



# REVIEW OF GREEN INVENTORY MODELS

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**Abstract:** A green inventory model is a type of inventory management approach that considers environmental factors such as waste reduction, reduction of carbon emissions, reduction of pollution, and sustainability. It involves optimizing the inventory system to reduce its impact on the environment while still meeting customer demand and maximizing profit. Green inventory models can include considerations such as minimizing transportation distances, reducing packaging waste, using renewable energy sources, and choosing sustainable suppliers. This review contains various works related to the green inventory model.

**Index Terms - Sustainability, green inventory model, environment, emission cost.**

## I. INTRODUCTION

A green inventory model considers various environmental factors. The green inventory model aims to optimize inventory decisions while considering the impact on the environment. This model generally involves reducing excess inventory, promoting the use of renewable materials, and optimizing transportation and supply chain networks to minimize carbon emissions.

The green inventory aims to identify and resolve potential trade-offs and manage inventories efficiently in terms of both costs and emissions. Inventory decisions are closely related to production and transportation decisions, which directly affect emissions. So, this decision-making is crucial in green inventory management. Emissions are generally categorized into Green House Gases (GHG), other harmful gases, and particles. GHG emissions are usually measured in CO<sub>2</sub> equivalents. This receives the most attention in the media and society due to its significant impact on global warming. In inventory management, decisions related to energy consumption can impact emissions, which are associated with energy use. Therefore, emissions associated with operating an inventory system can be classified into three categories: emissions related to ordering items, emissions related to holding items in stock, and emissions related to not meeting customer demand on time. This partition corresponds to the cost components typically considered in inventory management: procurement costs, holding costs, and shortage costs.

The challenges in green inventory management involve understanding the impact of decisions on both costs and emissions for the inventory system and leveraging this understanding to make optimal decisions. The ultimate objective is to minimize both costs and emissions. However, decisions that minimize the system's costs may not necessarily minimize its emissions, and vice versa. Therefore, finding the best possible balance between cost and emissions is challenging. This paper focused on identifying and reviewing the works related to the emission cost consideration and corresponding inventory model.

## II. DESCRIPTION OF REVIEWED WORKS

This paper reviewed twenty-five works related to the green inventory model. They are Multi-objective approach, Impact of carbon emission policies on single period news vendor problem, MDR and MV news vendor model, EOQ with emission condition, Transport mode selection problem, Green investment on a production inventory system with carbon tax, Two plants and uncertain inventory carrying cost, Variable demand under inflation, Green inventory routing problem, Green supply chain of auto industry, Model to regulate environment, Green growth perspective, Four layer green supply chain, Visual attention dependent

demand inventory model, Fuzzy inventory model, Sustainable inventory model under shortage, Hybrid carbon policy inventory model, Inventory model for deteriorating items, Sustainable price reliant demand inventory model, Sustainable inventory model for perishable products, Multi objective optimization modelling, Green retail model, Green inventory model with battery waste management cost, partial backlogging under fuzziness, and Sustainable vendor buyer inventory model. The separate review contents including future direction are included in the following subsections.

### **1. Multi-objective approach**

The inclusion of concerns related to sustainability in the classical inventory model is a rare research area. Bouchery et al. (2011) included sustainability concerns in the inventory model. In this work, the inventory model is reformulated as a multi-objective problem. An extension for the multi-objective problem was also proposed. The extension proposed is a multi-echelon type. Pareto optimal solutions were developed for both these models, and these can be used for capturing the effectiveness of carbon emission policies. The proposed interactive procedure is very helpful for decision-makers to find the best solutions.

A model considering multiple actors is the suggested future direction.

### **2. Impact of carbon emission policies on single period news vendor problem**

The news vendor problem is used to model a single season with no replenishment. The study by Song and Leng, (2012) investigates the impact of different carbon emissions policies. This includes mandatory emissions capacity, emissions tax, and cap-and-trade, on a firm's optimal production quantity and expected profit in a single-period (newsvendor) problem. For each policy, the developed method to find the optimal quantity of production and expected profit. The study finds that the tax rate imposed on high-margin firms should be lower than that on low-margin firms for high-profit perishable products, while the opposite is true for low-profit products. Song and Leng, (2012) suggest several directions for future research like relax the assumption of a single period and considering quantity decisions for non-perishable products over multiple periods, incorporating pricing decisions, assuming price-dependent aggregate demand in additive and multiplicative forms, methods for firms to select the best carbon emission reduction policy for their specific need, etc.

Models with non-perishable products, multiple periods, and pricing decisions are the suggested future directions.

### **3. MDR and MV News vendor models**

The news vendor model is suitable for fashion retailer-related inventory decision problems. Choi and Chiu, (2012) examines the mean-downside-risk (MDR) and mean-variance (MV) newsvendor models for supply chain management of fashionable products. The models are studied under both exogenous and endogenous retail price decision cases, and analytical solutions for both problems are developed. The study evaluates sustainability measures such as expected quantity of leftover goods, sales-to-goods leftover ratio, rate of return on investment, and probability of achieving a profit target for fashion retailers using mean-risk and risk neutral models. From these evaluations, insights on problems can be generated.

Optimal decision making for more expensive environmentally friendly supplier is a suggested future direction.

### **4. EOQ with emission condition**

To reduce the emission in a system, we have to add some cost to technologies. But by implementing operational adjustments, we can reduce the emission without increasing the cost. The analytical model for this statement was proposed by Chen, Benjaafar and Elomri (2013). The Economic order quantity model was added with a condition that connects emission and order quantities. The work discusses the relative emissions and the relative increase in cost. The factors behind these are also explained. The applicability of the model under different environmental regulations is also discussed in this work.

## 5. Transport mode selection problem

Modern transport companies have to make decisions for controlling the emission from the operation. This can be achieved by transport mode selection. A basic model will consider the lead time with inventory cost and transportation cost. Hoen et al., (2014) added the factor emission cost in to the model. The study uses a carbon emission measurement methodology based on real-life data and incorporates it into an inventory model. The work considers the effects of different types of emission regulation.

This study used the NTM (Network for Transport and environment Methodology) to estimate carbon emissions based on empirical data, with air transportation having the highest emissions and water transportation having the lowest emissions. They also established conditions for determining which mode of transport is selected for any given emission cost, as well as which modes are preferred and under what conditions they are selected based on distance, cost, and product characteristics. The numerical results of the study suggest that the impact of emission-related charges is small, and it rarely leads to a change in the selected transportation mode.

Models with frequency of operation, lead time variability, and origin destination consideration are the suggested future directions.

## 6. Green investment on a production inventory system with carbon tax

Datta, (2017) analyzed the effect of green technology investment on a production inventory system. The work used carbon taxation policy and the production rate and capital investments are considered as decision variables. This rate depends on the limits of machine used in the industry. The proportion of product under with defect category is calculated based on the production rate. Demand is considered as a selling price dependent factor. The proposed model contains profit maximization policy and emission minimization policy. The author concludes the negative effect of carbon tax on profit positive effect of carbon tax on pollution control.

Model with inflation, time value of money, progressive carbon tax, and shortages are the suggested future directions.

## 7. Two plants and uncertain inventory carrying cost

Khatua, Roymahapatra, and Maity, (2017) present a supply chain model with two plants under uncertain inventory holding costs. Raw materials are supplied by the supplier to the manufacturer, who possesses two plants for processing. The first plant P1 produces the main product, which is sold by the first retailer R1, to customers. The residue of the first plant is directed to the second plant P2 to produce a by-product sold by the second retailer R2. All costs are considered for the model and inventory holding costs are treated as uncertain variables. Decision variables are supply rate, production rate, and by-production rates, and the model has been solved analytically in both crisp and uncertain environments to maximize individual profits.

This study uses data collected from a sugar mill and suggests that the model could also be applied in other areas, such as thermal power plants where residue units like ash could be used as raw materials in other industries to increase profits and reduce pollution.

Models with imperfect production inventory systems, incorporation of deterioration, creating more realistic models using dynamic features are the suggested future directions.

## 8. Variable demand under inflation

By implementing the green supply chain inventory model concept, the industry can increase its profit while reducing emissions. The impact of the deterioration of products and inflation are very important factors and must be considered in the model Rani, Ali, and Agarwal, (2017). This work considered recycling, reverse logistics, and, inflation. The demand for remanufactured products is assumed as quadratic. The demand for the new product is assumed as linear in nature. Other special assumptions are time-dependent holding cost and Weibull-type deterioration. The proposed model can minimize the total cost during manufacturing and remanufacturing.

Models with shortage, learning effect, and fuzzy are the suggested future directions.

## 9. Green inventory routing problem

Production, transportation, and inventory are the three supply chain activities, in which transportation is the major source of CO<sub>2</sub>. Generally, the inventory routing problem is the base of transportation activities. Cheng et al. (2017) developed a green inventory routing problem in which the basic consideration is environmental impacts. They focused on a heterogeneous fleet. The proposed solution contains a mixed integer program and the model minimizes the sum inventory cost and routing cost. The routing cost contains the wage of the driver, the fixed cost of the fleet, fuel cost, and emission cost. For the calculation of fuel cost, we need fuel consumption. The fuel consumption and emissions are observed from the fleet characteristics like load speed and distance.

Models with time window constraints, the inclusion of fuel consumption and emissions in inventory activities, multi-objective optimization, and heuristic algorithms are the suggested future directions (Cheng et al., 2017).

## 10. Green supply chain of the Auto Industry

The automobile industry consists of manufacturer, warehouse, distributors, and retailers. All these levels have a share of deteriorating components. Yadav, Swami, and Ahlawat (2018) introduced particle swarm optimization that can study the stock level to make the system a green one. The assumptions made in this work includes manufacturing rate, demand rate, and holding cost are linear function of time. The distribution centers can store excess units. The developed model can consider the deterioration, multiple delivery cases, and time discounting. They implemented the proposed model using MATLAB.

## 11. Model to regulate the environment

Ritha and Poongadisathiya, (2018) work on environmental sustainability and explained the impact of social cost in the green inventory model, which reduces carbon emissions. The deterministic demand of a single product is the basic assumption of the proposed model. Green costs under various categories like setup, procurement, holding, logistics, pollution control, waste, packaging, and technology are introduced in the mathematical formulation of economic order quantity. By implementing this model, a company can improve its economic status in the green state.

## 12. Green growth perspective

Green growth directly depends on the implementation of green inventory management. In the view of company management, the inventory and pricing factors are more important to be under the green growth. Wang et al., (2019) studied various green growth strategies. They proposed models that contain inventory and pricing decisions. The single-period model with recycling mode is studied in this work. Government subsidy on account of green initiation is also considered in the model. The work introduced the methodology to make optimal order decisions.

Models with joint consideration of inventory and pricing, and multi-period model are the suggested future directions.

## 13. Four-layer green supply chain

The acceptability of green items is a new trend in the modern market. This vision is also important in the supply chain of products. The chain wings are suppliers of raw materials, manufacturer, and retailers. Panja and Mondal, (2019) studied the green supply chain and the green degree of the finished product. Customers' demand is considered as a function of green degree and wholesale price. This work incorporates two-level credit periods offered by a supplier to the manufacturer and manufacturer to the retailer where the retailer's credit period is considered in a type 2 fuzzy nature. The production cost and customer demand are based on green degree. They developed two algorithms to solve and optimize these problems. Models with variable demand, customer ratings and offers on payment are the suggested future directions.

Models with stochastic demand, customer rating, offers on delayed payment, and imperfect products are the suggested future directions.



#### 14. Visual attention-dependent demand inventory model

E-commerce is an acceptable modern trend in business. Online pharmacies are under this category. Interaction through the web and supply chain after this interaction are the two phases of E-commerce. Revenue growth, reducing waste, and reducing the cost of energy are the three areas to be covered in this topic. Chen, Chiu, and Chang, (2019) developed an inventory model which deals with profit and environmental factors in the single period multi-product inventory system. They characterized the customer demand using a visual attention-dependent demand rate (VADD). This will reduce the losses due to excessive inventory. To manage the complexity of solving real problems, they used a method based on a genetic algorithm. In short, the proposed model can provide the facts of the connection between the growth of sales and corresponding green status.

Models with loss of stock outs, price elasticity, and space elasticity are the suggested future directions.

#### 15. Fuzzy inventory model

The industry needs to design and frame strategies to reduce waste and carbon emissions. Producers and customers must have the same vision in this area to realize the nation's environmental policy. The industry's supply chain also needs such designs to reduce corresponding emissions. Rani, Ali, and Agarwal, (2019) proposed a model for items under the class named deteriorating items. There is a deterioration rate that depends on time. Recycling, reverse logistics, and remanufacturing were considered in this work. Demand is assumed in this work as carbon dependent. The work proposed a crisp model for minimizing the total cost is developed and impreciseness is handled by triangular fuzzy numbers. The signed distance method is used for defuzzifying the total cost function.

Models with shortage and backorder, inflation, learning, and forgetting effect are the suggested future directions.

#### 16. Sustainable Inventory model under shortages

Considering global warming, many developed nations were implemented a carbon tax and cap policies to reduce carbon emissions. These policies are based on the Kyoto Protocol. Mishra, Wu, and Sarkar (2020) introduced a sustainable economic production quantity carbon tax and cap model. No shortage, partial back ordering, and full back ordering are considered in this work. The model explains the problem with and without green technology investment. They developed a methodology for getting the optimal solutions for cycle time, green investment, and length of the period in positive inventory level. After checking with various cases, the study confirmed that the partial backorder case has a notable profit and highest cycle time than other cases.

The model with stochastic demand deterioration, a model with other sustainability parameters, and the model with capital investment are the suggested future directions.

#### 17. Hybrid carbon policy inventory model

Generally, the emissions are derived from various phases of a system like initial setup, production, and holding of product. The policies adopted by firms are carbon tax and cap and trade. Datta, Nath, and Dutta Choudhury, (2020) introduced a hybrid policy in which both the carbon tax and cap and trade policies exist together. This work deals with a single product that is produced with different qualities. For products with different qualities, the factors like cost of production, cost of set up, amount of emission, and demand rate are also different. The item with the master quality only occurs after the involvement of increased cost of production. The industry must invest separately in the phases to decrease emissions. They developed an algorithm to solve the model with the consideration of maximizing the policy. In short, this work is a source-based green investment model. The study reveals that the hybrid model is better than individual policies, but leads to a reduction in the profit of the industry.

Models with multiple quality, trade credit, inflation, and time value of money are the suggested future directions.

## 18. Inventory model for deteriorating items

Trade credit is a policy introduced by manufacturers as an allowable delay period in payment to retailers. Rani, Ali, and Agarwal, (2020) developed a green inventory model for a manufacturer that provides this kind of delay. The basic aim of this policy is to attract the retailers. The retailer has introduced a trade period to the consumer. In this work, they assumed that the demand is directly related to the credit period. Deterioration of the product is considered throughout the mathematical model. The model was solved in certain and uncertain environments. The work assumes simultaneous manufacturing and remanufacturing. The retailer collects the returned product and is directed to flow toward the manufacturer's end.

Models with inflation, seasoning, and shortages are the suggested future directions.

## 19. Sustainable price-reliant demand inventory model

Md Mashud et al., (2021) propose a sustainable price-reliant demand inventory model with controllable carbon emissions. This study aims to reduce CO<sub>2</sub> emissions from farm warehousing activities. The model involves investment in energy-efficient green technology in a two-warehouse inventory system to reduce carbon emissions during the transportation of products. The transportation activities are from the owned warehouse to the rented warehouse and the customer while maximizing profit. The paper includes two cases, one with allowable shortages and one without shortages, and applies pricing strategies and a hybrid payment scheme to make the business more profitable and attract new customers. Non-instantaneous deterioration and a constant backorder are considered, and a nonlinear model is proposed with a solution algorithm. A real case study is presented, and sensitivity analysis is performed to validate the model.

Models which consider emission during the holding of product, models with reduced ordering cost, the social implication to society, deterioration rate control, and stochastic demand are the suggested future directions.

## 20. Sustainable inventory model for perishable products

Consumer satisfaction against the perishable product is very much related to their variation quality due to spoilage and deterioration and they need special techniques for keeping this in stock. Product decay will create negative decisions on the side of a customer. Yadav and Khanna, (2021) introduced a model for perishable items with an expiry date. This assumes price-sensitive demand and a time-varying deterioration rate. Carbon tax policy is also considered in this work. This work proposes a model to find the optimal cycle length and selling price. This model will be a good method for managing the retail grocery business. The work concludes that the carbon tax policy is the best solution for maintaining a state of green inventory.

Models with multiple players in the supply chain, other carbon policies like carbon cap, carbon offset, quality sensitive demand, preservation cost against deterioration, non-perishable products and reverse supply chain are the suggested future directions.

## 21. Multi-objective optimization modeling

Ahmadini et al., (2021) proposed a multi-item multi-objective inventory model under the sustainable green supply chain. The model considered back order and green investment. They introduced solutions to profit maximization, holding cost minimization, total waste minimization, and total penalty cost minimization. Various constraints related to budget, space, order cost, waste disposal, pollution control, and electricity are also considered in the model. Fuzzy goal programming is used to optimize the formulated problem.

Models with price breaks, quantity discounts, late delivery, and shortage are the suggested future directions.

## 22. Green retail model

Paul et al., (2022) proposed an inventory model that incorporates green retail practices and variable holding costs. The work considers the impact of green concern level and selling price on-demand rate. They proposed a method to find optimal replenishment time and green concern level that maximizes profit. The effects of greening level and deterioration rate on profit are analyzed, and a mathematical model is introduced. This

model contains a carbon taxation policy. The model is then verified for its stability using numerical examples and sensitivity analysis.

Models with the advanced payment strategy, controllable carbon emission policy, trade credit policy, reliability, warranty period, and optimal control theory are the suggested future directions.

### **23. Green inventory model with battery waste management cost**

The manufacturing sector is a significant contributor to waste generation. Producing high-quality products while reducing waste generation becomes a challenging task. One emerging form of pollution is electric waste generated from modern machinery used in factories. Selvi and Ritha, (2022) propose an inventory model that includes battery waste management costs. This model aims to minimize environmental impact and maximize re-use, recovery, and recycling processes. The model is proposed for assisting decision-makers in achieving a balance between environmental sustainability and economic development.

The results suggest that battery waste management decreases environmental impact. However, to further promote sustainability, it is necessary to improve collection systems and management practices to reduce illegal trade in waste batteries and protect the environment and public health.

### **24. Partial backlogging under fuzziness**

Products having a less environmental impact are always acceptable to the customers. One example is the herbal industry. Plant extracts are the raw materials for this industry. Bhavani et al., (2022) introduced eco-friendly demand under partially backordered shortages in the green inventory system. This value is generated by considering the share of herbal and chemical items in the product. The developed model is suitable for controlling carbon emissions in industries. The study collects the emissions from inventory setup, degradation, and holding. The imprecision in the model is handled by Pythagorean fuzzy numbers.

Models with the variable backlog and deterioration rates, implementation in production, and supply chain are the suggested future directions.

### **25. Sustainable vendor buyer inventory model**

A company with a sustainability vision has to invest for maintaining its activities in a green state. The green incentive is support provided by the government having a green vision. This incentive is based on a target fixed by the companies to reduce emissions. Jauhari et al. (2023) proposed a model that say the review period, safety factor, shipment count, and investment needed in the green strategy. The model can help to minimize the total cost. The paper explains the green model under a vendor buyer system. The annual demand in this model is considered fuzzy. The vendor's total cost and joint total cost were formulated before the solution to total cost minimization. This can be used as a decision-making tool for inventory managers working under the vision of a green inventory model.

Models with imperfect production, other carbon policies, and improved coordination of inventory components are the suggested future directions.

## **III. CONCLUSION**

The reviewed articles contain studies in the field of green inventory models. A large number of future directions are observed in the reviewed literature. All the reviewed works are directed toward the ultimate objective of the green inventory model, which is to minimize both costs and emissions. As the green vision in all areas is vital for the sustainable development of the world, research conducted for the accounting of the emission cost will help to reduce the emission impact with profit maximization.

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