The Scientific Temper (2025) Vol. 16 (8): 4655-4658
E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2025.16.8.08
https://scientifictemper.com/

RESEARCH ARTICLE

An inventory model on the impact of green investment with deteriorating items and planned back orders for economic efficiency and environmental sustainability

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Abstract

Green investment emphasis allocating capital for the industries and research works that promote environmental sustainability and reduce GHG (Greenhouse gas) emissions. It holds up the energy consumption, toxic pollution and the sustainable environment. This research examines the impact of green investment in the inventory model for deteriorating items with planned backorders to balance the economic efficiency and the environmental sustainability. The items are deteriorating at a natural decay process and their rate is proportional to the inventory level per unit time. It leads to the level of inventory. Back ordering happens when inventory is null and it will deliver after production takes place in the industries. The purpose of this framework is to create a green inventory mathematical model for reducing the total cost and carbon (CO_2) emissions.

Keywords: Green investment, Deteriorating items, Backordering, CO_2 emission, Economic efficiency, Environmental sustainability.
关键词： 绿色投资、劣质物品、缺货、二氧化碳排放、经济效率、环境可持续性。

Introduction

Environmental sustainability has become a primary concern in supply chain and inventory management. Traditional inventory models are predominantly focused on minimizing the total cost, which includes ordering cost, holding cost and stock out costs. For the ecological concerns green inventory model has emerged as an important extension of inventory theories. The Green inventory model integrates environmental considerations into inventory decision-making by some factors such as carbon emissions, energy consumption, waste generation and environmental taxes or penalties. It aims to develop an inventory model for cost minimization and to reduce the carbon emissions of inventory systems. Items that lose their value, quality, or usability over time are said to be deteriorating items. It may happen because of expiring, decay, obsolescence, or damage. To avoid this kind of deterioration, follow the FIFO (First In First Out) method, proper storage conditions and demand forecasting. Backordering is a process that managing the inventory when a customer places an order when stock is unavailable. The order will be fulfilled after the stock is restored. The backordering happens because of limited storage, delayed supplies and increasing demand. Retaining customers, avoiding lost sales, and reducing the cost of holding are the merits of backordering in the inventory management.

Environmental sustainability refers to the responsible interaction with the environment to avoid degradation of natural resources. It consists of using renewable energy over non-renewable ones, reducing pollution and waste, also proper disposal of waste, preserving the ecosystems and sustainable development. Economic efficiency in the inventories refers to minimizing the total cost and loss, maximizing the service levels and profitability. Minimizing the holding cost, ordering cost, and avoiding stockouts leads to an increase the good manners among the customers.

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How to cite this article: Vinodini, R., Ritha, W., Nagapan, S. (2025). An inventory model on the impact of green investment with deteriorating items and planned back orders for economic efficiency and environmental sustainability. The Scientific Temper, **16**(8):4655-4658.

Doi: 10.58414/SCIENTIFICTEMPER.2025.16.8.08

Source of support: Nil

Conflict of interest: None.

Received: 16/07/2025 **Accepted:** 27/07/2025 **Published:** 30/08/2025

It will help the industries to assign the timing of orders, arrival, and demand rate of the inventories. In this paper, a model was created for reducing carbon emissions and energy consumption from natural resources. In this paper, a model was created for reducing carbon emissions and energy consumption from natural resources.

The rest of the paper is formulated as follows: Section 2 explains the literature review. Section 3 presents the mathematical formulation of the proposed model. Section 4 examines a numerical example and Section 5 has a brief explanation of the results and discussion. Finally, Section 6 concludes the outcome of this work and sorts out the references.

Literature Review

In the face of growing environmental concerns, integrating sustainability into inventory management. The Green Investment has become an interesting and necessary field of research. In the earlier stage, some researchers have created and developed the inventory models that are related to the green inventory model. Goyal, S. K., and Giri, B. C. (2001) explain Recent trends in the modeling of deteriorating inventory. Turkay, M. (2008) constructed the model of environmentally conscious supply chain management. Bonney, M., and Jaber, M. Y. (2011) formulated environmentally responsible inventory models: Non-classical models for a non-classical era. Luc Eyraud, Benedict Clements and Abdoul Wane (2013) explain about Green investments- Trends and determinants. Jaber, M.Y., Glock, C.H., and El Saadany, A.M. (2013) clarify about Supply chain coordination with emissions reduction incentives. Tang, S., Wang, W., Yan, H., and Hao, G. (2015) developed a model for low-carbon logistics, reducing shipment frequency to cut carbon emissions. Yeu-Shiang, Chih Chiang Fang and Ying-An Lin. (2020) are created inventory Management in supply chains with consideration of Logistics, green investment and different carbon emission policies. Caliskan, C. (2021) derived A simple derivation of the optimal solution for the EOQ model for deteriorating items with planned backorders. Maya Indriastuti and Anis Chariri (2021) describe the role of green investment and corporate social responsibility investment on sustainable performance. Selvi, P., and Ritha, W. (2021) created the Inventory Model on the Effect of Investment in Green Technology under Cap and Trade Policy.

Mathematical Formulation

To develop the proposed model, the following notations and assumptions are used.

Notations

Decision variables

Q - Order quantity per order
G_i - Green investment amount

Other parameters

D - Demand rate
O_c - Ordering cost
H_c - Inventory holding cost
P_c - Production cost
M_c - Manufacturing cost
d - Distance travelled
v - Average velocity
α - Proportion of demand returned ($0 < \alpha < 1$)
β - Social cost from vehicle emission
a - Fixed cost per trip
δ - Deterioration rate per unit of the inventory per unit time
b - Backordering cost per unit time
V_c - Variable cost per unit transported per distance travelled
L_p - Labor cost for packaging per parcel
M_p - The cost of material used for packaging per parcel
θ - Proportion of waste produced per lot Q
W_d - Cost to dispose waste to the environment
F_d - Fixed cost per waste disposal activity
N_p - Number of parcels
C_q - Carbon emission quantity from order per cycle
C_m - Carbon emission from manufacturing process
C_h - Carbon emission quantity from inventory holding
S - Screening cost
R_c - Recycling cost per unit
R_r - Carbon emission from recycling process
R_m - Number of returned materials that are suitable for recycle
λ - The carbon reduction efficiency factor
ω - The offsetting carbon reduction factor
U_c - The upper limit of carbon emissions
C_t - The carbon trading price of unit carbon emission

Assumptions

- The demand rate and exchanged goods are constant in each cycle.
- The production rate depends on the demand rate.
- The manufacturing industry has the possibility make investment on green technology to reduce the carbon emissions.
- The industry fix to reduce the energy consumption, pollution and waste generation.
- The products deteriorate at a constant rate proportional to the inventory level.
- Deteriorated products are taken out and they are not restored.
- There is no restriction on the storage limit or backorder quantity.

Mathematical Model

The mathematical model on the impact of Green Investment with deterioration items and planned back orders for

economic efficiency and environmental sustainability is classified into two categories. The two models are the formulation of total cost and order quantity without green technology and the formulation of total and order quantity with green technology. Demand is assumed for the deteriorating items $(D+\delta)$ and the holding cost is calculated with the backordering cost $(h+b)$.

Formulation of total cost and order quantity without green technology

Consider the case without green cost, the total cost contains manufacturing cost, production cost, holding cost, transportation cost, screening cost, disposal cost and carbon trading cost. Subtracting the total carbon emission from production and transportation and from the upper limit of carbon emissions required amount can be obtained. The total cost is

$$TC(Q) = \begin{bmatrix} \frac{(D+\delta)}{Q}\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) + \\ \frac{Q(h+b)}{2} + (D+\delta)\left(P_c + V_c d(1+\alpha) + W_d(\theta+\alpha)\right) - C_t U_c + \\ \frac{(D+\delta)}{Q} C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right) + \frac{Q}{2} C_t C_h \end{bmatrix} \quad (1)$$

To find optimal order quantity differentiate equation (1) with respect to Q and equate it to zero. The Optimal order quantity is derived as Q^*.

$$\begin{bmatrix} \frac{-(D+\delta)}{Q^2}\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) + \frac{h}{2} \\ -\frac{(D+\delta)}{Q^2} C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right) + \frac{C_t C_h}{2} \end{bmatrix} = 0 \quad (2)$$

Manipulate equation (2),

$$Q^* = \sqrt{\frac{2(D+\delta)\left[\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) + C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right)\right]}{(h+b) + C_t C_h}} \quad (3)$$

Formulation of total cost and order quantity with green technology

In modern word, every industries accept and adopt the green technology to sustain the environment, reduce usage of energy and reduce the carbon emission. This framework consist the green technology that is defined as,

Reducing the carbon footprint of green technology $= \lambda G_i - \omega G_i^{\,2}$

Then the derivation of total cost and optimal order quantity are derived as follows.

$$TC(Q) = \begin{bmatrix} \frac{(D+\delta)}{Q}\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) + \\ \frac{Q(h+b)}{2} + (D+\delta)\left(P_c + V_c d(1+\alpha) + W_d(\theta+\alpha)\right) - C_t U_c + G + \\ \frac{(D+\delta)}{Q} C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right) + \frac{Q}{2} C_t C_h - C_t\left(\lambda G_i - \omega G_i^{\,2}\right) \end{bmatrix} \quad (4)$$

To find optimal order quantity differentiate equation (4) with respect to Q and equate it to zero. The Optimal order quantity is derived as Q^*.

$$\begin{bmatrix} \frac{-(D+\delta)}{Q^2}\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) \\ + \frac{h}{2} - \frac{(D+\delta)}{Q^2} C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right) + \frac{C_t C_h}{2} \end{bmatrix} = 0 \quad (5)$$

Manipulate equation (5),

$$Q^* = \sqrt{\frac{2(D+\delta)\left[\left(O_c + F_d + \left(L_p + M_p\right)N_p + S + M_c + R_c R_m + 2a\right) + C_t\left(C_q + C_m + \frac{2\beta d}{\nu}\right)\right]}{(h+b) + C_t C_h}} \quad \text{... (6)}$$

To find optimal amount of green investment differentiate equation (4) with respect to G_i and equate it to zero. The optimal order quantity is derived as G_i^*.

$$G_i^* = \left(\frac{C_t \lambda - 1}{2C\omega}\right)$$

Numerical example

Consider the following parameters to illustrate the proposed model:

D - 5000
O_c - \$ 120
H_c - \$ 20
P_c - \$ 200
M_c - \$ 150
d - 250/km
ν - 50/km
α - 0.2
β - \$ 20
a - \$ 30
δ - 0.05
b - \$ 500
V_c - \$ 3
L_p - \$ 6
M_p - \$ 8
θ - 0.5
W_d - \$ 0.8
F_d - \$ 1

N_p - 15
C_q - \$ 130
C_m - \$ 160
C_h - \$ 55
S - \$ 0.2
R_c - \$ 120
R_r - \$ 130
R_m - 50
λ - 4
ω - 0.01
U_c - 6000
C_t - \$ 1.8

Table 1: The optimal solutions

Investment progress	Q^*	G_i^*	TC
Without green technology	773.725	-	$ 5,587,994.945
With green technology	773.725	$ 172.222	$ 5,587,461.207

Results

The optimal solutions are given Table 1.

Discussion

Caliskan, C. (2021) derived A simple derivation of the optimal solution for the EOQ model for deteriorating items with planned backorders. Maya Indriastuti and Anis Chariri (2021) describes the role of green investment and corporate social responsibility investment on sustainable performance. Selvi, P., and Ritha, W. (2021) created the Inventory Model on the Effect of Investment in Green Technology under Cap and Trade Policy. The proposed green inventory model is evaluated under two different categories. One is the formulation of total cost without green technology and the formulation of total cost with green technology. The value of the optimum order quantity and total cost are categorized in the table 1. The outcome value and cost of this inventory model is less than the existing model. The cost is reduced because of making investment in green technologies. Generally the objective of inventory models is maximize the profit and minimize the loss. But recently the environmental concern is also consider as a necessary part in day today life. Consumption of the energy from the environment which is not renewable is dangerous for our future generation. Then excess carbon emission is polluting the environment. Currently, researchers are more attracted by the green modernization. Developing these kind of green inventory model helps to reduce the carbon emission and energy consumption.

Conclusion

This study developed and analyzed a green inventory model that integrates environmental considerations specifically carbon emissions into the inventory model. The findings suggest that the green inventory model serve as a practical decision-support tool for manufacturing industries aiming to meet sustainability goals, comply with environmental regulations. Internalizing environmental impacts in inventory planning, organizations can move toward more sustainable operations without compromising profitability. The green inventory model provides a valuable framework for balancing economic efficiency and environmental sustainability, making it highly relevant in the context of sustainable supply chain management.

Acknowledgements

NIL.

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