounts, inspection errors
Tiwari *et al.* (2018)	Journal of Cleaner Production	Costs of carbon emissions from transportation, warehousing and holding deteriorating items, emission tax	Percentage of Defective items – Uniform Distribution	Impact of rework and recycle activities on carbon emission, Multi-product and delay in payments can be very good extension
Manupati *et al.* (2019)	Computers & Industrial Engineering	Carbon cap-and-trade, carbon tax	Demand – Normal Distribution	Extension can be done for reverse closed loop supply chain, some model restrictions can be relaxed
Gautam *et al.* (2019)	Journal of Cleaner Production	Costs of carbon emission	Repairable proportion, non-repairable proportion and scrap proportion – Unspecified Distribution Defect Percentage – Uniform Distribution	Inspection error can be incorporated, also some permissible delays can also considered. Model can be extended in fuzzy environment
Kaur *et al.* (2020)	Computers & Industrial Engineering	Carbon emissions during ordering, transportation and holding	Demand, Machine capacity, carrier capacity, supplier capacity - Normally distributed	Flexibility of supplier and carrier selection, fuzzy environments can be applied

Wang *et al.* (2020)	Transportation Research Part - E	Carbon emissions due to transportation, carbon cap	Demand zone – Poisson-Normal compound demand Random order inter arrival time – Exponential Distribution Random order sizes – Normal Distribution Carbon price – Uniform Distribution	Consideration of vehicle routing decisions, other carbon regulation schemes, more efficient heuristics
Modak and Kelle (2021)	Journal of Operational Research Society	Carbon footprint, carbon tax, Emission reduction due to recycling	Demand – Normal Distribution	Can be extended to multiple products, manufacturers and retailers case, also internet marketing, recycling activity influence can be incorporated
Liao and Li (2021)	Computers & Industrial Engineering	Carbon emissions in logistics and storage	Demand – Normal Distribution, Exponential Distribution	Study in hybrid manufacturing system, forward and reverse production system simultaneous consideration
Rizky *et al.* (2021)	Clean Technologies and Environmental Policies	Carbon emission costs, energy consumption	Demand – Normal Distribution Defective Percentage – Uniform Distribution	Model can be extended by considering imperfect raw material and impact of returned product
Jauhari *et al.* (2021)	Journal of Cleaner Production	Carbon emission due to storage, production, transportation, carbon tax	Demand – Normal Distribution	Extension can be done by considering inspection errors, variable production rate, more parties like supplier and distributors
Ahmad Jauhari (2022)	Cleaner Logistics and Supply Chain	Carbon emissions due to production, transportation and storage, investment in green technology	Demand – Normal Distribution	Inclusion of imperfect reworking process and investment in quality, other carbon regulations like carbon penalty, three party logistic supply chain

Mishra and Mishra (2022)	Arabian Journal for Science and Engineering	Carbon emissions and its cost from electricity generation, deterioration, fuel consumption by vehicle, energy consumption from Warehouse	Defective Percentage – Uniform Distribution	Consideration of imperfect screening with errors, demand variations like stochastic and fuzzy, can also be extended for manufacturer
De-la-Cruz-Márquez *et al.* (2022)	Mathematics	Carbon emissions and costs, carbon tax	Percentage of imperfect items – Unspecified in the model (Uniform Distribution in Numerical Example)	Model can be extended by incorporating investment in preservation technology to reduce deterioration
Mahato *et al.* (2023)	Environment, Development and Sustainability	Pollution control costs and scenarios	Time elapsed after which production becomes out of control – Unspecified Distribution in the model (Exponential Distribution in Numerical example)	Model can be extended by considering stochastic demand and default risk rate, partial backlogging, investment in low carbon technologies, transportation costs, screening errors, recycling, inflation
Murmu *et al.* (2023)	Journal of Industrial and Management Optimization	Carbon emission, emission cap, carbon tax, investment in green technology	Deterioration rate – Two parameter Weibull Distribution	Study can be expanded by considering three parameter weibull distributed deterioration rate, stochastic demand, non linear programming approach for fuzzy environment, trade credit, manufacturing process reliability
Jauhari *et al.* (2023)	Annals of Operations Research	Carbon emissions from transportation, storage, investment in green technology, carbon tax	Demand – Normal Distribution	Incorporation of human errors in inspection, other carbon reduction policies like carbon penalty, carbon cap and trade

Suef *et al.* (2023)	Process Integration and Optimization for Sustainability	Carbon emission from storage, production and transportation, investment in green technology, carbon tax	Demand – Normal Distribution	Investigation of influence of routes of transportation on emissions and costs, consideration of imperfect production and green transporters
Jauhari *et al.* (2023)	Cogent Business and Management	Carbon emissions, green investment and incentives, energy consumptions	Demand – Normal Distribution	Model can be extended by considering imperfect production process, other carbon policies like cap and trade, carbon offset, carbon cap

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