INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

A Sustainable Supply Chain Model on the Impact of Carbon Emission with Pre-Payment Based Partial Free Transportation

OPEN ACCESS

Received: 16-10-2024

Accepted: 29-11-2024

Published: 20-12-2024

Citation: Monika M, Vinotha JM (2024) A Sustainable Supply Chain Model on the Impact of Carbon Emission with Pre-Payment Based Partial Free Transportation. Indian Journal of Science and Technology 17(46): 4885-4894. https://doi.org/10.17485/IJST/v17i46.3278

* **Corresponding author**.

merlinevinotha@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

M Monika[1], J Merline Vinotha[2]*

1 Research Scholar, PG and Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli, 620002, Tamil Nadu, India

2 Assistant Professor, PG and Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirappalli, 620002, Tamil Nadu, India

Abstract

Objectives: To analyze and justify the importance of Green technology investment for both production and distribution processes in the supply chain along with a Pre-Payment Based Partial Free Transportation strategy. **Methods:** A non-linear sustainable supply chain model considering a single manufacturer and multi-retailer is formulated with an incorporation of green technology investment for both production and transportation processes along with partial pre-payment based free transportation. Lagrangian method is used to obtain the optimal solution of the problem. **Findings:** The proposed model has been solved with the prescribed method and it gives the average profit of the manufacturing firm with green technology investment is \$15537.360 and the average profit of the manufacturing firm without green technology investment is \$9864.8816. This shows that the model with green technology performs better than the other one. **Novelty:** Green technology investment has been incorporated for both production and transportation processes, along with partially pre-paid, free transportation, whereas earlier research focused only on green investment for production.

2020 Mathematics Subject Classification: 90B05, 90B06.

Keywords: Green technology; Carbon emission; Carbon cap; Carbon tax; Prepayment transportation

1 Introduction

Dynamic environments and consumer expectations are ever-evolving. Their expectations at every point of the supply chain are to have more customized, effective, and flawless experiences. The goal of delivering the ideal product in the correct place at the correct time is a challenge for any organization. To succeed in this, Organizations often innovate their strategies and incorporate new technologies in their supply chain. Building a successful supply chain is crucial for any business, as it directly impacts efficiency, customer satisfaction, and competitiveness. A well-structured supply chain streamlines operations, reducing costs and enabling faster delivery of products, which enhances customer experiences and loyalty. Most of the supply chain system consists of one manufacturer and multiple retailers where the majority of manufacturing firms establish networks with their retailers by providing various facilities to sell their products.

Ensuring a smooth supply chain between manufacturers and retailers often involves implementing different discount strategies. The most significant consideration for a business is lot sizing or ordering quantity.In accordance with the literature at hand, many inventory systems have been developed on the premise that consumers pay the entire purchase price of the items at the period of shipment. In practice, however, there are several options for paying the purchase price:(i) paying at the time of delivery, (ii)partial payment delay, (iii)partial pre-payment, (iv) both partial pre-payment and permissible partial delay-in-payment.In a supply chain model, Khakzad implemented a pre-payment policy for deteriorating items.[1] Md. Al-Amin Khan demonstrated an inventory model with partial backordering and prepayment.[2] BA Kumar examined the retailer's optimal ordering policy time under both pre-payment and late payment scenarios.[3] Both crisp and fuzzy models were developed for Weibull deteriorating items. In accordance with the literature at hand, many inventory systems have been developed on the premise that consumers pay the entire purchase price of the items at the period of shipment. Also, all of the above works focus primarily on the impact of payment policies on inventory systems, while overlooking the significant influence of transportation on the supply chain. AK Manna demonstrated a supply chain model with pre-payment-based partial free transportation.[4] For the first time, a profit maximization problem considering a single-manufacturer, multi-retailer for imperfect items under the concept of a pre-payment-based free delivery facility has been formulated and solved analytically.

To remain competitive in the marketplace, Organizations are enforced to pioneer their strategies in the supply chain. The pursuit of sustainable development within the supply chain has emerged as a crucial need and challenge for companies while most businesses substantially prioritize profit over sustainability. Businesses implement sustainability efforts only when they align with profit-making strategies. Although industries adopt sustainability measures, their primary focus often remains maximizing profits. A. Nagurney constructed a supply chain game theory network framework that captures labor constraints and found the impacts of a spectrum of disruptions to labor on the product flow and the profits of the firms in the supply chain network economy.[5] X Fan developed an analytical model consisting of a manufacturer with an online channel and an independent retailer and investigated the effects of the buyonline-and-pick-up-in-store strategy on the profitability of the supply chain.[6] BK Dey developed an inventory model for a single type of item and introduced an investment for the inspection process through the autonomation policy to increase the total profit of the system.[7]

The government has implemented several regulations to promote sustainability in the supply chain. European Union, China, Canada, and the United States are the leading countries to combat carbon emissions, leveraging ambitious policies such as carbon taxes, cap and trade systems, and other emission trading methods to drive progress toward climate goals. Green technology or green tech has the potential to minimize emissions in the supply chain. It generally refers to environmentally friendly technologies designed to reduce negative impacts on the planet through sustainable practices and innovation. It includes renewable energy, sustainable transportation, waste management and recycling, and energy efficiency solutions, all helping us move towards a more sustainable future. Green inventions and clean technologies offer significant benefits for businesses to stay competitive in a rapidly evolving, eco-conscious marketplace. These are profitable markets that are rapidly expanding. Industrialized countries' regulatory authorities are now taking steps to decrease emissions of global warming gases. N Sharma constructed the two-echelon supply chain inventory model and justified the valued insights of green technology investment through the Particle Swarm Optimization (PSO) method to reduce the emission.[8] CJ Lu looked at carbon emission policies with emissions reduction technology investment.[9] A Stackelberg game approach is used to determine the optimal solution to the problem under different emission reduction policies. Mishra constructed a sustainable production model with a carbon emissions rate under shortages.[10] Lagrangian method is used to determine the optimal strategies of cycle time, green technology investment, and the fraction period length. In all the above works, Green technology investment has been incorporated only for production systems where the transportation sector also substantially contributes to carbon emissions in the supply chain process. Green investment in transportation, weight reduction, and improvements in engines and tires are just a few of the ways for vehicles to become more fuel-efficient. C Ju analyzed the impacts of e-commerce and green logistics on advancing the sustainable development of developing countries and suggested that governments promote environmentally friendly projects and foster sustainable practices.[11] AS Karaman investigated the association between green logistics performance and sustainability reporting and found that the highlighted dimensions of green logistics performance may foster the circular economy while promoting the overall economic development of the countries.[12] X Li highlighted the significance of global green logistics and found that green logistics performance improves economic growth and environmental quality.[13] P Trivellas investigated the relationship between green supply chain management practices and supply chain, green and business performance, and controlling for environmental dynamism and provided guidance for logistics managers.[14]

Y Agyabeng-Mensah examined green logistics management practices with social, environmental, market, and financial performances in achieving sustainability and revealed that it has a significant influence on environmental performance. [15] SM Patella reviewed the adoption of green vehicles in urban freight transportation, paying specific attention to e-commerce. [16] A Jazairy analyzed the institutional pressures to adopt green supply chain management practices, which could drive shippers to purchase green logistics services. [17] M Huge-Brodin discussed the relationship between logistics service providers (LSPs) and shippers in the context of adopting more environmentally sustainable logistics practices. [18] R Stekelorum examined the extent to which different combinations of internal and external green supply chain management practices influence third-party logistics providers' operational and financial performances. [19] S Samad highlighted the significant influence of Green Supply Chain Management, with a potential enhancement of organizational sustainability performance. [20]

To the best of our knowledge, the majority of the existing literature has predominantly emphasized profit-driven strategies within the realm of production sustainability. Specifically, vast research has concentrated on investments in green technology in production inventory models. But the transportation sector also crucially contributes to carbon emissions with both direct and indirect environmental consequences. Therefore, research on the transportation sector to achieve sustainability is necessarily required. However, organizations often prioritize profit over sustainability. The most important factor for a firm is lot sizing or ordering quantity. So developing a model with an ordering strategy also influences the profit of the supply chain. Most studies have examined solely the optimality of sustainable parameters (i.e. green technology investment) or ordering strategy parameters (i.e. pre-payment). In particular, the existing literature either deals with the green technology investment for production or transportation but not at the same time. Consequently, this leads to the existence of a research gap that does not investigate both parameters simultaneously. So in this study, a single-manufacturer, multi-retailer supply chain problem for imperfect items under the concept of partial pre-payment based free delivery facility incorporated with a green technology investment for both production and distribution process has been formulated and solved to address the sustainable issue parameter.

The remainder of this research is subdivided into the sections below. In Section 2, the suggested model is mathematically formulated and the solution methodology has been explained. and in Section 3 the result and discussion have been given. Finally, the conclusion has been stated in Section 4.

2 Methodology

A non-linear sustainable supply chain model considering a single manufacturer multi-retailer is formulated and solved analytically. The Lagrangian method is used to obtain the optimal investment of green technology in the production and distribution process. Notations and Assumptions which are used to formulate the proposed model are given in 2.1 and 2.2.

2.1 Notation

- P: Rate of production
- θ: The amount of flawed items manufactured per unit of time
- δ: The amount of flawed items that are modified
- n: Shipments made throughout the manufacturing cycle
- m: Shipments made after the manufacturing cycle
- r: Total number of retailers
- Q_j: j^{th} retailer purchasing quantity per cycle,$j = 1, 2, ..., r$
- Q: Total orders placed by all merchants during each cycle, where $Q = \sum_{j=1}^{r} Q_j$
- A: Manufacturer set up cost per manufacturing cycle
- c_p: Production cost
- s_c: Screening cost
- r_{cm}: Reworking cost for flawed items
- h_c: Holding costs for manufacturer's perfect-quality products
- s_r: Price of a flawless product from a manufacturer
- c_t: The price of transportation for each unit
- d_{mj}: Distance of j^{th} retailer from the manufacturing company
- β_j: Amount paid in advance of the buying price of j^{th} retailer
- I_e: Rate of interest
- K_j: j^{th} retailer pre-payment in each cycle
- ξ: Control parameter of transportation cost

- c_d: Disposal cost
- T: Manufacturing period($T = 1, 2, 3, 4, \ldots$)
- G: Investment in green technology for Production
- G_1: Investment in green technology for Transportation
- Z: Cap for carbon emission (kg/year)
- c_2: Inventory carbon emission (kg/year)
- c_3: Inventory obsolescence carbon emission (kg/year)
- B: Set up cost associated with carbon emissions (kg/year)
- x: Production carbon tax
- w: Transportation carbon tax
- l: Emission for production
- ζ: Emission rate during transportation
- v: Environmental impact carbon emissions for inventory(kg/year)
- u: Greener technology's effectiveness in lowering emissions
- u_1: Greener technology's effectiveness in lowering emissions
- y: After green technology investment, a percentage of carbon emissions
- y_1: After green technology investment, a percentage of carbon emissions
- α: Rate of inventory obsolescence (%)
- a: The weight of expired inventory (kg/unit)
- b : Space needed for each product

2.2 Assumptions

(i) A multi-retailer and a single-manufacturer were considered. The manufacturer begins the manufacture at $t = 0$ with rate $P$and runs until $t = T$.

(ii) A portion of imperfect items were generated alongside perfect items during the manufacturing process. The defect rate is assumed to be constant. Rework is used to repair a portion of damaged products.

(iii) In the interval $\frac{T}{n}$, the manufacturer delivers the order quantity $\sum_{j=1}^{r} Q_j$ to the merchants.

(iv) The j^{th} merchant prepaid the manufacturer$\beta_j\,(<1)$part of the purchase price in $\left(K_j - 1\right)$ payments. The rest portion$\left(1-\beta_j\right)$of purchase price will be charged when the supplies are received. For this partial pre-payment sum, the manufacturer gets interest.

(v) Due to partial prepayment of purchase costs, the manufacturer provides chances to the suppliers, covering a portion of the transporting costs for transporting the purchase amount from the manufacturer to suppliers.

(vi) According to government environmental restrictions, manufacturers should pay a carbon emissions tax for the manufacturing and shipping of commodities. A carbon cap is also incorporated for reducing carbon emissions.

(vii) The manufacturer intends to invest in modern technology, and machinery that conserves energy, in order to transition to a more environmentally friendly manufacturing system. There is a cap on the total amount of money that can be invested. Fraction of reduction of average emission for production is$F = y\left(1 - e^{-uG}\right)$ where $y, u$and G were defined in the notations section. $F = y\left(1-e^{-uG}\right) \Rightarrow G = -\left(\frac{1}{u}\right)\left[ln\left(1-\frac{F}{y}\right)\right]$ which is like the relation assumed by Lou et al. The manufacturer might make improvements to his production methods to make them more environmentally friendly. The fraction of reduction F is zero, when $G = 0$ and tends to y when $G \to \infty$. Lou et al. took $y = 1$. The factor u indicates how effective greener technology is at lowering emissions. This investment function is consistent in various industries and has widely been used in literature to formulate various investing options considered by Lou et al.

(viii) The manufacturer also intends to invest in transportation systems such as vehicle weight reduction and enhanced engines and tires, advanced tracking systems for trucks, and transitioning to biofuels in order to move toward a more environmentally friendly logistics network. The fraction of reduction of average emission for transportation is$F = y_1\left(1-e^{-u_1 G_1}\right)$where$G_1$ were defined in the notations section and $F = y_1\left(1-e^{-u_1 G_1}\right) \Rightarrow G_1 = -\left(\frac{1}{u_1}\right)\left[ln\left(1-\frac{F}{y_1}\right)\right]$. The manufacturer might make improvements to his transportation methods to make them more environmentally friendly. The fraction of reduction $F$is zero, when $G_1 = 0$and tends to y_1 when $G_1 \to \infty$.

The costs essential for understanding the financial impact of each component within the supply chain are described in sections 2.3 to 2.7.

2.3 Production screening and reworking costs

The unit expenses for manufacturing, screening, and reworking are c_p, s_c, r_{cm} respectively. $P, \delta\theta P$and T are the production rate, repairing rate, and production period, respectively. As a result, the total cost for manufacturing, perfect and defective item screening, and imperfect item reprocessing is given by

$$PC = \{c_p + s_c + r_{cm}\delta\theta\}\, PT \tag{2.1}$$

2.4 Holding cost

The holding cost is given by

$$HC = h_c\left[\frac{1}{2}\{1-\theta P+\delta\theta P\}T^2 - \left\{\frac{T}{n}+\frac{2T}{n}+\frac{(n-1)T}{n}\right\}Q + \left\{\frac{T}{n}+\frac{2T}{n}+\frac{(m-1)T}{n}\right\}Q\right]$$

$$= \frac{h_c}{2n(m+n)}\{n(m+1)+m(m-1)\}\{(P-P\theta)+P\theta\delta\}T^2 \tag{2.2}$$

2.5 Transportation and setup costs

The manufacturer reimburses the retailer for a portion of the transportation costs to transfer the product from the manufacturer to the retailer due to partial prepayment. As a result, the total transporting cost for the $(m+n)$cycle is defined as

$$TC = (m+n)c_t \sum_{j=1}^{r} \beta_j{}^{\xi} d_{mj} Q_j \tag{2.3}$$

In addition, the manufacturer's setup cost for each manufacturing cycle is A. As a result, the total setup cost is given by

$$CS = nA \tag{2.4}$$

2.6 Disposal costs

Non-repairable goods will be destroyed in order to reduce environmental contamination.

The total disposal cost is indicated by

$$DC = c_d\,(1-\delta)\,\theta PT. \tag{2.5}$$

2.7 Cost associated with carbon emission

The total green technology investment cost for production is expressed as

$$GTI = G \tag{2.6}$$

The price of all carbon allowances for production is given by

$$CAP = xZ \tag{2.7}$$

The total emission related to the setup cost is defined as

$$SEC = xZ \tag{2.8}$$

The holding cost emission is determined using product availability in stock

$$= \frac{1}{2n(m+n)}\{n(m+1)+m(m-1)\}\{(P-P\theta)+P\theta\delta\}T^2$$

with multiplied by $c_2, b$and x. The holding cost for emissions is

$$= \frac{xbc_2}{2n(m+n)}\{n(m+1)+m(m-1)\}\{(P-P\theta)+P\theta\delta\}T^2 \tag{2.9}$$

The total cost of obsolescence is determined based on the average product availability in stock is

$$= \frac{1}{2n\left(m+n\right)}\left\{n(m+1)+m(m-1)\right\}\left\{(P-P\theta)+P\theta\delta\right\}T^2$$

As a result, the overall cost of maintenance is

$$= \frac{axc_3}{2n\left(m+n\right)}\left(P\theta-P\delta\theta\right)\left\{n(m+1)+m(m-1)\right\}\left\{(P-P\theta)+P\theta\delta\right\}T^2 \tag{2.10}$$

The total emission of production cost (perfect items) is given by

$$lQx \tag{2.11}$$

The carbon output of inventory's environmental effect cost is

$$vQx \tag{2.12}$$

The total green technology investment cost for transportation expressed as

$$G_1 \tag{2.13}$$

The total carbon allowance cost for transportation is derived by

$$CAT = wZ \tag{2.14}$$

The total carbon emission transportation costs are calculated by tax on transportation w, emission rate during transportation ζ, distance $\left(d_{mj}\right)$ and total number of cycle times per year, which is defined as

$$w\zeta d_{mj}\left(m+n\right) \tag{2.15}$$

The interest earned due to the pre-payment policy and sales revenue of the manufacturing firm are described in sections 2.8-2.9.

2.8 Manufacturer's interest earned by pre-payment policy

The j^{th} supplier pre-pays the manufacturer a $\beta_j\,(<1)$ part of the purchase price in $\left(K_j-1\right)$payments. The rest portion $\left(1-\beta_j\right)$ of purchase price will be repaid when the goods are received. Furthermore, in exchange for retailers' prepayment, the manufacturer provides them with a portion of free transportation.

The interest received by the manufacturer from j^{th} supplier in i^{th} cycle is

$$IE = (m+n)\sum_{j=1}^{r}\frac{s_r I_e}{2nK_j}\beta_j\left(K_j-1\right)Q_j T \tag{2.16}$$

2.9 Sales revenue

The income from sales gained by the manufacturer is defined by

$$SR = s_r\left\{(1-\theta)P+\delta\theta P\right\}T \tag{2.17}$$

2.10 Supply chain model with green technology investment

A non-linear sustainable supply chain model considering a single manufacturer and multi-retailer is formulated with the incorporation of green technology investment for both production and distribution processes along with pre-payment-based partial free transportation. Lagrangian method is used to obtain the optimal solution of the problem. Extensive research has focused on investments in green technology within production inventory models. [8–10], However, the transportation sector also plays a crucial role in carbon emissions. Here, the investment has been made for both production and distribution processes to address the sustainability issue parameter. The cap-trade system and taxes on carbon are two different methods that are used to cut down on carbon emissions. In developed countries, either of these two policies can be used to reduce carbon emissions. Incorporating both carbon cap-and-trade and carbon tax mechanisms simultaneously can enhance environmental and economic efficiency by providing price stability and emissions certainty. While cap-and-trade ensures a clear emissions limit and flexibility for companies to trade allowances, a carbon tax offers predictable costs, incentivizing ongoing emission reductions. Together, they can stabilize carbon prices, offer multiple revenue streams for green investments, and encourage businesses to adopt cleaner technologies. In this model, the manufacturer intends to invest in modern technology, and machinery that conserves energy, in order to transition to a more environmentally friendly manufacturing system. For green transportation, investment in weight reduction and improvements in engines and tires are just a few of the ways for vehicles to become more fuel-efficient. From (2.1)-(2.17), the total profit of the manufacturing company is given by

$$\begin{aligned}&TP(T)=SR+IE+CAP+CAT-PC-HC-TC-DC-CS-G-G_1\\&-CE_1\left\{x\left(1-y\left(1-e^{-uG}\right)\right)\right\}-CE_2\left\{w\left(1-y_1\left(1-e^{-u_1G_1}\right)\right)\right\}\end{aligned}$$

So, the profit of the manufacturing company is given by

$$APMF=\frac{TP(T)}{\frac{1}{n}(m+n)T}$$

$$=\frac{np}{(m+n)}\left[s_r\{(1-\theta)+\delta\theta\}-\left\{c_p+s_c+r_{cm}\delta\theta+c_d(1-\delta)\theta\right\}\right]$$

$$\begin{aligned}&+s_r\textstyle\sum_{j=1}^{r}\frac{I_e}{2nk_j}\beta_j\left(k_j-1\right)Q_j-\frac{h_c}{2(m+n)^2}\{n+m(n+m-1)\}\{(1-\theta)+\theta\delta\}\ PT\\&-\frac{nc_t}{T}\sum_{j=1}^{r}\beta_j^{\xi}d_{mj}Q_j-\frac{n^2A}{(m+n)T}-\frac{nG}{(m+n)}\\&+x\left[\frac{n}{m+n}Z-CE_1\ \{1-y(1-e^{-uG})\}\right]-\frac{nG_1}{(m+n)}\\&+w\left[\frac{n}{m+n}Z-CE_2\ \{1-y_1(1-e^{-u_1G_1})\}\right]\end{aligned}\tag{2.18}$$

Where,

$$CE_1=\frac{n}{(m+n)}\left\{[n+lQ+vQ]+\frac{1}{2(m+n)}[bc_2+ac_3(P\theta-P\delta\theta)][\{n(m+1)+m(m-1)\}\{(P-P\theta)+P\theta\delta\}]\right\}\tag{2.19}$$

$$CE_2=n\zeta d_{mj}\tag{2.20}$$

Taking any discrete value of T, the first and second-order partial derivatives of the above equation depending on G, the following results can be obtained:

$$\frac{\partial TP(T,G)}{\partial G}=-\frac{n}{(m+n)}+xuyCE_1e^{-uG}$$

And $\frac{\partial^2TP(T,G)}{\partial^2G}=-xyu^2CE_1e^{-uG}<0$

For the optimum solution of G, we must take,

$$-\frac{n}{(m+n)}+xuyCE_1e^{-uG}\tag{2.21}$$

Similarly, it follows for G_1.

2.11 Supply Chain model without green technology

A non-linear supply chain model considering a single manufacturer and multi-retailer is formulated with a pre-payment-based partial free transportation. Lagrangian method is used to obtain the optimal solution for the problem. If no expenditure is made on green technology, the producer's yearly profit under a carbon cap and tax function is as follows. The manufacturing company's entire profit is defined as

$$TP(T) = SR + IE + CAP + CAT - PC - HC - TC - DC - CS - xCE_1 - wCE_2$$

Thus, the manufacturing firm's average revenue is calculated by

$$APMF = \frac{TP(T)}{\frac{1}{n}(m+n)T}$$

$$\begin{aligned} &= \frac{np}{(m+n)}\left[s_r\{(1-\theta)+\delta\theta\} - \left\{c_p + s_c + r_{cm}\delta\theta + c_d(1-\delta)\theta\right\}\right] \\ &+ \sum_{j=1}^{r}\frac{I_e}{2nk_j}\beta_j(k_j-1)Q_j - \frac{h_c}{2(m+n)^2}\{n+m(n+m-1)\}\{(1-\theta)+\theta\delta\}PT \\ &- \frac{nc_t}{T}\sum_{j=1}^{r}\beta_j^{\xi}d_{mj}Q_j - \frac{n^2A}{(m+n)T} + x\left[\frac{n}{(m+n)}Z - CE_1\right] + w\left[\frac{n}{(m+n)}Z - CE_2\right] \end{aligned} \tag{2.22}$$

Where,

$$CE_1 = \frac{n}{(m+n)}\left\{[n+lQ+vQ] + \frac{1}{2(m+n)}[bc_2 + ac_3(P\theta - P\delta\theta)]\{(n(m+1)+m(m-1)\}\{(P-P\theta)+P\theta\delta\}]\right\}$$

$$CE_2 = n\zeta d_{mj}$$

3 Result and discussion

The existing literature has examined various payment strategies, but it does not adequately address the sustainability parameters in the transportation sector.[1–4] While some studies focus on investments in green technology, they typically neglect the ordering strategy aspect. Specifically, most researchers have developed models for green technology investment solely within the context of protection systems.[8–10] This study aims to fill the gap by considering both sustainability parameters and ordering strategy parameters simultaneously and thus it maximizes the profit of the supply chain. So, in this study, green technology investment has been incorporated for both production and distribution processes in a supply chain along with pre-payment-based partial free transportation.

3.1 Example

To show the efficiency of the proposed model the following numerical example is illustrated with the prescribed parameters as given below.

P=2000, n=7, m=5,θ=0.15,δ=0.90, s_r=\$48, c_p=\$30,s_c=\$2, r_{cm}=\$12, c_t=\$0.4, c_d=\$1.5, h_c=\$3, A=50, I_e=0.08, ξ=14, r=5, Z=900kg/year, x=0.33/kg, B=60/year, l=40kg/year, u=0.8,u_1=0.10,v=60kg/year, a=0.2kg/unit, b=0.4 meters/unit, c_2=4kg,c_3=3kg, α=0.6, y=0.2 unit,y_1=0.4 unit, w=5/km,ζ=0.768/km, Q_1=17, Q_2=18, Q_3=11, Q_4=16, Q_5=19, β_1=0.70, β_2=0.65, β_3=0.55, β_4=0.60, β_5=0.80, K_1=7, K_2=5, K_3=10, K_4=8, K_5=9, d_{m1}=20, d_{m2}=50, d_{m3}=30, d_{m4}=25, d_{m5}=15.

Using the methodology described in section 2.10 precisely using the equation (2.18), the average profit of the manufacturing firm with green technology (for production and transportation)

APMF=15,910.41671+90.078933-1272.291585-48.70096-204.16667-4.4030-1303.563273- 24809+2373.375977

= \$15,537.36074.

Using the methodology described in the section 2.11 precisely using the Equation (2.22), the average profit of the manufacturing firm without green technology (for production and transportation)

APMF=15,910.41671+90.078933-1272.291585-48.70096-204.16667+173.25-1845.10501- 2625-313.59982

= \$9864.8816.

Table 1 shows the efficiency of the suggested paradigm.

Table 1. Comparison of the manufacturing firm with and without Green technology investment

	With Green Technology Investment	Without Green Technology Investment
Average profit of the manufacturing firm	$15,537.36074	$9864.8816

3.2 Sensitivity analysis

In this subsection, sensitivity analyses have been carried out with respect to the system parameters of Example 3.1. For this purpose, the effects of the system parameters β_j,$CE_1$and CE_2 from -20% to +20% on the optimal policy have been studied. The corresponding results have been displayed in Tables 2, 3 and 4.

Table 2. Post optimality analyses w.r.t transportation parameter (ξ)

Transportation Parameter(ξ)	Transportation Cost(TC)	Average Profit$TP(T,G,G_1)$
-20%	+122.02%	-1.35%
-10%	+47.77%	-0.66%
+10%	-31.35%	+0.60%
+20%	-52.298%	+0.25%

Table 3. Post optimality analyses w.r.t carbon emission for production CE_1

Carbon emission for production (CE_1)	Green Technology for production(G)	Average Profit$TP(T,G,G_1)$
-20%	-3.98%	+1.37%
-10%	-1.84%	+0.69%
+10%	+1.61%	-0.70%
+20%	+3.03%	-1.41%

Table 4. Post optimality analyses w.r.t carbon emission for transportation CE_2

Carbon emission for transportation CE_2	Green Technology for transportation(G_1)	Average Profit$TP(T,G,G_1)$
-20%	-4.19%	-1.84%
-10%	-1.93%	-3.49%
+10%	+1.69%	-6.98%
+20%	+3.18%	+8.80%

4 Conclusion

In today's industrial landscape sustainability is not just a concept it is a shared responsibility. Organizations often innovate their strategy in their supply chain to maximize profit. Most studies have examined solely the sustainable parameter (i.e. green technology investment) or ordering strategy parameter (i.e. pre-payment) in the supply chain. In particular, numerous studies have focused on green technology investments within production-inventory models. However the transportation sector also significantly contributes to carbon emissions. So this study seeks to fill the gap by considering both parameters simultaneously and thus it aims to maximize the profit of the supply chain. A nonlinear sustainable supply chain model has been formulated with an incorporation of green technology investment for both production and distribution processes along with a partial pre-payment-based free transportation strategy. Lagrangian method is used to obtain the optimal solution of the green technology investment. Numerical examples are carried out to show the effectiveness of the proposed model. The results show that the average profit of the manufacturing firm with green technology investment is $15537.360 and the average profit of the manufacturing firm without green technology investment is $9864.8816. This work can also be extended for deteriorating items and other sustainability issue parameters. Further studies can also be broadened by comparing different types of fuels, and vehicles with respect to carbon emissions for more sustainable practices.

References

1) Khakzad A, Gholamian MR. The effect of inspection on deterioration rate: An inventory model for deteriorating items with advanced payment. *Journal of cleaner production*. 2020;254:120117–120117. Available from: https://doi.org/10.1016/j.jclepro.2020.120117.
2) Khan MA, Shaikh AA, Cárdenas-Barrón LE. An inventory model under linked-to-order hybrid partial advance payment, partial credit policy, all-units discount and partial backlogging with capacity constraint. *Omega*. 2021;103:102418–102418. Available from: https://doi.org/10.1016/j.omega.2021.102418.
3) Kumar BA, Paikray SK, Padhy B. Retailer's optimal ordering policy for deteriorating inventory having positive lead time under pre-payment interim and post-payment strategy. *International Journal of Applied and Computational Mathematics*. 2022;8(4):165–165. Available from: https://doi.org/10.1007/s40819-022-01374-6.
4) Manna AK, Mondal R, Shaikh AA, Ali I, Bhunia AK. Single-manufacturer and multi-retailer supply chain model with pre-payment based partial free transportation. . *RAIRO-Operations Research*. 2021;55:1063–76. Available from: https://doi.org/10.1051/ro/2021053.
5) Nagurney A. Supply chain game theory network modeling under labor constraints: Applications to the Covid-19 pandemic. *European journal of operational research*. 2021;293(3):880–91. Available from: https://doi.org/10.1016/j.ejor.2020.12.054.
6) Fan X, Tian L, Wang C, Wang S. Optimal service decisions in an omni-channel with buy-online-and-pick-up-in-store. *Journal of the Operational Research Society*. 2022;73(4):794–810. Available from: https://doi.org/10.1080/01605682.2020.1863753.
7) Dey BK, Pareek S, Tayyab M, Sarkar B. Autonomation policy to control work-in-process inventory in a smart production system. *International Journal of Production Research*. 2021;59(4):1258–80. Available from: https://doi.org/10.1080/00207543.2020.1722325.
8) Sharma N, Jain M, Sharma D. Collaboration Policy for Two-Echelon Green Industrial Supply Chain with Carbon Emissions Using Particle Swarm Optimization. *National Academy Science Letters2023*;21:1–5. Available from: https://doi.org/10.1007/s40009-023-01368-y.
9) Lu CJ, Yang CT, Yen HF. Stackelberg game approach for sustainable production-inventory model with collaborative investment in technology for reducing carbon emissions. *Journal of Cleaner Production*. 2020;270:121963–121963. Available from: https://doi.org/10.1016/j.jclepro.2020.121963.
10) Mishra U, Wu JZ, Sarkar B. A sustainable production-inventory model for a controllable carbon emissions rate under shortages. *Journal of Cleaner Production*. 2020;256:120268–120268. Available from: https://doi.org/10.1016/j.jclepro.2020.120268.
11) Ju C, Liu H, Xu A, Zhang J. Green logistics of fossil fuels and E-commerce: Implications for sustainable economic development. . *Resources Policy*. 2023;85:103991–103991. Available from: https://doi.org/10.1016/j.resourpol.2023.103991.
12) Karaman AS, Kilic M, Uyar A. Green logistics performance and sustainability reporting practices of the logistics sector: The moderating effect of corporate governance. *Journal of Cleaner Production*. 2020;258:120718–120718. Available from: https://doi.org/10.1016/j.jclepro.2020.120718.
13) Li X, Sohail S, Majeed MT, Ahmad W. Green logistics, economic growth, and environmental quality: evidence from one belt and road initiative economies. . *Environmental Science and Pollution Research*. 2021;28:30664–74. Available from: https://doi.org/10.1007/s11356-021-12839-4.
14) Trivellas P, Malindretos G, Reklitis P. Implications of green logistics management on sustainable business and supply chain performance: evidence from a survey in the greek agri-food sector. *Sustainability*. 2020;12:10515–10515. Available from: https://doi.org/10.3390/su122410515.
15) Agyabeng-Mensah Y, Afum E, Ahenkorah E. Exploring financial performance and green logistics management practices: examining the mediating influences of market, environmental and social performances. *Journal of cleaner production*. 2020;258:120613–120613. Available from: https://doi.org/10.1016/j.jclepro.2020.120613.
16) Patella SM, Grazieschi G, Gatta V, Marcucci E, Carrese S. The adoption of green vehicles in last mile logistics: A systematic review. *Sustainability*. 2020;13. Available from: https://doi.org/10.3390/su13010006.
17) Jazairy A, Haartman RV. Analysing the institutional pressures on shippers and logistics service providers to implement green supply chain management practices. *International Journal of Logistics Research and Applications*. 2020;23(1):44–84. Available from: https://doi.org/10.1080/13675567.2019.1584163.
18) Huge-Brodin M, Sweeney E, Evangelista P. Environmental alignment between logistics service providers and shippers-a supply chain perspective. . *The International Journal of Logistics Management*. 2020;31:575–605. Available from: https://doi.org/10.1108/IJLM-04-2019-0101.
19) Stekelorum R, Laguir I, Gupta S, Kumar S. Green supply chain management practices and third-party logistics providers' performances: A fuzzy-set approach. *International Journal of Production Economics*. 2021;235:108093–108093. Available from: https://doi.org/10.1016/j.ijpe.2021.108093.
20) Samad S, Nilashi M, Almulihi A, Alrizq M, Alghamdi A, Mohd S, et al. Green Supply Chain Management practices and impact on firm performance: The moderating effect of collaborative capability. *Technology in Society*. 2021. Available from: https://doi.org/10.1016/j.techsoc.2021.101766.