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A Framework Evaluation for Sustainable EOQ Considering Environmental Factors

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Abstract

One of the key concerns in production planning has always been determining the economic lot size. Researchers have been studying this issue for a while, and numerous models have been created to meet objectives with the least amount of expense. This study's objective is to assess a more sophisticated approach to deciding lot size by taking into account the costs associated with emissions taxes (environmental impact). It will be suggested to adopt a framework, called Sustainable Economic Order Quantity (SEOQ), for inventory control in the pump manufacturing industry.

For the purpose of assisting decision-makers and policies on inventory issues, this study included a useful numerical analysis as well as a sensitivity analysis. Finally, the experimental findings demonstrated that the suggested models would solve the issues with the lowest possible overall inventory costs.

Keywords: Sustainability, environmental factors, tax emission cost, Sustainable EOQ, supply chain

1. Introduction

The main factor that helps a business maintain its seamless functioning is its inventory. These days, environmental concerns are shared by all nations and businesses. Businesses must consider environmental factors, including carbon emissions.

The SEOQ model is a lot size strategy used to establish economic ordering when dealing with inventory by taking into account environmental factors [1]. The financial and environmental perspectives must be economically balanced within this framework in order for the business community to choose the best policy to promote sustainability.

Numerous research, like Chen, et al. [2], Jaber, et al. [3], dan He, et al. [4], have examined inventory concerns that take carbon emissions into account. The studies often take effects of carbon emissions, order frequency, and storage volume into account [5].

The model was built by several researchers by including the cost of taxes on environmental consequences [6, 7]. In addition, the purchase inventory model was modified by some researchers to include environmental and tax costs [8]. Sustainable EOQ models were examined by Maulana et al. [9] while taking capital restrictions and environmental considerations into account.

2. Frameworks

In the current study, author assessed the SEOQ framework, which took into account the expenses associated with the sustainable inventory, including order cost, purchase cost, holding cost and the fixed cost of an environmental effect (carbon emission tax cost) for each cycle. This study's goal is to assess a more complex approach to solving the issues of calculating lot size by taking environmental concerns into account. As a result, our research produced fresh perspectives on inventories, particularly for SEOQ models with cost of the emission tax.

2.1 Assumptions

* Demand rate (λ) is predictable, constant, and uniformly dispersed over the course of the year.
* Every demand is met on schedule.
* All of the model's variables remain constant over time.
* The impact on the environment is taken into account for all costs.
* The planning horizon is infinitely long.

* A fixed cost (k + f) is incurred each and every time an order is placed. Each unit of inventory has a holding cost in inventory of (h + g). And the cost per unit of purchase is (c + v).
* T years after the order was placed, it is delivered. T is taken to be known and deterministic.
* In a given period, demands, order cost, purchase cost, holding cost, tax fees, total emissions, and total capital
* Each model is applied to a single emission product, and the tax cost per item
* Tax price per unit of emissions

2.2 FRAMEWORK 1: Sustainable EOQ without Emission Tax

To determine the SEOQ is our aim. The order quantity, represented by Q, similarly stays unchanged throughout time because all the parameters are stationary. Since a reorder interval—also known as the cycle length—is equal to the amount of time between two subsequent epochs at which an order is placed, it is connected to the best moment to place an order. The interval between two consecutive orders is known as a cycle. In this architecture, the query of when to place an order gets a straightforward response. We would like the order to arrive precisely at the time the last unit is being sold because demand happens at a deterministic and fixed rate and the order, once placed, comes exactly T years later. As a result, the order must be placed T years before the inventory is depleted.

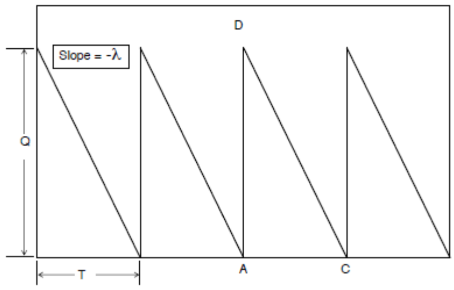

Figure 1. Change in inventory over time for the EOQ model.

The creation of cost expressions is the initial stage in the model's development.
Since the total annual demand is, the total purchasing cost for the sustainable inventory, taking into account the fixed cost of an environmental impact for each cycle for one year, is

$$\text{Purchasing cost} = (c + v) * \lambda \quad 1$$

Similar to this, the yearly quantity demanded / EOQ = λ / Q is equal to the number of orders placed annually.
So, taking into account the fixed cost of an environmental impact for each cycle, the total annual average cost of making orders in the sustainable inventory is

$$\text{Ordering cost} = (k + f) * \lambda/Q \quad 2$$

The calculation of the annual total holding cost involves extra steps.
We'll start by calculating the typical inventory per cycle.
The average inventory for a year is the same as the average inventory for a cycle, and each cycle is identical to every other cycle.
The holding cost is determined by multiplying the average annual inventory by the price of keeping one item of inventory for a year.
Figure 1 enables us to determine what the typical inventory per cycle is:

$$\text{Area of triangle ADC / Length of the cycle} = (½)QT/T = Q/2$$

Taking into account the fixed cost of an environmental effect for each cycle, the annual cost of maintaining inventory in the sustainable inventory is thus equal to

$$\text{Holding cost} = (h + g) * Q/2 \quad 3$$

We obtain the following objective function for total inventory cost taking into account environmental effect (4) after adding the three categories of costs together, which we wish to decrease over Q:

$$\text{TIC} = \text{Ordering cost} + \text{Purchasing cost} + \text{Holding cost}$$

$$\mathrm{TIC} = \frac{(k+f)*\lambda}{Q} + (c+v)*\lambda + \frac{(h+g)*Q}{2} \quad 4$$

Equation (4) is differentiated with respect to Q to obtain the optimal Q for the SEOQ model without tax, and the first derivative is then set equal to zero to obtain the minimal cost.

$$\frac{d}{dQ}[\mathrm{TIC}] = \frac{d}{dQ}\left[\frac{(k+f)*\lambda}{Q} + (c+v)*\lambda + \frac{(h+g)*Q}{2}\right] = 0$$

$$(k+f)*\lambda*\frac{d}{dQ}\left[\frac{1}{Q}\right] + (c+v)*\lambda*\frac{d}{dQ}[1] + \frac{(h+g)}{2}*\frac{d}{dQ}[\,Q] = 0$$

$$-(k+f)*\lambda*\left[\frac{1}{Qs^2}\right] + (c+v)*\lambda*[0] + \frac{(h+g)}{2}*[1] = 0$$

$$-(k+f)*\lambda*\left[\frac{1}{Qs^2}\right] + 0 + \frac{(h+g)}{2} = 0$$

$$-\frac{(k+f)*\lambda}{Qs^2} + \frac{(h+g)}{2} = 0$$

$$\frac{(k+f)*\lambda}{Qs^2} = \frac{(h+g)}{2}$$

$$Qs^2 = \frac{2(k+f)*\lambda}{(h+g)}$$

$$Qs = \sqrt{\frac{2(k+f)*\lambda}{(h+g)}} \quad 5$$

Further, equation (5) is substituted to equation (4) to determine the SEOQ total inventory cost (TIC) without tax ($TIC(Qs)$). $TIC(Qs)$ is shown in equation (6).

$$\mathrm{TIC} = \text{Ordering cost} + \text{Purchasing cost} + \text{Holding cost}$$

$$\mathrm{TIC}(Q) = \frac{(k+f)*\lambda}{Q} + (c+v)*\lambda + \frac{(h+g)*Q}{2}$$

From figure 2, At Optimal quantity ordering cost and holding cost are same.

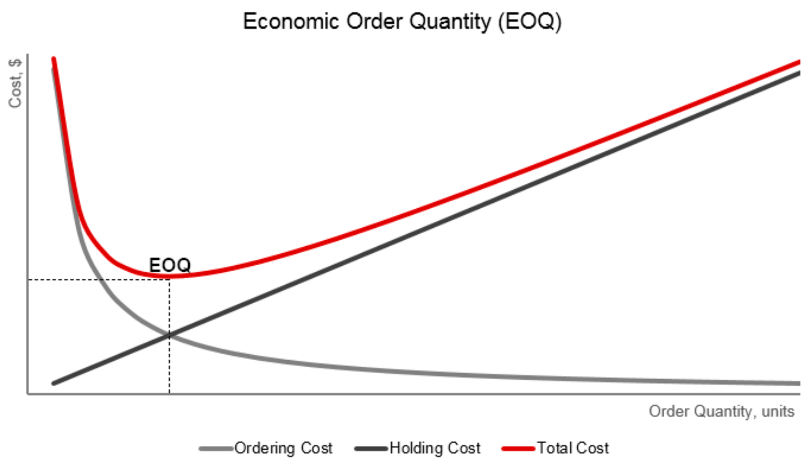

Figure 2. Ordering and holding costs as functions of the order quantity.

$$\mathrm{TIC}(Qs) = \frac{2(k+f)*\lambda}{Qs} + (c+v)*\lambda$$

$$\mathrm{TIC}(Qs) = \frac{2(k+f)*\lambda}{\sqrt{\frac{2(k+f)*\lambda}{(h+g)}}} + (c+v)*\lambda$$

$$\mathrm{TIC}(Qs) = \sqrt{\frac{4(k+f)^2\lambda^2}{\frac{2(k+f)\lambda}{(h+g)}}} + (c+v)*\lambda$$

$$\mathrm{TIC(Qs)} = \sqrt{2(k+f)\lambda(h+g)} + (c+v)\lambda \qquad 6$$

2.3 FRAMEWORK 2: Sustainable EOQ with Emission Tax

The expenses associated with the sustainable inventory, such as the fixed cost of an environmental effect for each cycle, order cost, purchase cost, and holding cost, were taken into account when developing this model. This is how the total inventory cost is calculated:

$$\mathrm{TIC} = \frac{(k+pf)*\lambda}{Q} + (c+pv)*\lambda + \frac{(h+pg)*Q}{2} \qquad 7$$

Equation (7) is differentiated with respect to Q to obtain the optimal Q for the SEOQ model with tax, and the first derivative is then set equal to zero to obtain the minimal cost.

$$\frac{d}{dQ}[\mathrm{TIC}] = \frac{d}{dQ}\left[\frac{(k+pf)*\lambda}{Q} + (c+pv)*\lambda + \frac{(h+pg)*Q}{2}\right] = 0$$

$$(k+pf)*\lambda*\frac{d}{dQ}\left[\frac{1}{Q}\right] + (c+pv)*\lambda*\frac{d}{dQ}[1] + \frac{(h+pg)}{2}*\frac{d}{dQ}[\,Q] = 0$$

$$-(k+pf)*\lambda*\left[\frac{1}{Qsp^2}\right] + (c+pv)*\lambda*[0] + \frac{(h+pg)}{2}*[1] = 0$$

$$-(k+pf)*\lambda*\left[\frac{1}{Qsp^2}\right] + 0 + \frac{(h+pg)}{2} = 0$$

$$-\frac{(k+pf)*\lambda}{Qsp^2} + \frac{(h+gp)}{2} = 0$$

$$\frac{(k+pf)*\lambda}{Qsp^2} = \frac{(h+pg)}{2}$$

$$Qsp^2 = \frac{2(k+pf)*\lambda}{(h+pg)}$$

$$Qsp = \sqrt{\frac{2(k+pf)*\lambda}{(h+pg)}} \qquad 8$$

To calculate the SEOQ total inventory cost (TIC) with tax (TIC(Qsp)), equation (8) is also added to equation (7). TIC(Qsp) is displayed in equation (9).

$$\mathrm{TIC} = \text{Ordering cost} + \text{Purchasing cost} + \text{Holding cost}$$

$$\mathrm{TIC(Q)} = \frac{(k+pf)*\lambda}{Q} + (c+pv)*\lambda + \frac{(h+pg)*Q}{2}$$

At Optimal quantity ordering cost and holding cost are same.

$$\mathrm{TIC(Qsp)} = \frac{2(k+pf)*\lambda}{Qsp} + (c+pv)*\lambda$$

$$\mathrm{TIC(Qsp)} = \frac{2(k+pf)*\lambda}{\sqrt{\frac{2(k+pf)*\lambda}{(h+pg)}}} + (c+pv)*\lambda$$

$$\mathrm{TIC(Qsp)} = \sqrt{\frac{4(k+pf)^2\lambda^2}{\frac{2(k+pf)\lambda}{(h+pg)}}} + (c+pv)*\lambda$$

$$\mathrm{TIC(Qsp)} = \sqrt{2(k+pf)\lambda(h+pg)} + (c+pv)\lambda \qquad 9$$

2.4 Numerical Example

This section shows the numerical experiment procedure on the proposed SEOQ models. The experiment was carried out to test the sensitivity of the proposed models. The data are presented in Table 1(S. K. B. Maulana et al).

Table 1. Experimental Data Variables

	Data Variables	Unit	Value
Demand	λ	kg	50
Cost per order	k	$/order	40
Purchasing cost per unit	c	$/kg	20
Emission tax cost	p	$/kg	2
Holding cost per unit	h	$/kg	10
Total emissions from ordering	f	$/kgCO2	60
Total emissions from purchasing	v	$/kgCO2	5
Total emissions from holding	g	$/kgCO2	1

2.5 Results And Discussion

The jamovi project (2022). jamovi. (Version 2.3) Software is used for solving frameworks and checking numerical sensitivity.

2.5.1 Sustainable EOQ without Emission Tax

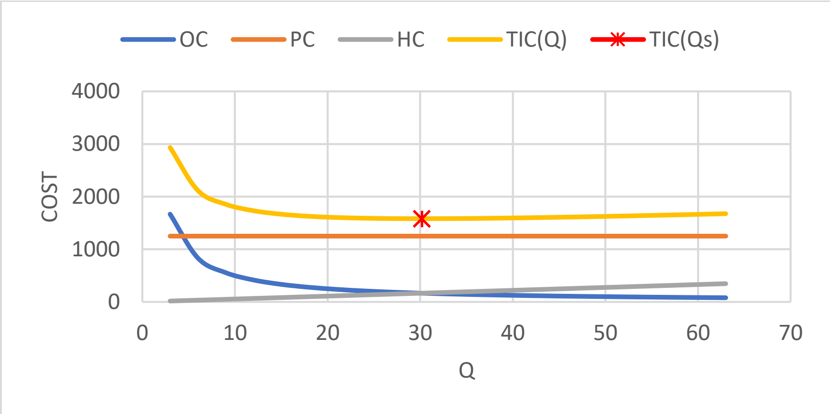

Figure 3. Ordering and holding costs as functions of the order quantity.

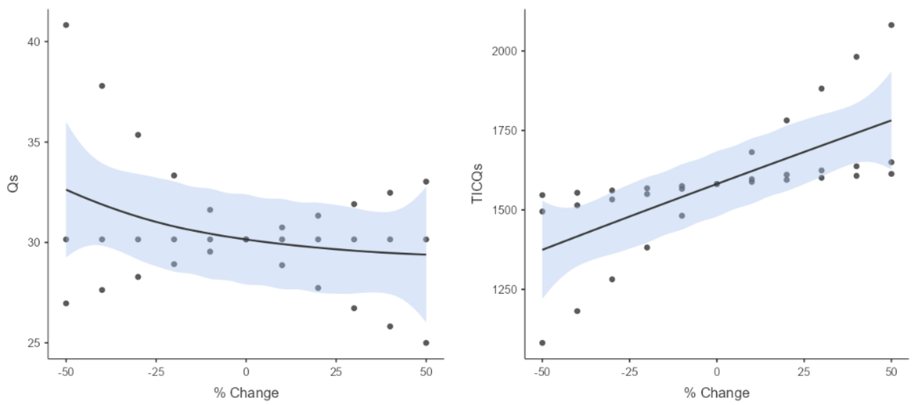

Figure 4. Effect of % Change in k, c, h on Qs and TICQs along with standard error (Std. Err.).

2.5.2 Sustainable EOQ with Emission Tax

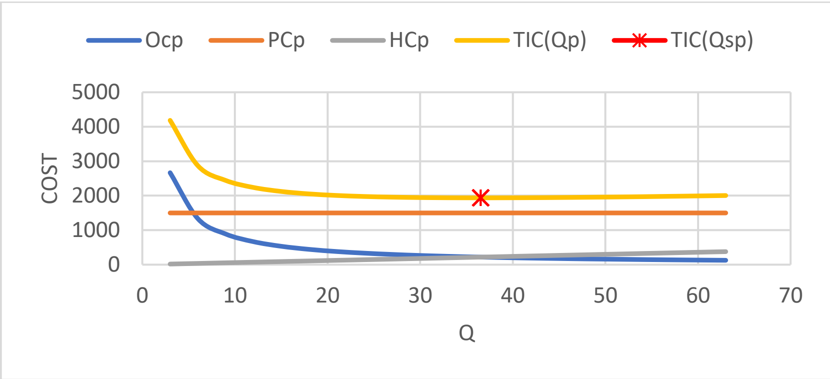

Figure 5. Ordering and holding costs as functions of the order quantity.

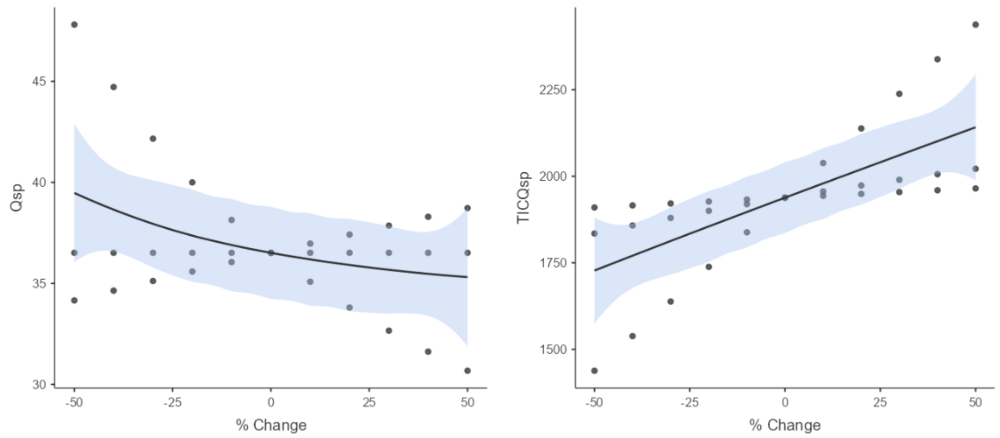

Figure 6. Effect of % Change in k, c, h on Qsp and TICQsp along with standard error (Std. Err.).

2.6 Sensitivity Analysis

2.6.1 Sensitivity

Table 2: Change in Qs, Qsp, TIC(Qs) and TIC(Qsp) due to change in cost per order.

% Change	k	f	λ	c	h	v	g	p	QS	TIC(Qs)	Qsp	TIC(Qsp)
-50	20	60	50	20	10	5	1	2	27	1547	34	1910
-40	24	60	50	20	10	5	1	2	28	1554	35	1916
-30	28	60	50	20	10	5	1	2	28	1561	35	1921
-20	32	60	50	20	10	5	1	2	29	1568	36	1927
-10	36	60	50	20	10	5	1	2	30	1575	36	1933
0	40	60	50	20	10	5	1	2	30	1582	37	1938
10	44	60	50	20	10	5	1	2	31	1588	37	1944
20	48	60	50	20	10	5	1	2	31	1595	37	1949
30	52	60	50	20	10	5	1	2	32	1601	38	1954
40	56	60	50	20	10	5	1	2	32	1607	38	1960
50	60	60	50	20	10	5	1	2	33	1613	39	1965

Table 3: Change in Qs, Qsp, TIC(Qs) and TIC(Qsp) due to change in purchase cost per unit.

% Change	k	f	λ	c	h	v	g	p	QS	TIC(Qs)	Qsp	TIC(Qsp)
-50	40	60	50	10	10	5	1	2	30	1082	37	1438
-40	40	60	50	12	10	5	1	2	30	1182	37	1538
-30	40	60	50	14	10	5	1	2	30	1282	37	1638
-20	40	60	50	16	10	5	1	2	30	1382	37	1738
-10	40	60	50	18	10	5	1	2	30	1482	37	1838
0	40	60	50	20	10	5	1	2	30	1582	37	1938
10	40	60	50	22	10	5	1	2	30	1682	37	2038
20	40	60	50	24	10	5	1	2	30	1782	37	2138
30	40	60	50	26	10	5	1	2	30	1882	37	2238
40	40	60	50	28	10	5	1	2	30	1982	37	2338
50	40	60	50	30	10	5	1	2	30	2082	37	2438

Table 4: Change in Qs, Qsp, TIC(Qs) and TIC(Qsp) due to change in holding cost per unit.

% Change	k	f	λ	c	h	v	g	p	QS	TIC(Qs)	Qsp	TIC(Qsp)
-50	40	60	50	20	5	5	1	2	41	1495	48	1835
-40	40	60	50	20	6	5	1	2	38	1515	45	1858
-30	40	60	50	20	7	5	1	2	35	1533	42	1879
-20	40	60	50	20	8	5	1	2	33	1550	40	1900
-10	40	60	50	20	9	5	1	2	32	1566	38	1920
0	40	60	50	20	10	5	1	2	30	1582	37	1938
10	40	60	50	20	11	5	1	2	29	1596	35	1956
20	40	60	50	20	12	5	1	2	28	1611	34	1973
30	40	60	50	20	13	5	1	2	27	1624	33	1990
40	40	60	50	20	14	5	1	2	26	1637	32	2006
50	40	60	50	20	15	5	1	2	25	1650	31	2022

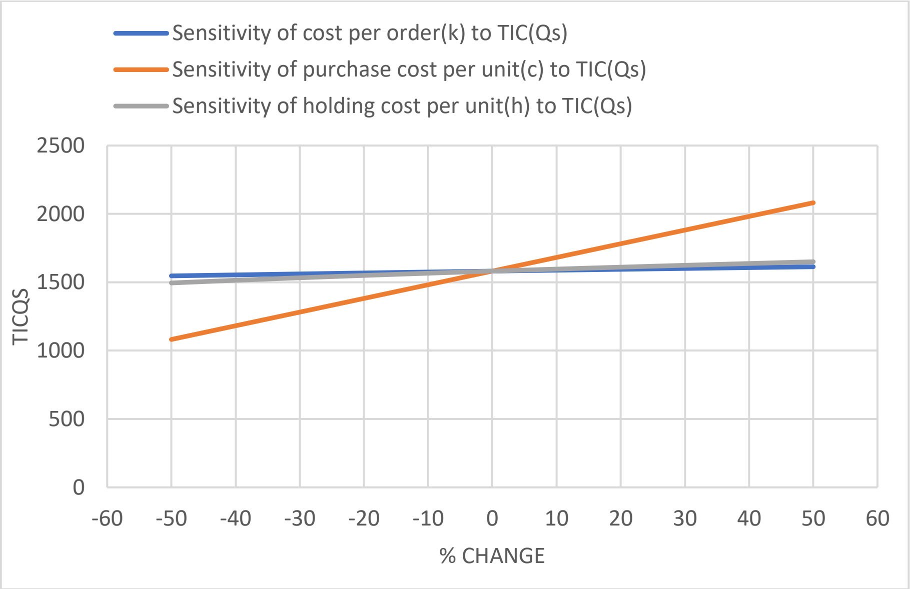

Figure 7. Change in TIC(Qs) without emission tax due to change in cost per order, purchase and holding cost per unit.

Figure 8. Change in TIC(Qsp) with emission tax due to change in cost per order, purchase and holding cost per unit.

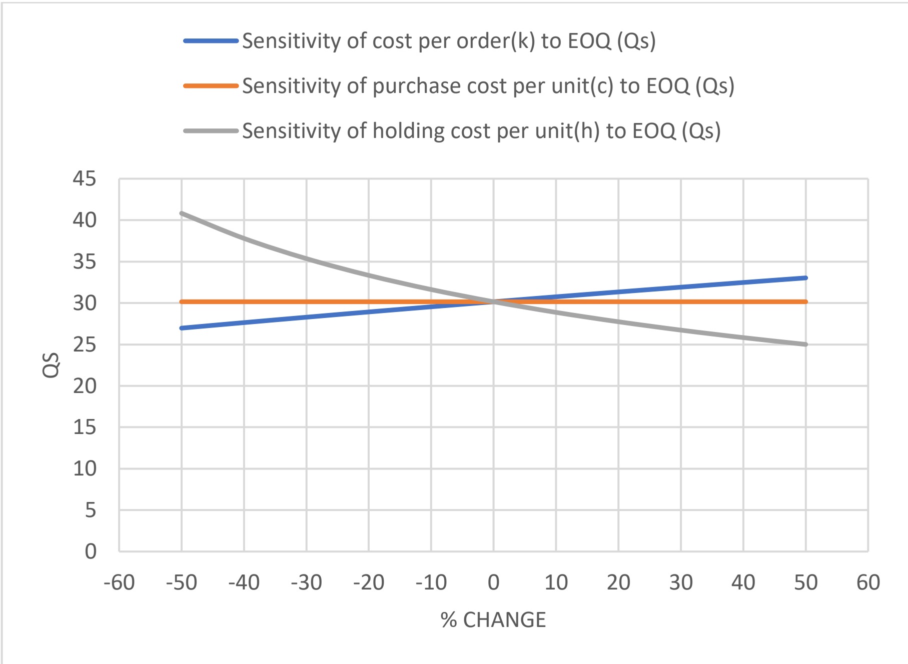

Figure 9. Change in EOQ without emission tax due to change in cost per order, purchase and holding cost per unit.

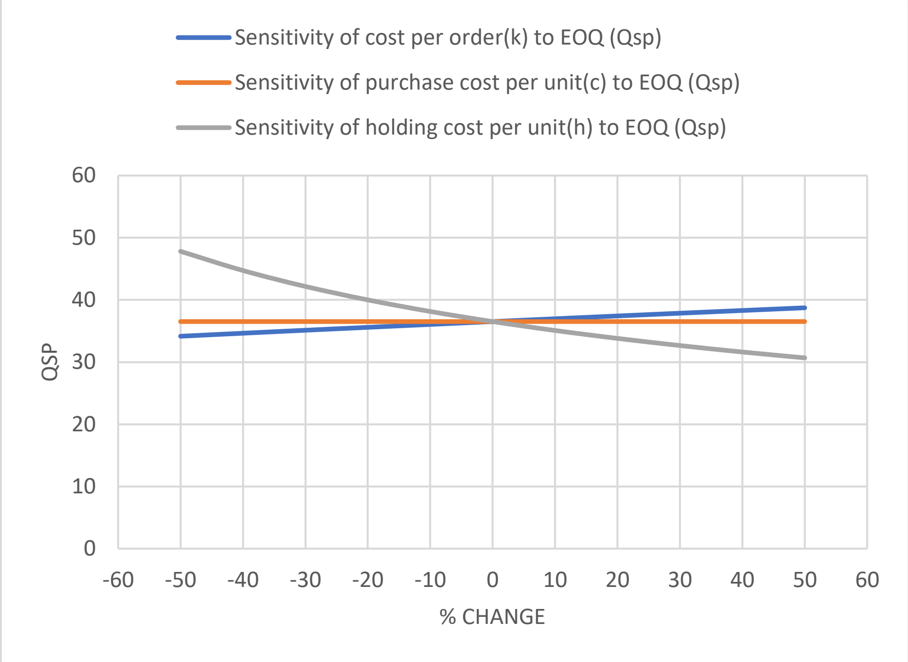

Figure 10. Change in EOQ with emission tax due to change in cost per order, purchase and holding cost per unit.

2.6.2 ANOVA

Table 5: ANOVA.

ANOVA – TIC(Qs)					
	Sum of Squares	**df**	**Mean Square**	**F**	**p**
Overall Model	1.13e+6	30	37703	4.83e+31	<0.001
K	4885	10	489	6.26e+29	<0.001
c	1.10e+6	10	110005	1.41e+32	<0.001
h	26148	10	2615	3.35e+30	<0.001
k✻c	0	NaN			
k✻h	0	NaN			
c✻h	0	NaN			
k✻c✻h	0	NaN			
Residuals	1.56e-27	2	7.80e-28		

2.6.3 Assumptions Checks

Table 6: Homogeneity of Variances & Normality Test

Homogeneity of Variances Test (Levene's)			
F	**df1**	**df2**	**p**
0.463	30	2	0.867

Normality Test (Shapiro-Wilk)	
Static	**P**
0.383	<0.001

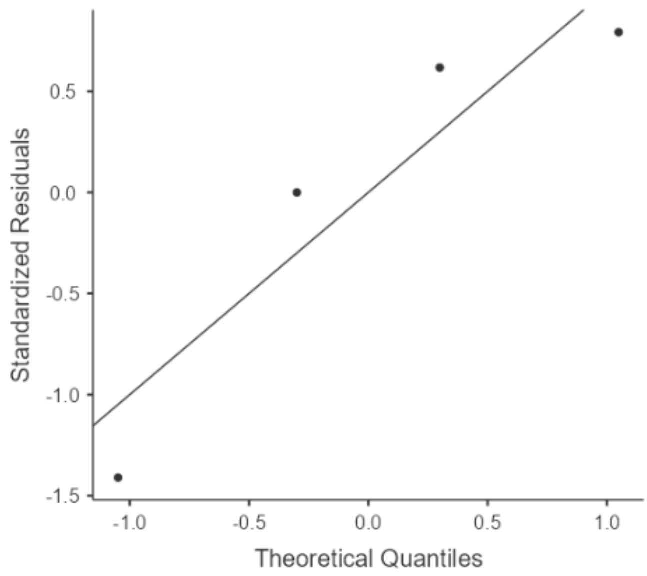

Figure 11. Q-Q Plot.

2.6.4 Correlation Matrix

Table 7: Correlation Matrix.

Correlation Matrix								
		Qs	**Qsp**	**TIC(Qs)**	**TIC(Qsp)**	**k**	c	h
Qs	Pearson's r	-						
	p-value	-						
	95% CI Upper	-						
	95% CI Lower	-						
	N	-						
Qsp	Pearson's r	0.910	-					
	p-value	<0 .001	-					
	95% CI Upper	0.955	-					
	95% CI Lower	0.824	-					
	N	33	-					
TIC(Qs)	Pearson's r	-0.116	-0.118	-				
	p-value	0.520	0.514	-				
	95% CI Upper	0.237	0.235	-				
	95% CI Lower	-0.442	-0.443	-				
	N	33	33	-				
TIC(Qsp)	Pearson's r	-0.135	0.082	0.844	-			
	p-value	0.453	0.650	<0.001	-			
	95% CI Upper	0.218	0.414	0.921	-			
	95% CI Lower	-0.457	-0.269	0.705	-			
	N	33	33	33	-			
k	Pearson's r	0.359	0.239	0.066	0.045	-		
	p-value	0.040	0.181	0.717	0.802	-		
	95% CI Upper	0.625	0.538	0.400	0.383	-		
	95% CI Lower	0.018	-0.114	-0.284	-0.303	-		
	N	33	33	33	33	-		
c	Pearson's r	0.000	0.000	0.986	0.829	0.000	-	
	p-value	1.000	1.000	<0.001	<0.001	1.000	-	

	95% CI Upper	0.343	0.343	0.993	0.912	0.343	-	
	95% CI Lower	-0.343	-0.343	0.972	0.678	-0.343	-	
	N	33	33	33	33	33	-	
h	Pearson's r	-0.899	-0.865	0.152	0.154	0.000	0.000	-
	p-value	<0.001	<0.001	0.400	0.393	1.000	1.000	-
	95% CI Upper	-0.804	-0.742	0.470	0.472	0.343	0.343	-
	95% CI Lower	-0.949	-0.931	-0.202	-0.200	-0.343	-0.343	-
	N	33	33	33	33	33	33	-

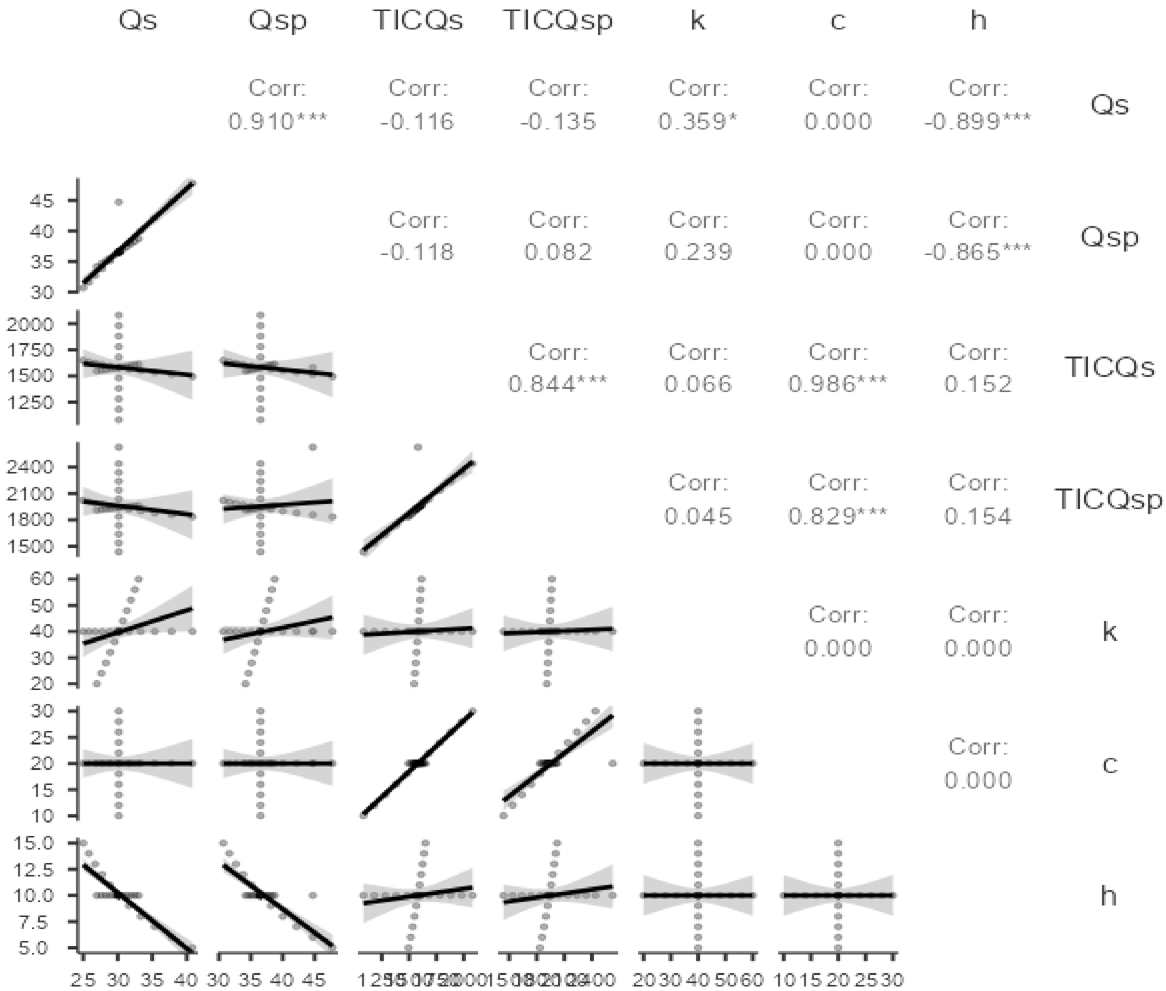

Figure 12. Correlation Matrix Plot.

Table 8: **Descriptives**							
	k	***c***	***h***	***TIC (Qs)***	***Qs***	***Qsp***	***TIC (Qsp)***
N	33	33	33	33	33	33	33
Missing	349	349	349	349	349	349	349
Mean	40.0	20.0	10.0	1580	30.5	36.9	1937
Median	40	20	10	1582	30.2	36.5	1938
Standard Deviation	7.42	3.71	1.85	188	3.13	3.27	189
Minimum	20	10	5	1082	25.0	30.7	1438
Maximum	60	30	15	2082	40.8	47.8	2438

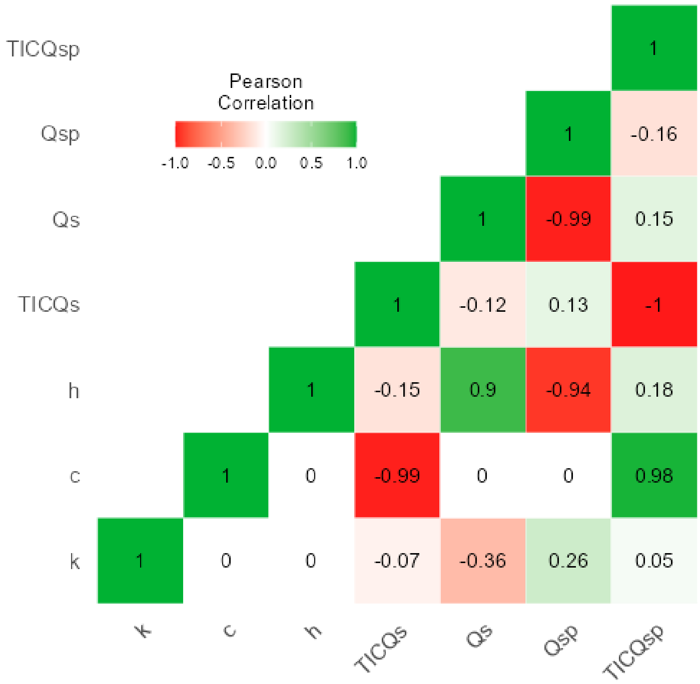

Figure 13. Correlation Heatmap.

2.7 Conclusion

In the current study, SEOQ framework is evaluated, which took into account the expenses associated with the sustainable inventory, including order cost, purchase cost, holding cost and the fixed cost of an environmental effect (carbon emission tax cost). As a result, research produced fresh perspectives on inventories, particularly for SEOQ models with cost of the emission tax. Further research on evaluation of frameworks including capital constraints with and without carbon emission tax cost is being under consideration.

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THE NOTATIONS:

λ : Demand
k : Cost per order
c : Purchasing cost per unit
h : Holding cost per unit
f : Total emissions from ordering
v : Total emissions from purchasing
g : Total emissions from holding
p : Emission tax cost
Q : Number of orders
Qs : Optimal sustainable number of orders without tax
Qsp : Optimal sustainable number of orders with tax
TIC : Total inventory cost
TIC(Qs) : Optimum total inventory cost without tax
TIC(Qsp) : Optimum total inventory cost with tax