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A Closed-Loop Supply Chain Inventory Model with Carbon Emissions and Green Technology Investment

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Abstract. *This paper proposes an inventory model that integrates a manufacturer and a retailer in a supply chain system. The model employs environmentally friendly technology investments to reduce the emissions produced in the process. Furthermore, the demand at the retailer's end is unpredictable, and green investments affect the average demand levels. This research aims to identify the optimal delivery lot, the number of deliveries, the Safety Factor, the level of green technology, and the collection level to maximize the joint total profit. Numerical examples illustrate the model's practical application, and algorithms are developed to solve the problem. Sensitivity analysis is used to determine the key model parameters' effect on the model's behavior. Green investments have been shown to reduce emissions and increase returns on second-hand goods, thus enhancing the environmental efficiency of supply chains.*

Keywords: *closed-loop supply chain, inventory management, carbon emissions, remanufacturing, carbon tax*

I. Introduction

The closed-loop supply chain concept is gaining popularity among companies due to growing awareness among consumers about the environment and the reuse of used goods (Khorshidvand et al., 2023). In order to increase their sustainability performance, businesses are investing in green technology and remanufacturing to recover used products because consumers are prepared to pay more for environmentally friendly products (Jauhari et al., 2021). The process of recovering used products can help organizations conserve resources, reduce environmental risks, and bridge the gap between expected and actual performance., understand the practical usage of the product, and form proactive relationships with consumers, thereby increasing company profits (Dominguez et al., 2019; Maiti & Giri, 2015). Companies such as Xerox, Apple, and Hewlett-Packard have implemented remanufacturing processes into their manufacturing activities (Wei et al., 2019). Remanufacturing is an effective way to save energy and raw materials, while reducing carbon emissions and production waste (Shu et al., 2017). For instance, Volkswagen is able to save up to 70% by using used car engines and parts. Similarly, Kodak can save between 40% to 60% of production costs by utilizing camera parts that return to the factory. Xerox also saves between 40% to 65% of production costs by reusing parts, components, and raw materials from products that return to the factory (Genc & Giovanni, 2017).

As the world's environmental concerns continue to grow, carbon emissions have become a significant issue for CLSC. Global warming and environmental change are putting the world's sustainability at risk. As a result, cooperation amongst all parties is essential to slowing the rate at which carbon emissions are rising in the Earth's atmosphere. The increasingly strict carbon policy regulations encourage CLSC companies to adopt various green technologies to reduce the emissions from their manufacturing operations.

Efficient management of operations is crucial for CLSC to remain competitive in the market. One of the key components to be considered in making decisions related to the recovery of scrap generated during manufacturing operations is the quality of the scrap product. This is because the emissions from manufacturing operations need to

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be controlled and monitored to ensure they are within the acceptable limits. High-quality scrap products still in good condition can be refurbished or remanufactured, and low-quality ones can be recycled. However, not all used products can be processed through recovery, so waste disposal is required (Hasanov et al., 2012).

According to the data above, although Closed-Loop Supply Chains (CLSC) have been the subject of numerous studies and in-depth discussions in the literature, carbon reduction, green investment, demand influenced by green technology level, and two recovery processes have received less attention. Therefore, given this context, we aim to address the following questions:

1. How can the inventory decision be determined in a CLSC system that involves manufacturers and retailers with regard to carbon emissions?
2. What is the effect of investments in green initiatives and collection efforts on CLSC systems inventory decisions?

In order to address the aforementioned queries, our main effort is to create an inventory model for a manufacturers and retailers CLSC system, where demand is shaped by the degree of green technology. Green technology is something that manufacturers invest in to lower emissions produced during production and remanufacturing. Carbon tax laws are put into effect by regulators to lower CLSC emissions. Remanufacturing and recycling procedures are included in this model to save raw materials, energy, and emissions.

II. RESEARCH METHOD

Notation

Decision variables

n : Number of shipments
Q : Lot size (units)
S : Green technology level
τ : Collection rate
k : Safety factor

Parameters for retailer

D : Demand (Units/h)
d : Basic demand (units/h)
p_r : Retailer selling price ($/unit)
y_1 : Variable sensitivity of demand to selling price, $0 < y_1 < 1$
T_t : Delivery time (h)
σ : Standard deviation of demand (units/h)
h^r : Retailer storage cost ($/unit/h)
A : Order cost ($/order)
F : Delivery cost ($/delivery)
π : Backorder cost ($/unit)

Table 1. Comparison of the proposed model with existing models

No	Author	Structure Supply Chain	Demands Depend on	Source of Carbon Emissions	Emission Policy	Investment	Recovery Process
1	Christy dkk (2017)	Manufaturer, collector, and retailer	Selling price and quality		Carbon tax and cap and trade		Remanufacturing and refurbishing
2	Ahmad Jauhari (2022)	Manufaturer and multi-retailer		Production, rework, transportation, and storage	Carbon tax	Green investment and collection effort	Remanufacturing
3	Bai dkk (2019)	Manufaturer and multi-retailer	Competitor selling price and green technology	Production and storage	Carbon tax	Green investmen	
4	Mohammed dkk (2017)	Manufaturer, distributor, and recycling center		Production, disposal, transportation, and storage	Cap and trade		Recycling
5	Proposed model	Manufatrurer and retailer	Green technology	Production and remanufacturing	Carbon tax	Green investment and collection effort	Remanufacturing and recycling

Parameters for manufacturer

p_m	:	Manufacturer's selling price ($/unit)
h^m	:	manufacturing storage cost ($/unit/h)
P	:	Production rate (units/h)
K	:	Setup cost ($/Setup)
s	:	Inspection cost ($/unit)
ε	:	Proportion of production rate form reworking process
γ	:	Defect rate
β_f	:	Quality function parameter in production
ω	:	Quality function parameter in production
RW	:	Reworking cost ($/unit)
$H_{0,p}$	:	Energy consumption during production under idle conditions (kW)
$H_{0,r}$	:	Energy consumption during reworking under idle conditions (kW)
Z	:	Constant for the power that the process of manufacturing uses (kWh/unit)
Z_r	:	Constant for the power that the process of reworking uses (kWh/unit)
g	:	Coefficient of collection effort
ϴ	:	Green investment coefficient
ρ	:	Percentage of used goods that can be remanufactured
λ	:	Percentage of used goods that can be waste disposed of
C_{en}	:	Energy cost ($/kWh)
C_{Raw}	:	Raw material procurement cost ($/unit)
C_{used}	:	Biaya pembelian barang bekas pakai ($/unit)
C_{was}	:	Waste disposal cost ($/unit)
C_{insp}	:	Inspection cost of used goods ($/unit)
C_{recy}	:	Cost of recycling of used goods ($/unit)
e_1	:	In the manufacturing process, carbon emissions per unit when there is no use of green technology (KgCo_2)
e_2	:	In the remanufacturing process, carbon emissions per unit when there is no use of green technology (KgCo_2)
β_1	:	Parameter of the green technology level on lessening carbon emissons generated from manufacturing process (KgCo_2)
β_2	:	Parameter of the green technology level on lessening carbon emissons generated from remanufacturing process (KgCo_2)

Assumptions

The following presumptions were made to create this study model:

1. Retailer demand is normally distributed with standard deviation σ and average demand $D_{(S)}$.
2. The green technology level influences the average demand.
3. The quality of remanufactured goods is equal to that of manufactured goods offered at the same price in the main market. (Maiti & Giri, 2015; Taleizadeh et al., 2017) .
4. The manufacturing system is still imperfect, so there are still defective products produced (Cárdenas-Barrón, 2008; Marchi et al., 2019).
5. All products that are defective are fixed, and the reworked items are of the same quality as the original items. (Jauhari et al., 2020; Marchi et al., 2019).
6. The government implements a carbon emission tax policy to reduce emissions.
7. Green investment can reduce emissions and increase the market share of manufacturers. (Bai et al., 2020).
8. Manufacturers also collect used goods. To increase the number of returned goods, manufacturers invest in collection efforts (Maiti & Giri, 2015; Zhang et al., 2015).

Retailer Model

Figure 1 shows the proposed CLSC system. In the proposed model, Retailers typically receive demand that is distributed with a mean D and standard deviation σ. This average demand depends on the green technology level, $D_{(S)} = d + Sy_1$. The retailer applies the continuous review method in its inventory control. The retailer will order nQ units of products to the manufacturer when the inventory reaches the reorder point (ROP). The delivery lead time is formulated as $LT = \sqrt{Q/P + T_t}$. The retailer's storage cost per unit is prepared as follows:

$$\boldsymbol{HRC = h^r\left(\frac{Q}{2} + k\sigma\sqrt{Q/P + T_t}\right)} \quad \textbf{(1)}$$

In addition, retailers also incur ordering costs and transportation costs formulated as follows:

$$\boldsymbol{ODC = \frac{D_{(p_r,S)}}{nQ}(A + nF)} \quad \textbf{(2)}$$

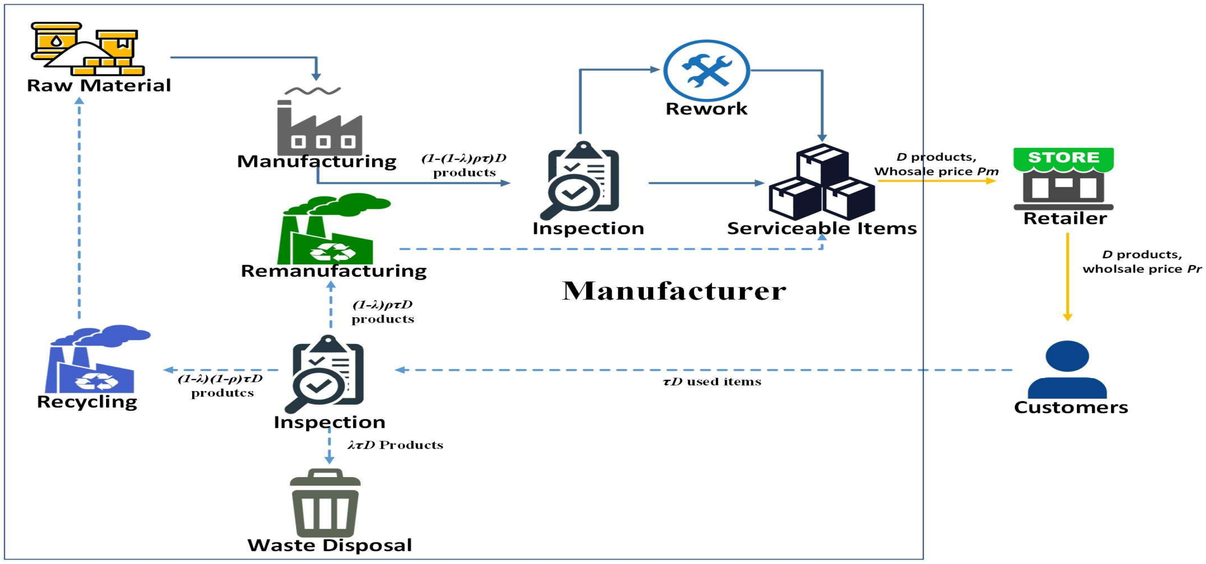

Figure 1. Schematic diagram of the proposed system

If the retailer cannot fulfill consumer demand due to insufficient inventory, there is a backorder fee incurred by the retailer. Backorder costs are formulated as follows.:

$$SRC = \frac{D_{(S)}}{nQ} \pi\sigma\sqrt{Q/P + T_t}\,\Psi(k) \qquad (3)$$

where $\Psi(k) = \{f_s(k) - k[1 - F_s(k)]\}$

The standard normal distribution's probability density function is denoted by $f_s(k)$ and $F_s(k)$ is the standard normal distribution's cumulative distribution function.. The retailer will earn revenue from product sales with the following equation:

$$TR_R = D_{(p_r,S)} p_r \qquad (4)$$

So, the total retailer profit, including product procurement cost, can be written as an equation:

$$TPR = D_{(S)} p_r - \left(\frac{D_{(S)}}{nQ}(A + nF) + D_{(S)} p_m + h^r \left(\frac{Q}{2} + k_1\sigma\sqrt{\frac{Q}{P} + T_t}\right) + \frac{D_{(S)}}{nQ} \pi\sigma\sqrt{\frac{Q}{P} + T_t}\,\Psi(k_1) \right) \qquad (5)$$

Manufacturer Model

The setup cost per unit of time is formulated by considering the setup frequency D/nQ and setup cost K. The manufacturing inventory accumulation is subtracted from the accumulative shipments to determine the manufacturing inventory level. As a result, the storage and setup costs per unit of time for the manufacturer are:

$$SCH = \frac{D_{(S)}K}{nQ} + h^m \frac{Q}{2}\left(n\left[1 - \frac{D_{(S)}}{P}\right] - 1 + \frac{2D_{(S)}}{P}\right) \qquad (6)$$

As was mentioned in the preceding section, there are flaws in the manufacturer's production system, which results in certain defective products. Even though the system produces good things at the beginning of production, there is a chance that it will go into an out-of-control state and make defective goods with a probability of γ. We assume an exponential distribution for the time that elapses before the production system enters an out-of-control condition. We assume that the system will remain in an out-of-control state until the batch has been created by Rosenblatt & Lee (1986).As a result, the following formula determines how many defective goods the production system produces.

$$E(N_{def}) = \gamma(b_f + \omega P^2)\frac{(nQ)^2}{2P} \qquad (7)$$

The resulting defective goods will enter the rework process stage to improve their quality. The rework cost is formulated in equation (8)

$$RWC = RW\frac{(1-(1-\lambda)\rho\tau)D_{(S)}}{nQ} E(N_{def}) \qquad (8)$$

Electrical energy is required to run the production process studied by Bazan et al (2015) and Gutowski et al (2006). $H_{0,p}$ and z are the energy consumption and idle power of the manufacturing and remanufacturing processes. $H_{0,r}$ and Z_r energy consumption and idle capacity during rework. This energy consumption equation can be written as:

$$ECC = C_{en}D_{(S)}\left((1-(1-\lambda)\rho\tau)\frac{H_{0,r}+Z_r\varepsilon P}{\varepsilon P}E(N_{def}) + \frac{H_{0,p}+zP}{P}\right) \quad (9)$$

Formula (11) represents the cost of procuring raw materials and used products to be reprocessed. In contrast, formula (12) includes the costs for recycling, waste disposal, and inspection of used goods conducted by the invoice.

$$RUC = C_{Raw}D_{(S)}(1-(1-\lambda)\tau) + C_{used}\tau D_{(S)} \quad (11)$$

$$RWI = C_{recy}(1-\lambda)(1-\rho)\tau D_{(S)} + C_{was}\lambda\tau D_{(S)} + C_{insp}\tau D_{(S)} \quad (10)$$

The manufacturer invests to increase the number of used products returned to the manufacturer. The collection effort investment is written with the following equation:

$$IVT_{col} = \frac{1}{2}g\tau^2 \quad (12)$$

Equation (13) is the cost of emission taxes manufacturers incur from manufacturing and remanufacturing processes, where this cost is generated from emissions per unit multiplied by the number of products processed in each process.

$$CTC = C_{tax}D_{(S)}[(1-(1-\lambda)\rho\tau)(e_1-\beta_1 S) + (e_2-\beta_2 S)(1-\lambda)\rho\tau] \quad (13)$$

Due to pressure from the government and consumers, manufacturers began switching to green technology. However, manufacturers are gradually replacing their facilities due to the high investment costs. Formula (14) is the formulation of green technology investment.

$$IVT_{green} = \frac{1}{2}\theta S^2 \quad (14)$$

So, the total profit of the manufacturer can be written with the equation:

$$TPM = D_{(S)}p_m - \left(\frac{D_{(S)}K}{nQ} + C_{Raw}D_{(S)}(1-(1-\lambda)\tau) + sD_{(S)} + C_{was}\lambda\tau D_{(S)} + h^m\frac{Q}{2}\left(n\left[1-\frac{D_{(S)}}{P}\right] - 1 + \frac{2D_{(S)}}{P}\right) + RW\frac{D_{(S)}(1-(1-\lambda)\rho\tau)}{nQ}\gamma(\beta_f + \omega P^2)\frac{(nQ)^2}{2P} + \frac{1}{2}g\tau^2 + \frac{1}{2}\theta S^2 + (C_{used}+C_{insp})\tau D_{(S)} + C_{en}D_{(S)}\left(\frac{H_{0,p}+zP}{P} + (1-(1-\lambda)\rho\tau)\frac{H_{0,r}+Z_r\varepsilon P}{\varepsilon P}\gamma(\beta_f + \omega P^2)\frac{nQ}{2P}\right) + C_{recy}(1-\lambda)(1-\rho)\tau D_{(S)} + C_{tax}D_{(S)}[(1-(1-\lambda)\rho\tau)(e_1-\beta_1 S) + (e_2-\beta_2 S)(1-\lambda)\rho\tau]\right) \quad (15)$$

Joint Total Profit

The joint total profit of the proposed system can be calculated by combining the profits earned by the manufacturer and retailer, as described in the following equation:

$$JTP = TPR + TPM \quad (16)$$

Solution methodology

In finding the optimal solution in this model, partial derivatives of the total joint profit (JTP) for Q, S, k, and τ are performed. The value of n is assumed to be fixed in this algorithm.

$$\frac{\partial JTP}{\partial k} = h^r\sigma\sqrt{Q/P+T_t} - \frac{\pi\sigma D_{(S)}}{Q}\sqrt{Q/P+T_t}[1-F_s(\mathrm{k})] \quad (17)$$

$$\frac{\partial JTP}{\partial Q} = \frac{D_{(S)}}{nQ^2}(A+nF) - \frac{h^r}{2} - \frac{\sigma h^r \mathrm{k}_1}{2P\sqrt{\frac{Q}{P}+T_t}} - \frac{D_{(S)}}{2nPQ}\frac{\pi\sigma\Psi k_1}{\sqrt{Q/P+T_t}} + \frac{D_{(S)}}{nQ^2}\pi\sigma\sqrt{Q/P+T_t}\Psi(k_1) + \frac{DK}{nQ^2} - \frac{h^m}{2}\left(n\left[1-\frac{D_{(S)}}{P}\right] - 1 + \frac{2D_{(S)}}{P}\right) - (1-(1-\lambda)\rho\tau)\mathrm{RW}\gamma(\beta_f+\omega P^2)\frac{nD_{(S)}}{2P} - C_{en}D_{(p_r,S)}\left(\frac{H_{0,r}+Z_r\varepsilon P}{\varepsilon P}\right)\gamma(\beta_f+\omega P^2)\frac{nD_{(S)}}{2P} \quad (18)$$

$$Q = \sqrt{\frac{-\frac{2D_{(S)}}{n}\{(A+nF)+\pi\sigma\sqrt{Q/P+T_t}\Psi(k_1)+K\}}{-h^r - \frac{\sigma h^r \mathrm{k}_1}{P\sqrt{\frac{Q}{P}+T_t}} - \frac{D_{(S)}}{nPQ}\frac{\pi\sigma\Psi k_1}{\sqrt{Q/P+T_t}} - h^m\left(n\left[1-\frac{D_{(S)}}{P}\right]-1+\frac{2D_{(S)}}{P}\right) - (1-(1-\lambda)\rho\tau)\mathrm{RW}\ (\beta_f+\omega P^2)\frac{nD_{(S)}}{P} - C_{en}(1-(1-\lambda)\rho\tau)\left(\frac{H_{0,r}+Z_r\varepsilon P}{\varepsilon P}\right)\gamma(\beta_f+\omega P^2)\frac{nD_{(S)}}{P}}} \quad (19)$$

$$\frac{\partial JTP}{\partial \tau} = -C_{Raw}D_{(S)}(-1+\lambda) - C_{en}D_{(S)}\left(\frac{(H_{0,p}+zP)}{P} - (1-\lambda)\rho\frac{(H_{0,r}+Z_r\varepsilon P)}{\varepsilon P}\gamma(\beta_f+\omega P^2)\frac{nQ}{2P}\right) - g\tau - RWD_{(S)}(1-\lambda)\rho\frac{(H_{0,r}+Z_r\varepsilon P)}{\varepsilon P}\gamma(\beta_f + \omega P^2)\frac{nQ}{2P} - (C_{used}+C_{insp})D_{(S)} - C_{recy}(1-\lambda)(1-\rho)D_{(S)} - C_{was}\lambda D_{(S)} - C_{tax}D_{(S)}[-(1-\lambda)\rho(e_1-\beta_1 S) + (e_2-\beta_2 S)(1-\lambda)\rho] \quad (19)$$

$$\frac{\partial JTP}{\partial S} = p_r y_1 - \frac{(A+Fn)y_1}{nQ} - \frac{y_1 \pi\sigma}{nQ}\sqrt{Q/P+T_t}\,\Psi(k_1) - \frac{y_1 K}{nQ} - y_1 C_{Raw}(1-(1-\lambda)\tau) - s y_1 - \frac{h^m}{2} Q y_1\left(\frac{2}{P}-\frac{n}{P}\right) - (1-(1-\lambda)\rho\tau)\mathrm{RW} y_1 \gamma(\beta_f+\omega P^2)\frac{nQ}{2P} - C_{en} y_1\left(\frac{H_{0,p}+zP}{P} + (1-(1-\lambda)\rho\tau)\frac{H_{0,r}+Z_r\varepsilon P}{\varepsilon P}\gamma(\beta_f+\omega P^2)\frac{nQ}{2P}\right) - \Theta S - (C_{used}+C_{insp})\tau y_1 - C_{recy}(1-\lambda)(1-\rho)\tau y_1 - C_{was}\lambda\tau y_1 - C_{tax}(1+(-1+L)\rho\tau)(e_1 y_1 - \beta_1(d+2Sy_1)) + C_{tax}(-1+L)\rho\tau(-e_2 y_1+\beta_2(d+2Sy_1)) \quad (20)$$

By setting the partial derivative of the total joint profit (JTP) for Q, S, k, and τ equal to zero, the equations for Q, S, k, and τ are obtained as follows

$$F_s(k_1) = 1 - \frac{h^r Q}{\pi D_{(S)}} \quad (21)$$

$$\tau = -\frac{1}{g}\Big((C_{used}+C_{insp})D_{(S)} - C_{Raw}D_{(S)}(1-\lambda) + C_{en}D_{(S)}\left(\frac{(H_{0,p}+zP)}{P} - (1-\lambda)\rho\frac{(H_{0,r}+Z_r\varepsilon P)}{\varepsilon P}\gamma(\beta_f+\omega P^2)\frac{nQ}{2P}\right) + C_{recy}(1-\lambda)(1-\rho)D_{(S)} - RW D_{(S)}(1-\lambda)\rho\gamma(\beta_f+\omega P^2)\frac{nQ}{2P} + C_{was}\lambda D_{(S)} + C_{tax}D_{(S)}[(e_2-\beta_2 S)(1-\lambda)\rho - (1-\lambda)\rho(e_1-\beta_1 S)]\Big) \quad (20)$$

Algorithm

The following is a solution algorithm for the values of n, Q, k, τ, and S using Matlab 2022a software:

1. Set n =1 and $JTP_{n-1}(Q_{n-1}, k_{n-1}, \tau_{n-1}, S_{n-1})$
2. $= 0$
3. Set initial values for τ dan S for the first iteration and determine the value of D.
4. Compute Q using equation (19).
5. Compute k using equation (17).
6. Compute τ using equation (20).
7. Compute S using equation (18).
8. Repeat steps 3-6 until there no change in the value Q, k, τ, and S
9. Use the values $Q_n = Q$, $k_n = k$, $\tau_n = \tau$, $S_n = S$ and calculate $JTP_n(Q_n, k_n, \tau_n, S_n)$ using equation (16).
10. if $JTP_n(Q_n, k_n, \tau_n, S_n) \geq$
11. $JTP_{n-1}(Q_{n-1}, k_{n-1}, \tau_{n-1}, S_{n-1})$ then repeat steps 2-7 with *n=n+1*, otherwise do step 9.
12. set $JTP_{n-1}(Q_{n-1}, k_{n-1}, \tau_{n-1}, S_{n-1},)$ as the maximum value of the total joint profit (JTP) with $n, Q, k_1, \tau,$ dan S as the optimal solution in solving the problem.

III. Result and Discussion

Numerical Example

The parameter values used to perform numerical analysis are adapted from the research of Ahmad Jauhari (2022) and Bai et al (2020). The parameters used are shown as follows: d=240 unit, y_1=0.8, T_t= 10, σ=8, h^r =1, A=90, F=38, π=40, p_r = 120, p_m = 50, C_{Raw}=10, h^m =0.5, C_{used}=3, P=2500, K=400, s=1, ε=1.2, γ=0.02, β_f = 0.015, e_1 = 50, e_2 = 40, β_1 = 0.54, β_2 = 0.42, C_{recy}=6, C_{was} =0.5, C_{insp}=0.2, ω = 0.00001, RW=3, C_{tax} =0.0618, $H_{0,p}$ = 1000 , $H_{0,r}$ = 800, Z=1, Z_r=0.8, g =2200, ϴ = 25, λ = 0.1, ρ=0.7, C_{en} = 0.015.

Table 2 shows that the optimal number of deliveries, delivery size, and safety factor are 3, 100.03, and 2.28. For the green technology level, the collection rate and demand are 3.78, 0.651, and 243.02 units. Based on these results, the manufacturer must invest \$179.09 for green investment and \$466.32 for collection effort investment. By making these investments, the resulting emissions are 10,091 KgCO_2. The total benefits to retailers, manufacturers, and the supply chain are \$16,783, \$8,477, and \$25,260, respectively.

Table 2. Optimal Solution

Parameters	Values
Number of shipments	6
Delivery size	100.03 units
Demand	243.02 units
Safety factor	2.28
Green Technology Level	3.78
Collection Rate	0.651
Green Investment	$466.323
Collection Effort	$179.091
Emissions Supply chain	10,910 KgCO_2
Manufacturer profit	$16,783
Retailer profit	$8.477
Joint total profit	$25.260

Green Technology Coefficient Analysis

The level of green technology increases significantly as y_1 increases. As a result, the profits of manufacturers, retailers and total combined profits increase. Table 3 illustrates how y_1. affects profit. In the real system, producers will increase the level of green technology to attract more customers when the technology significantly affects the level of demand. Producers should increase investment to increase the level of green technology presented in Figure 2.

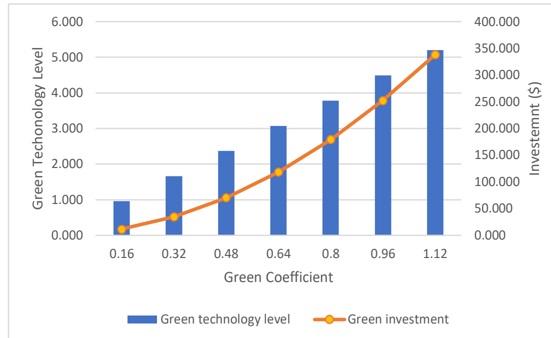

Figure 3. Effect of green technology coefficient on green technology level and green investment

Green Investement Coefficient Analysis

The impact of green investment costs on model behavior is also investigated in this model. Table 4 shows that if the green investment

Table 3. Effect of changing the green technology coefficient parameter on the proposed model

Green technology coefficeint	0.16	0.32	0.48	0.64	0.8	0.96	1.12
Number of shipments	6	6	6	6	6	6	6
Delivery size	99.562	99.614	99.710	99.852	100.037	100.267	100.539
Safety factor	2.278	2.278	2.278	2.279	2.280	2.281	2.282
Green Technology Level	0.961	1.664	2.372	3.078	3.785	4.492	5.201
Collection Rate	0.648	0.648	0.649	0.649	0.651	0.653	0.655
Green Investment	11.554	34.712	70.328	118.440	179.091	252.331	338.220
Collection Effort	463.917	463.211	463.379	464.417	466.323	469.096	472.740
Emissions Supply chain	11,110	11,032	10,992	10,947	10,910	10,882	10,863
Manufacturer profit	8,222	8,216	8,504	8,493	8,477	8,457	8,433
Retailer profit	16,538	16,573	16,652	16,709	16,783	16,873	16,978
Joint total profit	25,099	25,122	25,156	25,202	25,260	25,330	25,411

Table 4. Effect of changes in green investment costs on the proposed model

Green investment coefficient	5	15	25	35	45	55	65
Number of shipments	6	6	6	6	6	6	6
Delivery size	101.863	100.349	100.037	99.902	99.827	99.779	99.746
Safety factor	2.291	2.282	2.280	2.279	2.279	2.279	2.278
Green Technology Level	19.07	6.316	3.785	2.702	2.101	1.718	1.454
Collection Rate	0.648	0.651	0.651	0.651	0.651	0.651	0.651
Green Investment	909.18	299.35	179.091	127.78	99.33	81.23	68.72
Collection Effort	463.20	466.16	466.323	466.35	466.36	466.35	466.35
Emissions Supply chain	9,578	10,702	10,910	10,998	11,046	11,076	11,098
Manufacturer profit	8,328	8,452	8,477	8,487	8,493	8,497	8,500
Retailer profit	17,634	16,924	16,783	16,723	16,689	16,668	16,653
Joint total profit	25,963	25,377	25,260	25,211	25,183	25,165	25,153

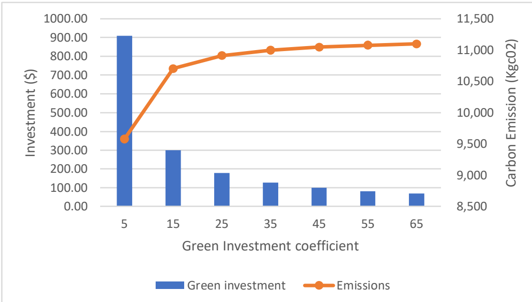

Figure 3. Effects of green investment costs on carbon emissions and green investment

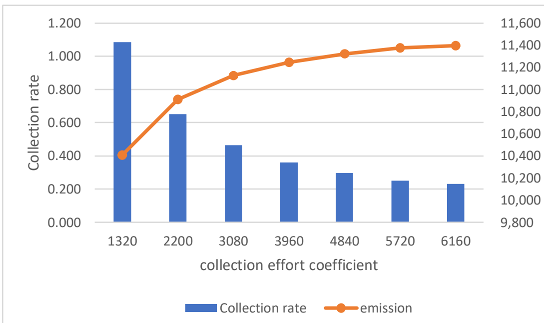

Figure 5. Effect of collection effort investment cost on collection rate and carbon emissions

parameter increases, the green technology level will decrease from 3.78 to 1.45 (160% increase). This happens because of the large cost burden of making investments. The increase in green investment costs makes manufacturers reduce their investment so that the emissions released will increase. In addition, the profits earned by manufacturers and retailers decrease.

Collection Effort Coefficient Analysis

The results of testing the investment coefficient of scrap collection are shown in Table 5 and Figure 4. The variables Q, k, and S do not change when the coefficient of investment in scrap collection (g) increases; the only variable that changes is τ, which decreases from 0.651 to 0.232, which is a 180% increase. This result is consistent with the actual system, where the collection rate only affects when a manufacturer attempts to collect scrap. In order to avoid losing money, the manufacturer will lower its collection rate if the investment cost is higher. A high collection rate will cause the manufacturer and retailer to make more money, which means the total combined profit will be lower. Furthermore, manufacturers make more regular products than remanufactured products because there are not many used goods that are reprocessed. The amount of regular product production rather than remanufacturing increases the emissions produced by the manufacturer, as shown in Figure 5.

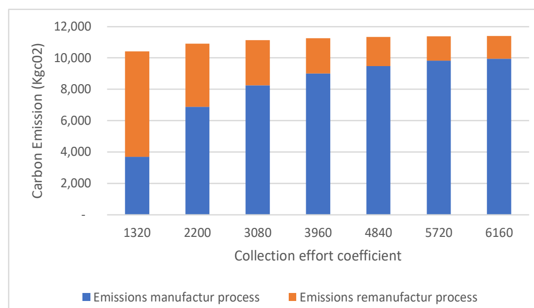

Figure 4. Effect of collection effort investment cost on emissions manufactur and remanufacture

Table 5. Effect of changes in green investment costs on the proposed model

Collection effort coefficient	1320	2200	3080	3960	4840	5720	6160
Number of shipments	5	6	6	6	6	6	6
Delivery size	120.946	100.037	97.289	95.857	94.978	94.384	94.153
Safety factor	2.213	2.280	2.290	2.295	2.298	2.300	2.301
Green Technology Level	3.867	3.785	3.750	3.730	3.718	3.709	3.706
Collection Rate	1.085	0.651	0.465	0.361	0.296	0.250	0.232
Green Investment	186.963	179.091	175.803	173.984	172.828	179.349	171.716
Collection Effort	777.218	466.323	333.083	259.062	211.959	172.030	166.538
Emissions Supply chain	10,407	10,910	11,126	11,246	11,322	11,375	11,396
Manufacturer profit	8,651	8,477	8,404	8,363	8,338	8,320	8,313
Retailer profit	16,793	16,783	16,779	16,777	16,776	16,775	16,774
Joint total profit	25,443	25,260	25,183	25,141	25,114	25,095	25,088

Table 4. Effect of changes in carbon tax on the proposed model

Carbon tax	0.01236	0.03708	0.0618	0.08652	0.11124	0.13596	0.16068
Number of shipments	6	6	6	6	6	5	5
Delivery size	97.565	98.778	100.037	101.342	102.697	117.236	118.854
Safety factor	2.288	2.284	2.280	2.276	2.271	2.224	2.22
Green Technology Level	3.567	3.675	3.785	3.895	4.005	4.118	4.23
Collection Rate	0.485	0.568	0.651	0.733	0.815	0.898	0.98
Green Investment	159.067	168.899	179.091	189.646	200.569	212.069	223.752
Collection Effort	259.754	355.626	466.323	591.763	731.866	887.185	10,564
Emissions Supply chain	11,117	11,013	10,910	10,807	10,704	10,602	10,500
Manufacturer profit	9,060	8,773	8,477	8,170	7,854	7,526	7,190
Retailer profit	16,769	16,776	16,783	16,790	16,797	16,805	16,812
Joint total profit	25,829	25,550	25,260	24,961	24,652	24,331	24,003

Carbon Tax Analysis

Table 6 and Figure 6 illustrate how the suggested model is affected by the carbon tax. As the cost of the carbon tax rises, manufacturers are incentivized to decrease their emissions, as the graphic illustrates. The manufacturer will cut emissions by 3.7% if the carbon tax is raised to 0.1608. Manufacturers improve the degree of green technology from 3.78 to 4.23, which reduces these pollutants. and producers raise the rate of collection from 0.65 to 0.98. this is a result of manufacturers' increased interest in creating remanufactured goods with lower emissions as they are being offered. Furthermore, as a result of a decline in manufacturer earnings, the overall combined profits have also declined by 4.9%. This is a result of manufacturers making more investments in green projects.

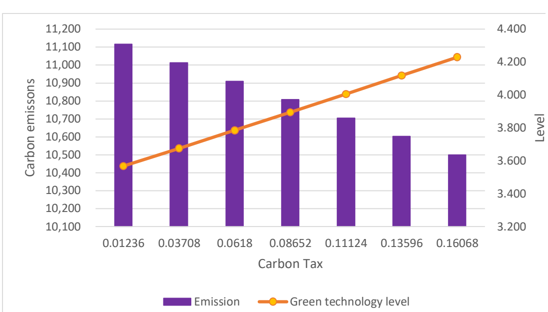

Figure 6. Effects of carbon tax on carbon emissions and green investment

IV. Conclusion

This study proposes a CLSC model considering carbon emissions and green technology. This study considers emissions resulting from manufacturing and remanufacturing processes. By optimizing the model, the maximum profit of the manufacturer-retailer can be obtained by setting several decision variables at the optimal level, namely the number of shipments, lot size, safety factor, green technology level, and collection rate simultaneously.

The sensitivity analysis results provide some interesting insights. Managers should be able to consider decision variables to balance carbon emissions and profit. First, the model allows managers to increase their green technology level to attract more customers. Second, managers need to consider green investment if the government increases the tax value of carbon emissions. Green investment must be increased to reduce the emissions produced by manufacturers. Third, with the change in collection effort costs, manufacturing managers need to consider the carbon emission tax that will be generated. If the collection rate of used goods is low, the manufacturer must produce more regular products to meet market demand. The large production of regular products rather than remanufacturing can increase excess carbon emissions.

For future research, emissions from each process also need to be considered, such as emissions from transportation, rework, recycling, waste disposal, etc. In addition, in this proposed model, there is no inventory control on storing used goods that return to the manufacturer. In the next model, other emission policies such as carbon cap and trade and carbon cap can also be applied.

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