An Integrated Vendor – Buyer Inventory Model with Logistics and Environmental Consideration Based on a Strict Carbon Cap Policy

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Abstract

Carbon emissions from the firm's various activities pose a significant threat to the environment. Companies are looking for ways to reduce carbon emissions as a result of carbon policies imposed by various government regulatory bodies. In this paper, a strict carbon cap policy is considered for inventory management in supply chains while taking logistics and green investment into account. The major sources of emissions that affect the environment are inventory holding, production, setup, emission from green technology, and transportation. The primary goal is to determine the optimal order quantity and number of shipments. The goal is to reduce the total cost of the supply chain while meeting the carbon emission constraint. Finally, a numerical example is provided to illustrate the proposed model.

Keywords: Supply chain, strict carbon cap, Integrated Vendor-Buyer inventory, carbon emission, Green technology.

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1.Introduction:

Global warming is the biggest problem in the world because of environmental pollution. It occurs because of the emission of carbondioxide and other green house gases. Construction, production and transportation activities are the reason for pollution. Various environmental factors of sustainability include natural resources, energy, pollution and waste products. In the supply chain Model, energy process related to inventory storage, production and transportation have an impact on carbon emissions. To make green environment without pollution, organizations and persons need to be fully involved in the planning and operations of the supply chain activities. It is the big challenge for organizations to control and minimize the carbon emissions of the entire supply chain. As the increment of the number of transportation increases, transportation cost increases which results in increasing percentage of carbon emissions. Minimizing stock holdings, recycling and refurbishing of products, designing the products such that to repair and reuse, reducing shipment distance etc are some of the measures to reduce resource usage and pollution.

Bonney and Jaber (2011) introduced various environmental issues arising from the inventory and demonstrate an EOQ inventory model. Chih-Chiang Fang and Ying-An-Lin (2020) discussed an inventory management in supply chains with consideration of Logistics, green investment and different carbon emission policies. Arindam Ghosh, J. K. Jha and S.P. Sarmah (2017) discussed Optimal Lot Sizing under strict carbon cap policy considering stochastic demand. Ritha and Eveline (2019) studied an integrated inventory model for imperfect production process with backorder price discount under strict carbon cap policy. Yen-Shiang Huang, Arindam Ghosh (2020) discussed the effect of investment in green technology in a two echelon supply chain under strict carbon-cap policy.

The rest of the paper is structured as follows: Section 2 provides fundamental assumptions and notations. Section 3 describes the Mathematical formulation. Section 4 illustrates a numerical example. Section 5 concludes the paper. A list of references is also provided.

2. Notations and Assumptions:

2.1Notations:

D Demand rate for the retailer

P Production rate for the supplier and P>D

Q Transportation lot size

A_V Production setup cost for the supplier

A_B Order processing cost for the retailer

h_V Storage cost for the supplier

h_B Storage cost for the retailer

n Number of shipments within the production cycle

F Unit transportation cost

d Delivery distance

M Maintenance cost

I_C Inspection cost

LCA(T) Life cycle Assessment technology cost

F_d Fixed cost per waste disposal activity

W_d Cost to dispose waste to the environment

θ Proportion of waste produced per lot Q

φ Proportion of demand returned $(0 < \varphi < 1)$

G Green technology cost per unit of time for reducing the emission rate

R Emission from green technology

E_h Carbon emissions from storage a unit product

E_T Carbon emissions from delivering a unit product

E_P Carbon emissions from producing a unit product

E_S Carbon emissions from production setup

α The efficiency factor of carbon emissions reduction

β The offset factor of carbon emissions reduction

2.2 Assumptions

1. The production rate is constant, which is greater than the demand rate of the retailer.
2. Demand is not affected by seasonal factors.
3. Shortages are not allowed.
4. Average method is used for the estimation of the carbon emission from different types of trucks and shipments weight.
5. Carbon emissions occur in the processes of production, transportation, storage and emission from green technology.
6. The green investment cannot completely reduce carbon emissions but its effect can be measured.

3. Mathematical Formulation based on strict carbon cap policy

The demand rate for the retailer is D and the production rate for the supplier is P, which has to be greater than D. The supplier delivers Q units to the retailer for every delivery cycle and the delivery cycle time is calculated as $\frac{Q}{D}$. The supplier delivers Q units for n times to the retailer within the production cycle and the production cycle time is denoted as $\frac{nQ}{D}$. The cycle ends when the supplier's inventory has run out. Since the production time is $\frac{nQ}{P}$ and the consumption period is calculated as $nQ\left(\frac{1}{D}-\frac{1}{P}\right)$, which is obtained by subtracting the production time from the production cycle.

The supplier's production setup cost can be obtained as $\frac{D}{nQ}A_V$.

The supplier's transportation cost can be obtained as $\frac{D}{Q}Fd$

The supplier's inventory holding cost can be derived as $\left(\frac{Q}{2}+\frac{nQ(P-D)}{2P}\right)h_V$

The supplier's maintenance cost, Inspection cost,Green technology cost and Life cycle assessment cost can be obtained as $\frac{D}{Q}\left(G+M+I_C+LCA(T)\right)$

The supplier's waste disposal cost can be obtained as $\frac{D}{Q}F_d+DW_dQ(\theta+\varphi)$

The total cost for the supplier is the sum of the production setup cost, holding cost, transportation cost, maintenance cost, Inspection cost, green technology cost and waste disposal cost which is given by

$$\frac{D}{nQ}A_V+\frac{D}{Q}Fd+\frac{Q}{2}\left(1+n\left(1-\frac{D}{P}\right)\right)h_V+\frac{D}{Q}\left(G+M+I_C+LCA(T)\right)+\frac{D}{Q}F_d+DW_dQ(\theta+\varphi)$$

The retailer order processing cost can be obtained as $\frac{D}{Q}A_B$.

The retailer's inventory holding cost can be obtained as $\frac{Q}{2}h_B$.

The total cost for the retailer's is the sum of the order processing cost and inventory holding cost which is given by $\frac{D}{Q}A_B+\frac{Q}{2}h_B$.

Therefore, the sum of the total costs for the supplier and retailer is given by,

$$TC(n,Q)=\frac{D(A_V+nA_B)}{nQ}+\frac{D}{Q}Fd+\frac{Q}{2}\left(\left(1+n\left(1-\frac{D}{P}\right)\right)h_V+h_B\right)+\frac{D}{Q}\left(G+M+I_C+LCA(T)\right)+\frac{D}{Q}F_d+DW_dQ(\theta+\varphi)$$

Suppose that the production rate in the production process, P is constant and the carbon emissions from producing a unit product is E_P. The supplier has to setup production equipment at the beginning of each production cycle, which would result in carbon emissions E_S. Therefore, the carbon emissions from the production process are given by $E_P+\frac{D}{nQ}E_S$. The emissions from green technology is denoted as R.

The carbon emissions from the transportation process can be obtained as $\frac{D}{Q}E_Td$.

The carbon emissions from product storage are $\frac{Q}{2}\left(2+n\left(1-\frac{D}{P}\right)\right)E_h$.

We consider that a green technology can be invested in order to reduce the emissions and the carbon reduction function for the green technology is given by $R(G)=\alpha G-\beta G^2$, where α denotes the carbon reduction efficiency factor and β denotes the offsetting carbon reduction factor. This indicates that as the supply chain invests the green cost, G in the green technology, αG of carbon emissions reduction can be obtained. The use of the green technology may also cause energy consumption, βG^2 denotes such additional carbon emissions.

The total amount of carbon emissionsare given by,

$$CE(n,Q)=E_P+\frac{D}{nQ}(E_S+nE_Td)+\frac{Q}{2}\left(2+n\left(1-\frac{D}{P}\right)\right)E_h+R-\alpha G+\beta G^2$$

As we are considering strict carbon cap policy, the total carbon emission per unit time should not exceed the specified limit $\hat{C}$. Then the carbon emission constraint can be written as

$$E_P + \frac{D}{nQ}(E_S + nE_T d) + \frac{Q}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h + R - \alpha G + \beta G^2 \leq \hat{C}$$

Thus the problem is to find the optimal order quantity Q and the number of shipments n, that minimize the total cost and satisfies the carbon constraint.

Ignoring the carbon constraint initially, the optimal value of Q is obtained by taking the partial derivative of the total cost with respect to Q and equating to zero, we get

$$\frac{-D}{Q^2}\left(Fd + \frac{(A_V + nA_B)}{n} + F_d + G + M + I_C + LCA(T)\right) + \frac{1}{2}\left(\left(1 + n\left(1 - \frac{D}{P}\right)\right)h_V + h_B\right) = 0$$

$$Q_0 = \sqrt{\frac{2D\left[Fd + \frac{(A_V + nA_B)}{n} + F_d + G + M + I_C + LCA(T)\right]}{\left(\left(1 + n\left(1 - \frac{D}{P}\right)\right)h_V + h_B\right)}}$$

We need to determine the optimal value of Q for fixed n that satisfies the carbon constraint. The method proposed by Chen et al. (2013) is adopted for this purpose. The carbon constraint can be written as

$$\frac{D}{nQ}(E_S + nE_T d) + \frac{Q}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h + E_P + R - \alpha G + \beta G^2 - \hat{C} \leq 0$$

The roots of the quadratic equation of the above inequality is given by

$$Q_1 = \frac{\hat{C} - E_P - R + \alpha G - \beta G^2 - \left\{(E_P + R - \alpha G + \beta G^2 - \hat{C})^2 - 4\left(\frac{1}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h\right)\left(\frac{D}{n}(E_S + nE_T d)\right)\right\}^{\frac{1}{2}}}{2\left(\frac{1}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h\right)}$$

$$Q_2 = \frac{\hat{C} - E_P - R + \alpha G - \beta G^2 + \left\{(E_P + R - \alpha G + \beta G^2 - \hat{C})^2 - 4\left(\frac{1}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h\right)\left(\frac{D}{n}(E_S + nE_T d)\right)\right\}^{\frac{1}{2}}}{2\left(\frac{1}{2}\left(2 + n\left(1 - \frac{D}{P}\right)\right)E_h\right)}$$

Where Q_1 and Q_2 are lower and upper bounds respectively for the feasible range of Q and they are positive.

Now for fixed n, the optimal Q will be obtained at $\hat{Q}$ as given below which will satisfy the carbon constraint

$$\hat{Q} = \begin{cases} Q_0 & if\ Q_1 \leq Q_0 \leq Q_2 \\ Q_1 & if\ \ Q_0 \leq Q_1 \\ Q_2 & if\ \ Q_0 \geq Q_2 \end{cases}$$

Finding the suitable value of $\hat{Q}$ from above equation and the process is repeated untilthere isno changes occur in the value of $\hat{Q}$.

4. Numerical example:

Consider the following data to illustrate the proposed model.

D	8000	h_B	\$60
P	10000	F	\$10
A_V	\$1200	d	\$120
A_B	\$100	M	\$280
h_V	\$50	I_C	\$250

LCA(T)	\$0.25	R	\$60
F_d	\$1	E_h	\$4
$\hat{C}$	\$265 Ton/unit	E_T	\$0.1
W_d	\$0.8	E_P	\$2
θ	0.5	E_S	\$2
φ	0.2	α	15
G	\$300	β	0.01

The optimal solution is given as

$$n^* = 10Q^* = 421.3357CE = 64.3278$$
$$TC = 1{,}974{,}569.208$$

5. Conclusion:

Environment is affected mainly by emissions of carbon from the industry during various processes involved in the inventory. This paper investigates the feasibility of investing in green technology to obtain an integrated strategy with consideration of environmental and economic merits and thus offers the managerial insights for the firm's managers to benefit both sides of the supply chain. Strict carbon cap policy is one of the basic policies for highly emitting firms to reduce extreme emissions. In order to preserve our environment, we need to reduce the emissions of carbon-dioxide and other green house gases.

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