Considering $\theta << 1$,

$$TC_b = \frac{o}{T} + r_c\frac{n}{T} + \left((h_b + w_e)\frac{DT}{2n}\left(1 + \frac{1}{3}\frac{\theta T}{n} + \frac{1}{12}\frac{\theta^2 T^2}{n^2}\right)\right) + \left((d_{cb} + d_{eb})\left(\frac{1}{2}\frac{D\theta T}{n} + \frac{1}{6}\frac{D\theta^2 T^2}{n^2} + \frac{1}{24}\frac{D\theta^3 T^3}{n^3}\right)\right)$$

and by neglecting $\theta^2 T^2$ and more,

$$TC_b = \frac{o}{T} + r_c\frac{n}{T} + \left((h_b + w_e)\frac{DT}{2n}\left(1 + \frac{1}{3}\frac{\theta T}{n}\right)\right) + \left((d_{cb} + d_{eb})\frac{D\theta T}{2n}\right) \tag{9}$$

3.2. Vendor's Total Cost Function

Eq. (10) describes the vendor's total cost per unit time (*TCv*). It is the function of the vendor's setup cost (C_S), transport cost (C_{TE}), holding cost (C_{HEv}) and deteriorating cost (C_{DEv}) per unit time:

$$TC_v = C_s + C_{TE} + C_{HEv} + C_{DEv} \tag{10}$$

$$C_s = \frac{s}{T} \tag{11}$$

The vendor's transportation cost consists of a fix transport cost, variable transport cost, and carbon emission cost. Bonney & Jaber (2011) considered the vehicle delivery time to calculate the transport emission. In this study, the emission cost depends on the delivery quantity (Q) or the vehicle payload.

$$C_{TE} = \frac{n}{T}\left(t_f + \left(2dt_v c_1 + dt_v c_2 bQ\right) + \left(2de_1 + de_2 Q\right)\right) = \frac{n}{T}\left(t_f + \left(2dt_v c_1 + dt_v c_2 bI_b(0)\right) + \left(2de_1 + de_2 I_b(0)\right)\right) \tag{12}$$

By substituting (5) to (12) we gain:

$$C_{TE} = \frac{n}{T}\left(t_f + \left(2dt_v c_1 + dt_v c_2 b\frac{D}{\theta}(e^{\frac{\theta T}{n}} - 1)\right) + \left(2de_1 + de_2\frac{D}{\theta}(e^{\frac{\theta T}{n}} - 1)\right)\right) \tag{13}$$

The vendor's total inventory model is identical to that of Yang & Wee (2000) and Lee & Kim (2014). Eq. (14) consists of total inventory during the production period plus the total inventory during the non-production period minus the inventory of the transported goods at the buyer's side.

$$I_v(t) = \int_0^{T_{v1}} I_{v1}(t_1)dt_1 + \int_0^{T_{v2}} I_{v2}(t_2)dt_2 - n\int_0^{T/n} I_b(t)dt \tag{14}$$

During the production period T_{v1},

$dI_{v1}(t_1) = P\,dt_1 - D\,dt_1 - I_{v1}(t_1)\theta\,dt_1$, therefore vendor's inventory level at any time t is

$$I_{v1}(t_1) = \frac{P - D}{\theta}\left(1 - e^{-\theta t_1}\right), \quad 0 \le t_1 \le T_{v1} \tag{15}$$

And during the non-production period T_{v2},

$dI_{v2}(t_2) = -D\,dt_2 - I_{v2}(t_2)\theta\,dt_2$, therefore

$$I_{v2}(t_2) = \frac{D}{\theta}\left(e^{\theta(T_{v2} - t_2)} - 1\right), \quad 0 \le t_2 \le T_{v2} \tag{16}$$

Therefore, the vendor's holding cost per unit time considering both traditional inventory carrying cost and carbon emission cost generated by warehousing is:

$$C_{HEv} = \frac{(h_v + w_e)}{T}\left[\int_0^{T_{v1}}\frac{P - D}{\theta}\left(1 - e^{-\theta t_1}\right)dt_1 + \int_0^{T_{v2}}\frac{D}{\theta}\left(e^{\theta(T_{v2} - t_2)} - 1\right)dt_2 - n\int_0^{T/n} I_b(t)dt\right] \tag{17}$$

Similar to Yang & Wee (2000) and Lee & Kim (2014), as $\theta << 1$ we use Misra (1975) approximation

$$T_{v1} \approx \frac{D}{P - D}T_{v2}\left(1 + \frac{1}{2}\theta T_{v2}\right), \tag{18}$$

and as $T = T_{v1} + T_{v2}$, we can derive

$$T \approx \frac{T_{v2}}{P-D}\left(P+\frac{1}{2}\theta T_{v2}\right) \tag{19}$$

The vendor's deteriorating cost per unit time considering both traditional deteriorating cost and carbon emission cost generated by deteriorated items is:

$$C_{DEv} = \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1} - DT - n\left(I_b(0) - D\frac{T}{n}\right)\right) \tag{20}$$

By substituting (4) to (20) we gain:

$$C_{DEv} = \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1} - DT - n\left(\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1) - D\frac{T}{n}\right)\right) \tag{21}$$

By substituting (11), (13), (17), (21) to (10) we gain:

$$\begin{aligned} TC_v = {} & \frac{s}{T} + \frac{n}{T}\left(t_f + \left(2dt_v c_1 + dt_v c_2 b\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1)\right) + \left(2de_1 + de_2\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1)\right)\right) + \\ & \frac{(h_v + w_e)}{T}\left[\int_0^{T_{v1}} \frac{P-D}{\theta}\left(1-e^{-\theta t_1}\right)dt_1 + \int_0^{T_{v2}} \frac{D}{\theta}\left(e^{\theta(T_{v2}-t_2)}-1\right)dt_2 - n\int_0^{T/n} I_b(t)dt\right] + \\ & \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1} - DT - n\left(\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1) - D\frac{T}{n}\right)\right) \end{aligned} \tag{22}$$

From the analysis of buyer's inventory on Eq. (6) and (9),

$$n\int_0^{T/n} I_b(t)dt = n\left[\frac{DT^2}{2n^2}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)\right] \tag{23}$$

Therefore,

$$\begin{aligned} TC_v = {} & \frac{s}{T} + \frac{n}{T}\left(t_f + \left(2dt_v c_1 + dt_v c_2 b\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1)\right) + \left(2de_1 + de_2\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1)\right)\right) + \\ & \frac{(h_v + w_e)}{T}\left[\frac{P-D}{\theta}T_{v1} + \frac{P-D}{\theta^2}\left(e^{-\theta \mathrm{T}_{v1}}-1\right) - \frac{DT_{v2}}{\theta} - \frac{D}{\theta^2}(1-e^{\theta \mathrm{T}_{v2}}) - \left(\frac{DT^2}{2n}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)\right)\right] + \\ & \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1} - DT - n\left(\frac{D}{\theta}(e^{\frac{\theta T}{n}}-1) - D\frac{T}{n}\right)\right) \end{aligned} \tag{24}$$

$$\begin{aligned} TC_v = {} & \frac{s}{T} + \frac{n}{T}\left(\begin{aligned} & t_f + \left(2dt_v c_1 + dt_v c_2 b\left(\frac{DT}{n} + \frac{1}{2}\frac{D\theta T^2}{n^2} + \frac{1}{6}\frac{D\theta^2 T^3}{n^3} + \frac{1}{24}\frac{D\theta^3 T^4}{n^4}\right)\right) + \\ & \left(\left(2de_1 + de_2\left(\frac{DT}{n} + \frac{1}{2}\frac{D\theta T^2}{n^2} + \frac{1}{6}\frac{D\theta^2 T^3}{n^3} + \frac{1}{24}\frac{D\theta^3 T^4}{n^4}\right)\right)\right) \end{aligned}\right) + \\ & \frac{(h_v + w_e)}{T}\left[\frac{(P-D)T_{v1}{}^2}{2}\left(1-\frac{\theta T_{v1}}{3}\right) + \frac{DT_{v2}{}^2}{2}\left(1+\frac{\theta T_{v2}}{3}\right) - \left(\frac{DT^2}{2n}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)\right)\right] + \\ & \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1} - DT - n\left(\frac{1}{2}\frac{D\theta T^2}{n^2} + \frac{1}{6}\frac{D\theta^2 T^3}{n^3} + \frac{1}{24}\frac{D\theta^3 T^4}{n^4}\right)\right) \end{aligned}$$

For $\theta << 1$, and neglecting $\theta^2 T^2$ and more terms, one has:

$$
\begin{aligned}
TC_v = {} & \frac{s}{T}+\frac{n}{T}\left(t_f+2dt_vc_1+dt_vc_2b\left(\frac{DT}{n}+\frac{1}{2}\frac{D\theta T^2}{n^2}\right)+2de_1+de_2\left(\frac{DT}{n}+\frac{1}{2}\frac{D\theta T^2}{n^2}\right)\right)+\\
& \frac{(h_v+w_e)}{T}\left[\frac{(P-D){T_{v1}}^2}{2}\left(1-\frac{\theta T_{v1}}{3}\right)+\frac{D{T_{v2}}^2}{2}\left(1+\frac{\theta T_{v2}}{3}\right)-\left(\frac{DT^2}{2n}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)\right)\right]+\\
& \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1}-DT-\frac{1}{2}\frac{D\theta T^2}{n}\right)
\end{aligned}
\tag{25}
$$

The integrated total cost function for the vendor and the buyer with carbon emission consideration TC_E is the sum of TC_v and TC_b:

$$
\begin{aligned}
TC_E = {} & \frac{s}{T}+\frac{n}{T}\left(t_f+2dt_vc_1+dt_vc_2b\left(\frac{DT}{n}+\frac{1}{2}\frac{D\theta T^2}{n^2}\right)+2de_1+de_2\left(\frac{DT}{n}+\frac{1}{2}\frac{D\theta T^2}{n^2}\right)\right)+\\
& \frac{(h_v+w_e)}{T}\left[\frac{(P-D){T_{v1}}^2}{2}\left(1-\frac{\theta T_{v1}}{3}\right)+\frac{D{T_{v2}}^2}{2}\left(1+\frac{\theta T_{v2}}{3}\right)-\left(\frac{DT^2}{2n}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)\right)\right]+\\
& \frac{(d_{cv}+d_{ev})}{T}\left(PT_{v1}-DT-\frac{1}{2}\frac{D\theta T^2}{n}\right)+\frac{o}{T}+r_c\frac{n}{T}+(h_b+w_e)\frac{DT}{2n}\left(1+\frac{1}{3}\frac{\theta T}{n}\right)+(d_{cb}+d_{eb})\frac{D\theta T}{2n}
\end{aligned}
\tag{26}
$$

3.3. Solution Procedure

The objective of this model is to minimize the expected total cost function with carbon emission consideration TC_E. For this purpose we need to determine the optimal number of deliveries (n^*). Because n is a discrete variable, we can derive n as follows:
Step 1. Substitute Eq. (18) and (19) to (26).
Step 2. Input all the system parameters.
Step 3. Determine the partial derivative of TC_E with respect to T_{v2} and set it to zero.
Step 4. For a range of n-value, denote the resulting minimum value of T_{v2}. For each n and T_{v2} find the corresponding value of T_{v1} and T from Eq. (18) and (19).
Step 5. Derive the optimal number of deliveries (n^*) such that satisfy $TC_E(n^*-1) \geq TC_E(n^*) \leq TC_E(n^*+1)$.
Step 6. Find the optimal delivery quantity, Q, from equation (5).
Step 7. Find the optimal vendor's production quantity, R.

4. Numerical Example

To illustrate the performance of the developed model, we adopt the numerical example from Yang & Wee (2000) and Lee & Kim (2014) with some modification. The parameters are as follows:

P = 2,000,000 units/year, D = 500,000 units/year,
C = \$2,000/order, S = \$100,000 /setup,
θ = 0.1, r_c = \$500/delivery,
h_b = \$60/unit/year, h_v = \$40/unit/year,
d_{cb} = \$600/unit, d_{cv} = \$400/unit.

To incorporate the carbon emission, we use several data and assumption as follow:

V = 2.6 kgCO_2/litre diesel fuel (US. EPA)
E = 500 grCO_2/kWh (CCC – UK Parliament)
c_1 = 30 litre/100 km (Volvo truck report for Long haul)
c_2 = 0.45 litre/100 km/ton payload (Volvo truck report for Long haul)
tx = \$61.8/tonCO_2 (Taiwan government's plan; Chan, 2009)
w = 100 kWh/unit/year
b = 4 kg/unit
v_{de} = 4 kgCO_2 /unit
b_{de} = 5 kgCO_2 /unit

Therefore,

e_1 = \$ 0.048/km, e_2 = \$ 2.89 x 10^{-6} /unit/km, w_e = \$ 3.09/unit/year,
d_{eb} = \$ 0.31/unit, d_{ev} = \$ 0.25/unit.

Further, to solve our developed model we need several additional parameters as follow:

d = 100 km, t_f = \$ 500/trip, t_v = \$ 0.75/litre,

By implementing the proposed solution procedure, we found the optimal value of *n* that minimize the integrated total cost as n^* = 8 with the TC_E^* = \$3,246,283. The corresponding time parameter and total cost are given in Table 1. From Eq. (5), the order delivery size Q^* is 5,372 units. Further, the optimal vendor's production quantity (R) is 43,052 units. From Eq. (6) and (14), the buyer's and vendor's inventories are 2,685 units and 13,444 units respectively. Fig. 2 shows the graphical representation of TC_E concavity when n^* = 8.

As T = 0.08590, the total demand during the order cycle time (DT) is 42,950 units. Considering the loss due to deterioration at the vendor and buyer inventory, the vendor can fulfill the demand by producing 43,052 units per order cycle time. In one unit of time (e.g. one year), the total vendor's production quantity is 501,206 units. Comparing this result to the demand (D), we can see a significant amount of loss due to item deterioration.

From Table 1, we found that when the decision is made solely from the buyer's perspective, the optimal value of *n* is $n^\sharp$ = 24 and the minimum TC_b is \$269.238. In this situation, the total cost TC_E both for vendor and buyer is \$3,357,490 which is 3.31% higher than the integrated total cost with joint decision. This result shows the cost reduction due to the supply chain joint decision. From Eq. (5), the order delivery size $Q^\sharp$ is 1978 units. Further, the optimal vendor's production quantity is 47,584 units. From Eq. (6) and (14), the buyer's and the vendor's inventories are 989 units and 16,836 units respectively.

The total carbon emission per year calculation for n^* are as follow:

- Fuel consumption = 1 year/0.08590 year/order cycle x 8 delivery/order cycle x [(2 x 100 km/delivery x 30 litre/100 km) + (100 km/delivery x 0.45 litre/100 km/ton x 4 kg/unit x 1.10^{-3} ton/kg x 5,372 unit)] = 6488.56 litre
- Fuel emission = 6488.56 litre x 2.6 $kgCO_2$/litre 1.10^{-3} ton/kg = 16.87 ton CO_2
- Vendor's warehouse emission = 156,506.64 unit x 100 kwh/unit x 500 $grCO_2$/kwh x 1.10^{-6} ton/gr = 7,825.33 ton CO_2
- Vendor's deteriorated item emission = 937.31 unit x 4 $kgCO_2$/unit = 3.75 ton CO_2
- Buyer's warehouse emission = 250,089.48 unit x 100 kwh/unit x 500 $grCO_2$/kwh x 1.10^{-6} ton/gr = 12,504.47 ton CO_2
- Buyer's deteriorated item emission = 268.68 unit x 5 $kgCO_2$/unit = 1.34 ton CO_2

Therefore, the total carbon emission (*TE*) from the vendor and the buyer is 20,351.77 ton of CO_2 per year. A similar carbon emission calculation was performed for $n^\sharp$ = 24 and the result is 21,417.75 ton of CO_2/year. It is 4.98% higher than the total carbon emission for n^*.

Table 1. Result of optimal solution *n*

n	$Tv_2\,(10^{-5})$	$Tv_1\,(10^{-5})$	$T\,(10^{-5})$	$TC_b\,(10^3)$	$TC_v\,(10^3)$	$TC_E\,(10^3)$
1	4935	1649	6585	2067.001	1737.468	3804.469
2	5587	1867	7454	1188.198	2279.829	3468.027
3	5884	1967	7851	850.482	2503.280	3353.762
4	6064	2027	8092	672.301	2627.992	3300.293
5	6191	2070	8260	563.141	2709.006	3272.147
6	6288	2103	8391	490.145	2766.806	3256.951
7	6368	2129	8498	438.466	2810.789	3249.256
8*	**6437**	**2153**	**8590**	**400.404**	**2845.879**	**3246.283***
9	6498	2173	8671	371.565	2874.905	3246.470
10	6553	2192	8745	349.259	2899.609	3248.868
20	6973	2332	9305	272.180	3048.286	3320.466
21	7009	2344	9353	270.747	3058.794	3329.541
22	7044	2356	9400	269.823	3068.928	3338.751
23	7078	2368	9446	269.339	3078.734	3348.074
24$^\#$	**7112**	**2379**	**9491**	**269.238**$^\#$	**3088.252**	**3357.490**
25	7146	2390	9536	269.470	3097.513	3366.983

When all the carbon emission costs are set to 0, we found the optimal value of n that minimizes the integrated total cost TC'' is $n''= 9$. The total cost ($3,194,209) is lower because the emission cost is excluded. The corresponding time parameter and total cost are given in Table 2. By substituting the result into Eq. (26), one has TC_E = $3,246,970. It is 0.021% higher than the total carbon emission from n^*. From Eq. (5), the order delivery size Q'' is 4916 units. Further, the optimal vendor's production quantity is 44329 units. From Eq. (6) and (14), the buyer's and vendor's inventories are 2457 units and 14149 units respectively. A similar carbon emission calculation was performed for $n'' = 9$ and the result is 20,526.97 ton CO_2/year. It is 0.854% higher than the total carbon emission for n^*. Table 3 provides the summary of cost and emission savings from the integrated inventory model considering carbon emissions.

Sensitivity analyses were carried out for several parameters by 20% increase or decrease. Table 4 - 8 shows the result of the sensitivity analysis. The main conclusion drawn from the sensitivity analyses are as follows:

1. The range of percentage of cost reduction (*PoCR*) and percentage of emission reduction (*PoER*) is from 0.006% to 0.043% and from 0% to 0.856% respectively.
2. The values of n^*, *PoCR* and *PoER* are most sensitive to the parameter θ.
3. The higher the value of the parameter tx, c_1 & c_2, w and d, the smaller the values of n^*.
4. The higher the value of the parameter θ, the higher the value of n^*.

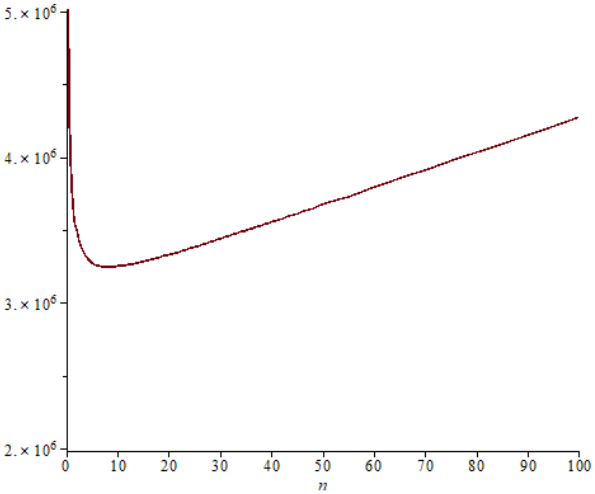

Fig. 2 Graphical representation of TC_E concavity when $n^* = 8$

Table 2. Optimal solution of n when emission costs are 0

n	$Tv_2\,(10^{-5})$	$Tv_1\,(10^{-5})$	$T\,(10^{-5})$	$TC_b\,(10^3)$	$TC_v\,(10^3)$	$TC_E\,(10^3)$
6	6409	2143	8553	486.197	2720.463	3206.660
7	6493	2171	8664	434.876	2763.350	3198.226
8	6564	2195	8759	397.039	2797.567	3194.606
9"	**6627**	**2216**	**8844**	**368.341**	**2825.868**	**3194.209"**
10	6685	2236	8920	346.120	2849.949	3196.069

Table 3. Summary of cost and emission saving

	Buyer's individual decision (a)	*Integrated decision considering emission (b)*	*Saving ((a-b)/a)*	*Integrated decision (c)*	*Saving ((c-b)/c)*
n	24	8		9	
TC_E ($/year)	3,357,490	3,246,283	3.31%	3,246,970	0.021%
TE (tonCO_2/year)	21,417.75	20,351.77	4.98 %	20,526.97	0.854%

Table 4. Sensitivity analysis when *tx* is changed by 20%

tx (\$/tonCO$_2$)	37.08	49.44	{61.8 }	74.16	86.52
n^*	9	8	8	8	8
$TC_E(n^*)$	3225684	3236027	3246283	3256504	3266687
$TE(n^*)$	20526.89	20351.80	20351.77	20351.74	20351.71
n''	9	9	9	9	9
$TC_E(n'')$	3225866	3236420	3246970	3257524	3268077
$TE(n'')$	20526.97	20526.97	20526.97	20526.97	20526.97
PoCR	0.006%	0.012%	0.021%	0.031%	0.043%
PoER	0.0004%	0.853%	0.854%	0.854%	0.854%

* The optimal integrated decision of *n* that minimizes TC_E by considering carbon emission
’’ The optimal integrated decision of *n* without considering carbon emission
PoCR, percentage of cost reduction = $[TC_E(n'')-TC_E(n^*)]/ TC_E(n'')$
PoER, percentage of emission reduction = $[TE(n'')- TE(n^*)]/ TE(n'')$
{}, base column

Table 5. Sensitivity analysis when c_1 & c_2 are changed by 20%

c_1 (litre/km) c_2 (litre/km/ton)	18/100 0.27/100	24/100 0.36/100	{30/100} {0.45/100}	36/100 0.54/100	42/100 0.63/100
n^*	9	8	8	8	8
$TC_E(n^*)$	2974016	3110168	3246283	3382405	3518525
$TE(n^*)$	20519.42	20348.39	20351.77	20355.14	20358.52
n''	9	9	9	9	9
$TC_E(n'')$	2974524	3110750	3246970	3383198	3519423
$TE(n'')$	20519.67	20523.32	20526.97	20530.61	20534.25
PoCR	0.018%	0.019%	0.021%	0.023%	0.026%
PoER	0.0012%	0.852%	0.854%	0.855%	0.856%

Table 6. Sensitivity analysis when *w* is changed by 20%

w (kWH)	60	80	{100}	120	140
n^*	9	8	8	8	8
$TC_E(n^*)$	3226266	3236296	3246283	3256231	3266141
$TE(n^*)$	12325.56	16285.82	20351.77	24417.69	28483.58
n''	9	9	9	9	9
$TC_E(n'')$	3226445	3236708	3246970	3257233	3267496
$TE(n'')$	12325.55	16426.26	20526.97	24627.67	28728.38
PoCR	0.006%	0.013%	0.021%	0.031%	0.041%
PoER	0.0000%	0.855%	0.854%	0.853%	0.852%

Table 7. Sensitivity analysis when θ is changed by 20%

θ (kWH)	0.06	0.08	{0.1}	0.12	0.14
n^*	8	8	8	9	9
$TC_E(n^*)$	3021552	3136514	3246283	3351501	3452519
$TE(n^*)$	20342.83	20347.47	20351.77	20530.89	20534.70
n''	8	9	9	9	9
$TC_E(n'')$	3022204	3137479	3246970	3351944	3452914
$TE(n'')$	20342.88	20522.58	20526.97	20531.05	20534.89
PoCR	0.022%	0.031%	0.021%	0.013%	0.011%
PoER	0.0002%	0.853%	0.854%	0.0008%	0.00094%

Table 8. Sensitivity analysis when d is changed by 20%

d (km)	60	80	{100}	120	140
n^*	9	8	8	8	8
TC_E(n*)	2974014	3110165	3246283	3382401	3518519
TE(n*)	20519.42	20348.39	20351.77	20355.14	20358.52
n''	9	9	9	9	9
$TC_E(n'')$	2974522	3110746	3246970	3383194	3519417
$TE(n'')$	20519.67	20523.32	20526.97	20530.61	20534.25
PoCR	0.017%	0.019%	0.021%	0.023%	0.026%
PoER	0.0012%	0.852%	0.854%	0.855%	0.856%

5. Conclusion

In this study, we extend the single vendor-buyer integrated inventory model to consider deterioration and carbon emission cost. The model extends previous studies by considering carbon emission from warehousing as well as transport activities and from the disposal of deteriorated items**.** The numerical example shows that in an integrated supply chain decision, the delivery frequency (n) is smaller and the delivery quantity (Q) is bigger when compared with the decision made solely from the buyer's perspective. The integrated inventory model has significantly reduced the total cost and the total carbon emissions. It is also shown that by incorporating emission cost into the inventory model decreases the delivery frequency and increases the quantity. Incorporating carbon emission into the integrated inventory model will reduce the total carbon emissions and slightly reduce the total supply chain cost. Further research can be considered for different backordering situation and different emission control policies.

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