Greenhouse gas penalty and incentive policies for a joint economic lot size model with industrial and transport emissions

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| CHRONICLE	ABSTRACT
	This paper presents a joint economic lot size model for a single manufacturer-a single buyer. The purposed model involves the greenhouse gas emission from industrial and transport sectors. We divide the emission into two types, namely the direct and indirect emissions. In this paper, we consider the Government's penalty and incentive policies to reduce the emission. We assume that the demand of the buyer is normally distributed and partially backordered. The objective is to minimize joint total cost incurred by a single manufacturer-a single buyer and involves the transportation costs of the freight forwarder. Transportation costs are the function of shipping weight, distance, fuel price and consumption with two transportation modes: truckload and less-than-truckload shipments. Finally, an algorithm procedure is proposed to determine the optimal order quantity, safety factor, actual shipping weight, total emission and frequency of deliveries. Numerical examples and analyses are given to illustrate the results.

1. Introduction

Global warming as an indicator of climate change occurs as a result of increasing greenhouse gasses (GHGs). Human activities produce the increasingly large amount of GHGs, particularly CO2, which is accumulated in the atmosphere. GHG reduction, an especially CO_2 emission reduction is the only way for human survival in facing global warming. The Kyoto Protocol is issued and signed in 1998 by the members of the United Nations (UN) and the European Union (EU), aiming for all participating countries to be committed to reducing the GHG emission amount by 5% to the 1990 level. As a result, many countries have ratified the protocol and have enacted regulations to reduce carbon emission. Policymakers designed regulations such as carbon caps, carbon tax, carbon cap and trade or carbon offset (Benjaafar et al., 2012). An example of the emission standards for diesel engines implemented by EU is that it will be given penalties for vehicles that do not meet minimum standards (Piecyk et al., 2007). Carbon emission can be incurred at various activities.

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Freight transportation and manufacturing industry are viewed as leading sectors in economic development. These sectors are the major factors in emission sources and energy consumption. For instance, GHG emissions from transport and industry in the US accounted for 26% and 21% of the total in 2014, respectively (www.epa.gov). GHG emissions from transport sector come from burning fossil fuels for trucks, cars, ships, trains and planes. Meanwhile, GHG emissions from industry come from fossil fuels for energy to produce products from raw materials. The energy consumption of transport and industry sectors is affected by direct and indirect emissions. Direct emissions are the emissions produced from the activities controlled by the companies that are directly related to GHG emissions, such as controlled boilers (generators), furnaces, vehicles, production process and equipment (forklifts) etc. Indirect emissions are the emissions resulted from company activities but are produced by the sources beyond the company. Indirect emission is associated with the amount of energy used and the utility supplying it such as purchased electricity, heat, steam, and cooling. The classification of emissions in this article is shown in Fig. 1.
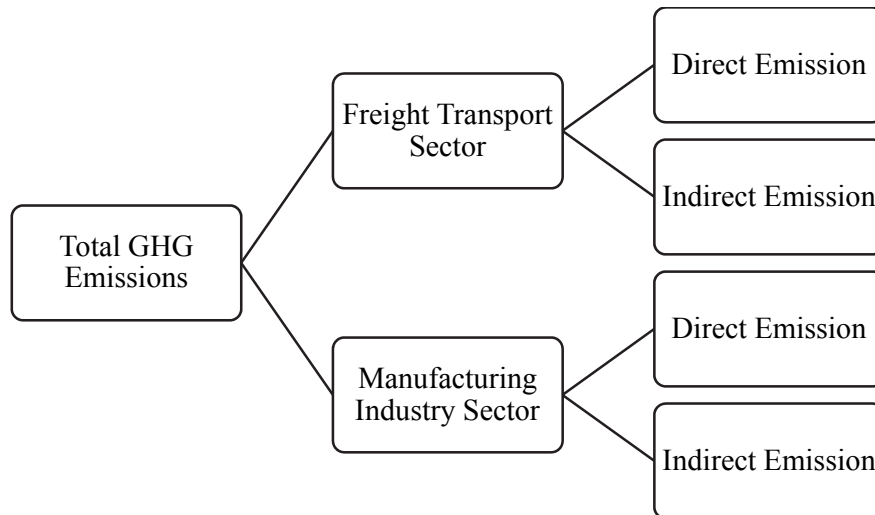
Fig. 1. The classification of emissions in this article

There are three common carbon policies, namely: carbon emission tax, inflexible cap, the cap-and-trade (Hua et al., 2011; Benjaafar et al., 2012; Hoen et al., 2014). Policymakers can also provide penalties and incentives to reduce emission or impose costs on carbon emissions. A firm can reduce its carbon emission by changing its production, inventory, warehousing, logistics and transportation (Hua et al., 2011; Benjaafar et al., 2012). For more details, the firm can use less polluting generators (boilers), machines or vehicles (direct emissions). While the firm can reduce their carbon emission by using cleaner or environmentally friendly energy sources for indirect emission (Helmrich et al., 2015). This paper developed a mathematical model of a supply chain, i.e. GHG emissions from transport and industrial sectors. The objective was to minimize the integrated costs of supply chain and total emissions produced by these sectors. Subsequently, we analyzed of how imposing on carbon emission tax, penalty and incentive policies impacts the optimal decision variables.

The rest of this paper is organized as follows. The existing literature is reviewed in Section 2. Section 3 describes the problem description, notation, and assumptions. Section 4 develops two mathematical models (with and without penalty and incentive policies) and solution algorithms. Sections 5 and 6 contain numerical example; analysis and discussion, and section 7 concludes the paper.

2. Literature review

In recent years, research dealing with supply chain inventory management system has attracted attention many scholars. One of the first works that studied the Joint Economic Lot Size model (JELS) was conducted by Goyal (1977). Banerjee (1986) relaxes the assumption of lot-for-lot policy and infinite

production rate. Goyal (1988) developed a model with Lu (1995) relaxed the assumption of Goyal (1988) and specified the optimal production and shipment policies when the shipment sizes are equal. Goyal (1995) then developed a model where successive shipment sizes increase by a ratio equal to the production rate divided by the demand rate. Later, Hill (1997) considered the geometric growth factor as a decision variable and he suggested a solution method based on an exhaustive search for both the growth factor and the number of shipments. Based on previous researches, Hill (1999) developed a general optimal policy model. Most of these coordinated models assume as deterministic demand. In fact, the buyer has usually faced lead time and demand uncertainties. Liao and Shyu (1991) developed an inventory model with probability in which lead time is the unique variable. Later, Ben-Daya and Raouf (1994) extended Liao and Shyu's model (1991) model with lead time and ordering quantity as decision variables. Ouyang et al. (1996) generalized Ben-Daya and Raouf's model (1994) model by considering shortages. Moon and Choi (1998) and Hariga and Ben-Daya (1999) further improved and revised Ouyang et al.'s model (1996) by optimizing the reorder point. The integrated inventory models under stochastic environment were developed by Ben-Daya and Hariga (2004), Ouyang et al. (2004) and Jauhari et al. (2011).

Pioneering research works on carbon emission models can be found in Hua et al. (2011) and Wahab et al. (2011). Hua et al. (2011) adopted the emission constraints into classical EOQ model, i.e. carbon emission through a cap-and-trade system under the assumption that carbon emission is linear with the order quantity. Wahab et al. (2011) developed mathematical models: a domestic and an international supply chains that took the environmental impacts. Benjaafar et al. (2012) and Chen et al. (2013) developed emission constraints to a single-level lot sizing (EOQ) and an integrated lot sizing models with the dynamic demand under different carbon emission policies (carbon emission tax, inflexible cap, the cap-and-trade) and analyzed the trade-off between costs and emissions. Jaber et al. (2013) developed a mathematical model for a two-level supply chain with incorporating carbon emission tax and penalties to reduce emission amount. This model takes into the emission amount as a function of the production rate. Setup cost, holding cost and emission cost are involved in determining the optimal production rate. Hoen et al. (2014) studied the problem of transportation model selection with carbon emission regulations and stochastic demand. Helmrich et al. (2015) introduced integrated carbon emission constraints in lot sizing problems. The main difference among of the models of Helmrich et al. (2015) with Benjaafar et al. (2012) and Chen et al. (2013) is the type of emission constraints, that their functions of emissions are sensitive with setups and holding cost. Xu, et al. (2015) derived the optimal total emission and production quantities of products overall levels of the cap and analyzed the impact on these optimal decisions. Zanoni et al. (2014) extended the model of Jaber et al. (2013) with Vendor Managed Inventory and Consignment Stock system (VMI-CS). Bazan et al. (2015a) extended and compared the works of Jaber et al. (2013) and Zanoni et al. (2014) by developing the mathematical model for a two-echelon supply chain system that considered the energy used for production. Bazan et al. (2015b; 2017) extended their previous work and investigated a reverse logistic model and considered emissions from manufacturing, remanufacturing and transportation activities.

The above-mentioned papers mostly focus on the single-echelon system or two-echelon system without incorporating transportation costs. The inventory-theoretic model with transportation and inventory costs was first introduced by Baumol and Vinod (1970). Lippman (1971) assumed transportation cost with a constant cost per truckload. Langley (1980) considered actual freight rates function into lot sizing decision. Carter and Ferrin (1996) developed a lot-sizing model using enumerations techniques that consider actual freight rate schedules to determining the optimal order quantity. Swenseth and Godfrey (2002) proposed a method to approximate the actual transportation cost with actual truckload freight rates. Abad and Aggarwal (2005) involved transportation cost into inventory model and determining lot-size and pricing decision with downward sloping demand. Nie et al. (2006) and Ertogral et al. (2007) presented an integrated inventory model with transportation cost. Ben-Daya et al. (2008) presented joint economic lot sizing models with different shipment policies. Mendoza and Ventura (2008) presented an algorithm based on a grossly simplified freight rate structure for truckload (TL) or least-then-truckload

(LTL) shipments. Rieksts and Ventura (2008; 2010) considered a combination of two different modes of transportation: LTL and FTL (full truckload). In the field of supply chain coordination, researches such as Viau et al. (2009) and Kim and Goyal (2009) focused on the integration of inventory and transportation decisions. Yildirmaz et al. (2009) considered joint pricing and lot-sizing decision with transportation. Leaveano et al. (2014a, 2014b) extended Nie et al's model (2006) with distance parameter. Gurtu et al. (2015) developed the inventory models with involving the fuel price.

Addressing the gap between the studies, this paper developed JELS model by incorporating FTL and TL carriers, GHG emission and stochastic demand for a two-level supply chain between a manufacturer and a buyer. We assume that GHG emissions are produced by direct and indirect emissions of industrial and transport sectors. The Government can provide penalties and incentives to reduce emissions. Therefore, we developed a JELS model involving the penalty, incentive and industrial and transport emissions.

3. Problem description, notation, and assumptions

3.1 Problem description

This paper studied a supply chain system and GHG emission. The GHG emission is one Key Environmental Performance Indicator (KePI) used as a tool to measure a company's sustainability performance of environmental aspect. The GHG Protocol defines direct and indirect emissions as follows (www.ghgprotocol.org):

1. Direct GHG emissions are the emissions from the sources owned or controlled by the reporting entity.
2. Indirect GHG emissions are the emissions as the consequences of the activities of the reporting entity but occur at the sources owned or controlled by another entity.

   The GHG Protocol has been defining of how the companies should manage and establish three categories of emissions as shown in Table 1 (www.ghgprotocol.org).

Table 1
Three categories of emissions

Scope 1 (direct)	Scope 2 (indirect)	Scope 3 (other indirect)
From sources owned or controlled by a company: - own vehicles and equipment - fuel of production combustion - wastewater treatment, etc	Consumption of purchased: - electricity - heating - hot water - steam - cooling For internal use	From sources not owned or directly controlled by Other indirect emissions, such as: - business travel - employee travel - transport and distribution (related activities in vehicles not owned or controlled) - electricity-related activities not covered in Scope 2 - outsourced activities - waste disposal, etc.

This paper considered a two-echelon supply chain system consisting of a manufacturer and a buyer. The buyer sells items to the end customers whose demand follows a normal distribution with a mean of D and standard deviation of σ. The buyer orders the item at a constant lot of size Q from the manufacturer. Once an order is placed, a fixed ordering cost S_b incurs. The manufacturer produces the product in a batch size of Qn with a finite production rate P ($P > D$) with a fixed setup cost S_m. The manufacturer also produces the indirect (EI_1) and direct (EI_2) emission quantities to the atmosphere from its production facilities. Indirect emission is consumed by electricity (e_{co}), steam (s_{co}), heating (h_{co}), cooling (c_{co}) and loss of energy to produce a production quantity. While boiler (generator) directly produces direct emission to the atmosphere and also produces a production quantity. The manufacturer will pay the cost of emissions corresponding to the number of emissions produced and the Government's carbon emission taxes (C_{GHG}). During the production period, when the first Q units have been produced, the manufacturer

may schedule to the third party (freight forwarding services) to pick-up its product. In this policy, the freight will give surcharge per shipment (θ) to the manufacturer and the manufacturer will send the invoice as freight costs to the buyer. The surcharge may consist of the setup cost for the fleet and material handling costs (www.fedex.com). In this policy, the manufacturer will not pay the transportation cost. As a consequence of the pick-up policy, the distance from the location from the freight to the buyer is $(2d_m + d_b)$. We assume the distance between these parties is linear. The freight cost also influences the fuel prices (δ) and fuel consumed by diesel truck (γ). The freight rate, F_x is charged to the buyer. The buyer pays the freight rate to the freight for each shipment weight (W_x) which is scheduled by the freight. In this activity, the freight will produce the transport indirect emission quantity (ET_1). The buyer will receive the lot size of Q with average every D/Q unit of time the inventory level until to zero. The buyer will produce the transport direct emission quantity (ET_2) in which the emission comes from the material handling process, such as fuel of forklift, etc. Similarly, the buyer also pays these quantity emissions with the carbon emission tax (C_{GHG}). The Government made a penalty (ρ) and incentive (η) policies to reduce direct and indirect emissions from manufacturing industry and freight transport. The penalties are given if total emissions have exceeded the Emission Limit Value (ELV), otherwise, if total emissions are below the ELV then the incentive will be provided so that it can be derived using improvement activities. The partial backorder (π_x) and lost sales (π_0) are permitted. The system description is illustrated in Figure 2.
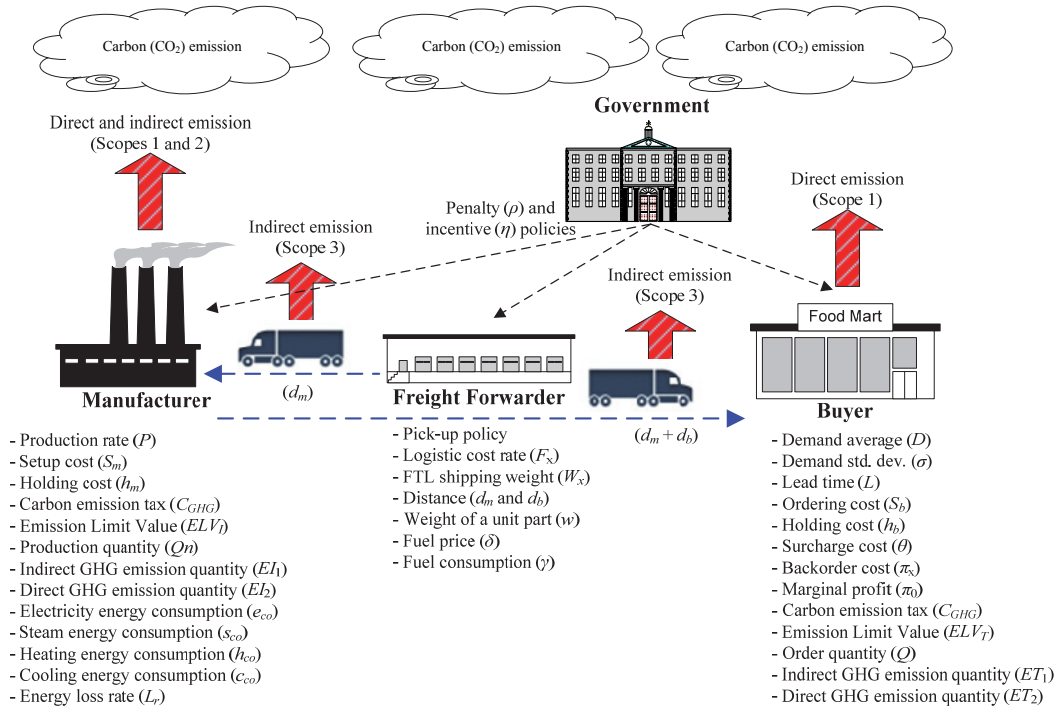
Fig. 2. The overview of problem in this paper

The following parameters and decision variables notation are listed below:

3.2 *General parameters*

D	average demand of the buyer	(units/year)
P	production rate of the manufacturer, $P > D$	(units/year)
σ	standard deviation demand of the buyer	(unit/week)
L	length of the lead time for the buyer	(days)
S_b	buyer's ordering cost per order	($)
S_m	manufacturer's setup cost per setup	($)
h_b	holding cost of the buyer, $h_b > h_m$	($/unit/year)
h_m	holding cost of the manufacturer	($/unit/year)

C_{GHG}	carbon emission tax	(\$/ton CO_2)
ρ	penalty, $\rho \geq \eta$	(\$/year/ton CO_2)
η	incentive	(\$/year/ton CO_2)
ELV_T	transport emission limit value	(ton CO_2)
ELV_I	industrial emission limit value	(ton CO_2)
E_{T1}	transport indirect emission quantity	(ton CO_2)
E_{T2}	transport direct emission quantity	(ton CO_2)
E_{I1}	industrial indirect emission quantity	(ton CO_2)
E_{I2}	industrial direct emission quantity	(ton CO_2)
θ	surcharge per shipment for pick-up policy	(\$)
w	weight of a unit part	(lbs/unit)
α	discount factor for LTL shipments, $0 \leq \alpha \leq 1$	(-)
F_x	the freight rate for full truckload (FTL)	(\$/lb/mile)
F_y	the freight rate for partial load	(\$/lb/mile)
W_x	full truckload (FTL) shipping weight	(lbs)
W_y	actual shipping weight	(lbs)
π_x	backorder cost per unit of the buyer	(\$)
π_0	marginal profit per unit of the buyer	(\$)
β	the backorder ratio, $0 \leq \beta \leq 1$	(-)
$B(r)$	expected demand shortage at the end of the cycle	(units)
X	the lead time demand, which follows a normal distribution with finite mean D_L and standard deviation $\sigma\sqrt{L}$, $X \sim N(D_L, \sigma\sqrt{L})$	(units)
JTC_1	joint total cost without penalty and incentive policies	(\$/year)
JTC_2	joint total cost with penalty and incentive policies	(\$/year)

3.3 *Parameters from transport sector*

δ	fuel price	(\$/liter)
γ	fuel consumed by diesel truck	(liters/mile)
d_b	distance from the freight to the buyer	(miles)
d_m	distance from the manufacturer to the freight	(miles)
Δ_{T1}	transport indirect emission factor	(ton CO_2/liter)
Δ_{T2}	transport direct emission factor	(ton CO_2/lb)

3.4 *Parameters from industry sector*

e_{co}	electricity energy consumption	(Kwh)
s_{co}	steam energy consumption	(Kwh)
h_{co}	heating energy consumption	(Kwh)
c_{co}	cooling energy consumption	(Kwh)
L_r	energy loss rate	(%)
Δ_{I1}	industrial indirect emission factor	(ton CO_2/Kwh)
Δ_{I2}	industrial direct emission factor	(ton CO_2/unit)

3.5 *Decision variables*

Q	order quantity of the buyer	(units)
k	safety factor of the buyer	(-)
n	the number of deliveries per one production cycle (integer)	(times)
TE	total emission quantity	(ton CO_2)

3.6   *Assumptions*

In addition, the following assumptions are made in deriving the model:

1. The model assumes a single item with a single-vendor and a single-buyer inventory system and involves a single freight provider.
2. We consider the pick-up policy which is offered by the freight provider. The product will be picked by the freight and delivered from the manufacturer's location to the buyer's location. In this policy, the buyer will be charged an additional charge (surcharge) with θ (in dollar) by the freight.
3. The product is manufactured with a finite production rate of P, where $P > D$.
4. The buyer orders a lot of size Q and the manufacturer's produce nQ with a finite production rate P in one setup, but ship quantity Q to the buyer over n times. The vendor incurs a setup cost S_m for each production run and the buyer incurs an ordering cost S_b for each order of quantity Q.
5. The demand X during lead time L follows a normal distribution with mean D_L and standard deviation $\sigma\sqrt{L}$.
6. Shortages are allowed with partial backorders and lost sales.
7. All items are purchased Free On Board (F.O.B) origin. The buyer incurs all the freight costs.

4. Model

In this section, we formulate an integrated inventory model with GHG emissions penalty and incentive policies, emission from transport and industry sectors, and stochastic demand.

4.1   *Buyer's total cost per year*

The total cost of the buyer is composed of ordering cost, holding cost, shortage cost, freight cost, surcharge cost and carbon emission cost. These components are evaluated as following:

1. *Ordering cost.*

$$\text{The ordering cost per year} = \frac{D}{Q} S_b \tag{1}$$

2. *Holding cost.* The expected net inventory level just before receipt of an order is $(R - D_L)$, and the expected net inventory level immediately after the successive order is $(Q + R - D_L)$. Hence, the average inventory over the cycle can be approximated by $(Q/2 + R - D_L)$. Therefore, the buyer's expected holding cost per unit time is $h_b(Q/2 + R - D_L)$. Using the same approach as in Montgomery et al. (1973), the expected net inventory level just before receipt of a delivery is $R - D_L + (1 - \beta)B(r)$. The expected shortage quantity at the end of the cycle is given by $B(r) = \sigma\sqrt{L}\psi(k)$, where, $\psi(k) = \phi(k) - k[1 - \Phi(k)]$, and $\emptyset$, Φ denote the standard normal density function (*p.d.f*) and *c.d.f.*, respectively. Where, $k\sigma\sqrt{L} = (R - D_L)$.

$$\text{The holding cost per year} = h_b\left[\frac{Q}{2} + k\sigma\sqrt{L} + (1 - \beta)\sigma\sqrt{L}\psi(k)\right] \tag{2}$$

3. *Shortage cost.* As mentioned earlier, the lead time demand X has a *c.d.f.* with finite mean D_L and standard deviation $\sigma\sqrt{L}$. Shortage occurs when $X > r$, then, the expected shortage quantity at the end of the cycle is given by $B(r)$. Thus, the expected of backorders and lost sales per order is $\beta B(r)$ and $(1 - \beta)B(r)$, respectively.

$$\text{The shortage cost per year} = \frac{D}{Q}[\pi_x\beta + \pi_0(1 - \beta)]\sigma\sqrt{L}\psi(k) \tag{3}$$

4. *Freight cost*. We extended the work of Swenseth and Buffa (1990) and Gurtu et al. (2015) to determine the freight cost. Using the notations: d_m is the distance from the manufacturer to the freight (in miles), d_b is the distance from the freight to the buyer (in miles), δ is the fuel price ($/liter) and γ is the fuel consumption (liters/mile). Let F_x set the lower bound when shipping weights $(W_y \leq W_x)$. Hence, the freight rate (F_y) for the actual shipping weight (W_y) is as follows:

$$F_y = \frac{F_x W_x + \delta \gamma}{W_y} \tag{4}$$

The freight cost rate per pound per mile can be represented by:

$$F = \alpha F_y + (1 - \alpha)\left[F_x + \frac{\delta \gamma}{W_y}\right] \tag{5}$$

Subject to $0 \leq \alpha \leq 1$

Upon substitution of Eq. (4) into Eq. (5) and simplifying, the resulting unit rate is

$$F = F_x + \frac{\delta \gamma}{W_y} + \alpha \left[\frac{F_x(W_x - W_y)}{W_y}\right] \tag{6}$$

By substituting the Eq. (6) into the total freight, we have: (Swenseth & Buffa, 1990; Swenseth & Godfrey, 2002)

$$F_z = \left\{F_x + \frac{\delta \gamma}{W_y} + \alpha \left[\frac{F_x(W_x - W_y)}{W_y}\right]\right\} D(2d_m + d_b)w \tag{7}$$

where the actual shipping weight $(W_y = Qw)$ and 2 represents a pick-up policy from the freight to the manufacturer and from the manufacturer to the buyer.

The freight cost per year $= \frac{D}{Q}[\alpha F_x W_x + \delta \gamma](2d_m + d_b) + D(1 - \alpha)F_x w(2d_m + d_b) \tag{8}$

5. *Surcharge cost*. In this policy, we assume that the freight offers pick-up services (by on call) and the products will be picked from the manufacturer and delivered to the buyer with the surcharge per shipment, θ (in dollar). This fee includes ordering cost by phone call, material handling cost, labor cost, wooden pallet collars etc.

The surcharge cost per year $= \frac{D}{Q}\theta \tag{9}$

6. *Carbon emission cost*. As described in the problem description, transport GHG emissions are divided into two parts: indirect and direct transport emissions, with the notations: Δ_{T1} is transport indirect emission factor (ton CO_2 per liter), γ is the fuel consumption (liters per mile), d_m is the distance from the manufacturer to the freight (in miles), and d_b is the distance from the freight to the buyer (in miles).

Transport indirect emission quantity $ET_1 = \Delta_{T1}\gamma(2d_m + d_b) \tag{10}$

For the transport direct emission quantity, we use the notations: Δ_{T2} is transport direct emission factor (ton CO_2 per lb), w is the weight of unit part (lbs per unit) and Q is order quantity (units).

Transport direct emission quantity $ET_2 = \Delta_{T2}wQ \tag{11}$

The carbon emission tax (C_{GHG}), hence total transport emission cost per year with indirect and direct emissions is given by:

$$\text{Total transport emission cost per year} = \frac{D}{Q}(ET_1 + ET_2)C_{GHG} \tag{12}$$

The Eq. (12) can be rewritten into:

$$\text{Total transport emission cost per year} = D\left[\frac{\Delta_{T1}\gamma(2d_m + d_b)}{Q} + \Delta_{T2}w\right]C_{GHG} \tag{13}$$

Finally, the total cost for the buyer per year without penalty and incentive policies can be formulated by considering Eqs. (1)-(3), Eq. (8), Eq. (9) and Eq. (13). The total cost for the buyer (TC_{b1}). One has:

$$
\begin{aligned}
TC_{b1}(Q,k) = {}& \frac{D}{Q}S_b + h_b\left[\frac{Q}{2} + k\sigma\sqrt{L} + (1-\beta)\sigma\sqrt{L}\psi(k)\right] + \frac{D}{Q}\theta \\
& + \frac{D}{Q}[\pi_x\beta + \pi_0(1-\beta)]\sigma\sqrt{L}\psi(k) + \frac{D}{Q}[\alpha F_x W_x + \delta\gamma](2d_m + d_b) \\
& + D(1-\alpha)F_x w(2d_m + d_b) + D\left[\frac{\Delta_{T1}\gamma(2d_m + d_b)}{Q} + \Delta_{T2}w\right]C_{GHG}
\end{aligned}
\tag{14}
$$

4.2 Manufacturer's total cost per year

Total cost for the manufacturer consists of setup cost, holding cost and carbon emission cost. These components are evaluated as following:

1. *Setup cost.* The manufacturer produces nQ in one production run time. Therefore, the setup cost

   $$\text{per year} = \frac{D}{nQ}S_m \tag{15}$$

2. *Holding cost.* The manufacturer's inventory per cycle can be calculated by subtracting the buyer's accumulated inventory level from the manufacturer's accumulated inventory level. Hence, the manufacturer' average inventory level per year is given by $= \frac{Q}{2}\left[n\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right]$.

   $$\text{The manufacturer's holding cost per year is} = h_m\frac{Q}{2}\left[n\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right] \tag{16}$$

3. *Carbon emission cost.* As the same describe in the buyer's carbon emission, industrial GHG emissions are divided into two parts: indirect and direct emissions. We used the notations: Δ_{I1} is industrial indirect emission factor (ton CO_2 per Kwh), e_{co} is the electricity energy consumption (Kwh), s_{co} is the steam energy consumption (Kwh), h_{co} is the heating energy consumption (Kwh) and c_{co} is the cooling energy consumption (Kwh) and L_r is energy loss rate (%).

   $$\text{Industrial indirect emission quantity } EI_1 = \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})L_r \tag{17}$$

   We use the notations: Δ_{I2} is industrial direct emission factor (ton CO_2 per unit), nQ is production quantity (units) to determine the industrial direct emission quantity.

   $$\text{Industrial direct emission quantity } EI_2 = \Delta_{I2}nQ \tag{18}$$

   Hence, total industrial emission cost per year with indirect and direct emissions is given by:

   $$\text{Total industrial emission cost per year} = \frac{D}{nQ}(EI_1 + EI_2)C_{GHG} \tag{19}$$

   The Eq. (19) can be rewritten into:

   $$\text{Total industrial emission cost per year} = D\left[\frac{\Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})L_r}{nQ} + \Delta_{I2}\right]C_{GHG} \tag{20}$$

Finally, the total cost for the manufacturer per year without penalty and incentive policies can be formulated by considering Eqs. (15-16) and Eq. (20). The total cost for the manufacturer (TC_{m1}). One has:

$$TC_{m1}(Q,n) = \frac{D}{nQ}S_m + h_m\frac{Q}{2}\left[n\left(1-\frac{D}{P}\right) - 1 + \frac{2D}{P}\right] + D\left[\frac{\Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})\,L_r}{nQ} + \Delta_{I2}\right]C_{GHG} \tag{21}$$

Accordingly, the integrated total cost for a single manufacturer and a single buyer inventory system without penalty and incentive policies is the sum of the Eq. (14) and Eq. (21). One has:

$$\begin{aligned}
\min JTC_1(Q,k,n) &= TC_{b1}(Q,k) + TC_{m1}(Q,n)\\
&= \frac{D}{Q}\Bigg\{S_b + \theta + [\alpha F_x W_x + \gamma(\delta + \Delta_{T1}C_{GHG})](2d_m + d_b) + [\pi_x\beta + \pi_0(1-\beta)]\sigma\sqrt{L}\psi(k)\\
&\quad + \frac{S_m + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})\,L_r C_{GHG}}{n}\Bigg\}\\
&\quad + h_b[k\sigma\sqrt{L} + (1-\beta)\sigma\sqrt{L}\psi(k)] + \frac{Q}{2}\Bigg\{h_b + h_m\left[n\left(1-\frac{D}{P}\right) - 1 + \frac{2D}{P}\right]\Bigg\}\\
&\quad + D[(1-\alpha)F_x w(2d_m + d_b) + (\Delta_{T2}w + \Delta_{I2})C_{GHG}]
\end{aligned} \tag{22}$$

4.3 Penalty and incentive policies

To formulate the penalty and incentive policies, the Government sets the overall limit on emission (also called "cap") as a basis value at first. Figure 3 illustrates the penalty and incentive policies.

The transport emission model with the penalty and incentive policies

Fig. 3 describes that if total transport emission exceeds the ELV_T, $(\sum_{i=1}^{2} E_{Ti} > ELV_T)$, the buyer would have to pay an exceed emissions (penalty and loss of incentive) from the gap of $\sum_{i=1}^{2} E_{Ti}$ and ELV_T. Otherwise, if total emission is lower than the ELV_T, $(\sum_{i=1}^{2} E_{Ti} < ELV_T)$ then the buyer will receive the Government's incentive and benefit of the penalty. Furthermore, the transport emission model with the penalty and incentive policies is given by:

$$\tau_T = \rho\left(\sum_{i=1}^{2} E_{Ti} - ELV_T\right) - \eta\left(ELV_T - \sum_{i=1}^{2} E_{Ti}\right) \tag{23}$$
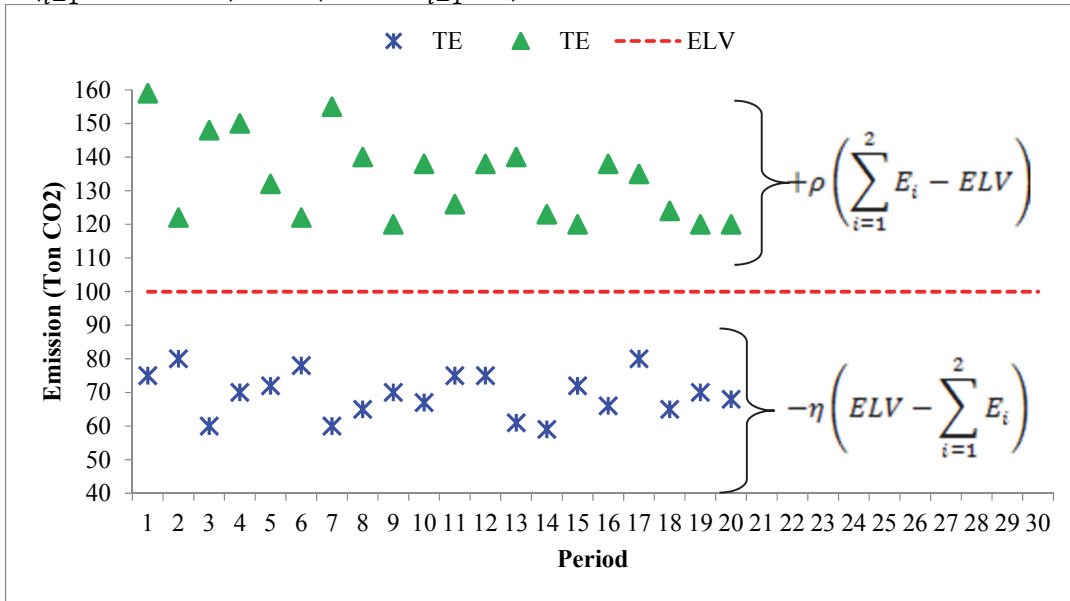

Fig. 3. The illustrated of penalty and incentive formulas

The industrial emission model with the penalty and incentive policies

The penalty and incentive from industry sector will be paid by the manufacturer. Similarly, the model of the industrial emission with the penalty and incentive policies is given by:

$$\tau_I = \rho \left(\sum_{i=1}^{2} E_{Ii} - ELV_I \right) - \eta \left(ELV_I - \sum_{i=1}^{2} E_{Ii} \right) \tag{24}$$

Total transport and industrial emissions with the penalty and incentive policies

Accordingly, the formula of transport and industrial emissions with the penalty and incentive policies is the sum of the Eqs. (23-24). One has:

$$\tau_T + \tau_I = \rho \left(\sum_{i=1}^{2} E_{Ti} - ELV_T \right) - \eta \left(ELV_T - \sum_{i=1}^{2} E_{Ti} \right) + \rho \left(\sum_{i=1}^{2} E_{Ii} - ELV_I \right) - \eta \left(ELV_I - \sum_{i=1}^{2} E_{Ii} \right)$$

$$\tau_T + \tau_I = \rho \sum_{i=1}^{2} E_{Ti} - \rho ELV_T - \eta ELV_T + \eta \sum_{i=1}^{2} E_{Ti} + \rho \sum_{i=1}^{2} E_{Ii} - \rho ELV_I - \eta ELV_I + \eta \sum_{i=1}^{2} E_{Ii}$$

$$\tau_T + \tau_I = -\rho ELV_T - \eta ELV_T - \rho ELV_I - \eta ELV_I + \rho \sum_{i=1}^{2} E_{Ti} + \eta \sum_{i=1}^{2} E_{Ti} + \rho \sum_{i=1}^{2} E_{Ii} + \eta \sum_{i=1}^{2} E_{Ii}$$

$$\tau_T + \tau_I = (\rho + \eta)(-ELV_T - ELV_I) + (\rho + \eta) \left(\sum_{i=1}^{2} E_{Ti} + \sum_{i=1}^{2} E_{Ii} \right)$$

$$\tau_T + \tau_I = (\rho + \eta) \left(\sum_{i=1}^{2} E_{Ti} + \sum_{i=1}^{2} E_{Ii} - ELV_T - ELV_I \right) \tag{25}$$

By substituting the Eqs. (10-11, 17-18) to Eq. (25), the Eq. (25) can be rewritten into:

$$\tau_T + \tau_I = (\rho + \eta)[\Delta_{T1}\gamma(2d_m + d_b) + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co}) L_r + (\Delta_{T2}w + \Delta_{I2}n)Q - ELV_T - ELV_I] \tag{26}$$

Finally, adding the Eq. (26) to the Eq. (22), we find the integrated total cost for a single manufacturer and a single buyer inventory system with the penalty and incentive. One has:

$$\min JTC_2(Q, k, n) = JTC_1(Q, k, n) + \tau_T(Q) + \tau_I(Q, n)$$

$$= \frac{D}{Q} \left\{ S_b + \theta + [\alpha F_x W_x + \gamma(\delta + \Delta_{T1} C_{GHG})](2d_m + d_b) + [\pi_x \beta + \pi_0(1 - \beta)]\sigma\sqrt{L}\psi(k) \right.$$

$$\left. + \frac{S_m + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co}) L_r C_{GHG}}{n} \right\} \tag{27}$$

$$+ h_b \left[k\sigma\sqrt{L} + (1 - \beta)\sigma\sqrt{L}\psi(k) \right] + \frac{Q}{2} \left\{ h_b + h_m \left[n \left(1 - \frac{D}{P} \right) - 1 + \frac{2D}{P} \right] \right\}$$

$$+ D[(1 - \alpha)F_x w(2d_m + d_b) + (\Delta_{T2}w + \Delta_{I2})C_{GHG}]$$

$$+ (\rho + \eta)[\Delta_{T1}\gamma(2d_m + d_b) + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co}) L_r + (\Delta_{T2}w + \Delta_{I2}n)Q - ELV_T - ELV_I]$$

4.4 Solution procedure

Our objective is to find the optimal decision variables which minimize the above functions. For fixed n, we take the partial derivatives of Eq. (22) with respect to Q and k, respectively. The results for the first model, we obtain:

$$\frac{\partial JTC_1(Q,k,n)}{\partial Q} = \frac{-D}{Q^2}\left\{S_b + \theta + [\alpha F_x W_x + \gamma(\delta + \Delta_{T1}C_{GHG})](2d_m + d_b) + [\pi_x\beta + \pi_0(1-\beta)]\sigma\sqrt{L}\psi(k) \right.$$
$$\left. + \frac{S_m + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})\, L_r C_{GHG}}{n}\right\} + \frac{1}{2}\left\{h_b + h_m\left[n\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right]\right\} \tag{28}$$

and

$$\frac{\partial JTC_1(Q,k,n)}{\partial k} = \frac{D}{Q}\{\pi_x\beta + \pi_0(1-\beta)\sigma\sqrt{L}[\Phi(k) - 1]\} + h_b\{\sigma\sqrt{L} + (1-\beta)\sigma\sqrt{L}[\Phi(k) - 1]\} \tag{29}$$

By setting Eq. (27-28) equal to zero and solving for Q and $\Phi(k)$. One has:

$$Q_1^* = \sqrt{\frac{2D\left\{\begin{array}{c}S_b + \theta + [\alpha F_x W_x + \gamma(\delta + \Delta_{T1}C_{GHG})](2d_m + d_b) \\ +[\pi_x\beta + \pi_0(1-\beta)]\sigma\sqrt{L}\psi(k) + \frac{S_m + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})\, L_r C_{GHG}}{n}\end{array}\right\}}{h_b + h_m\left[n\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right]}} \tag{30}$$

and

$$\Phi(k_1^*) = 1 - \frac{h_b Q_1}{[\pi_x\beta + \pi_0(1-\beta)]D + h_b Q_1(1-\beta)} \tag{31}$$

In order to examine the effect of n on $JTC_1(Q,k,n)$, we take the first and the second partial derivatives of Eq. (22) with respect to n. One has:

$$\frac{\partial JTC_1(Q,k,n)}{\partial n} = -\frac{SD}{n^2 Q} + \frac{Q}{2}h_v\left(1 - \frac{D}{P}\right) \tag{32}$$

and

$$\frac{\partial^2 JTC_1(Q,k,n)}{\partial n^2} = 2\frac{S.D}{n^3.Q} > 0 \tag{33}$$

This show that $JTC_1(Q,k,n)$ is a convex function in n, for fixed (Q,k). Thus, the search finding the optimal number of deliveries, n^* is reduced to finding a local optimal solution. In the same way the first model, to obtain the minimum of Eq. (27), take the first partial derivatives of $JTC_2(Q,k,n)$ with respect to Q and k and setting them to zero. One has:

$$Q_2^* = \sqrt{\frac{2D\left\{\begin{array}{c}S_b + \theta + [\alpha F_x W_x + \gamma(\delta + \Delta_{T1}C_{GHG})](2d_m + d_b) \\ +[\pi_x\beta + \pi_0(1-\beta)]\sigma\sqrt{L}\psi(k) + \frac{S_m + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co})\, L_r C_{GHG}}{n}\end{array}\right\}}{h_b + h_m\left[n\left(1 - \frac{D}{P}\right) - 1 + \frac{2D}{P}\right] + 2(\rho + \eta)(\Delta_{T2}w + \Delta_{I2}n)}} \tag{34}$$

and

$$\Phi(k_2^*) = 1 - \frac{h_b Q_2}{[\pi_x\beta + \pi_0(1-\beta)]D + h_b Q_2(1-\beta)} \tag{35}$$

4.5 *Solution algorithm*

The following algorithm is developed to find the optimal values for order quantity, safety factor, total emission, and the optimal number of deliveries in one production cycle.

Step 1   Set $n = 1$.
Step 2   Set $k_0 = 0$ [implies $\psi(k_0) = 0.39894$ and $\Phi(k_0) = 0.50$] for each model.

Step 3   Evaluate the optimal Q^*.

   (Step 3.1) For the first model, find Q_1^* by substituting $\psi(k_0)$ into Eq. (30)

   (Step 3.2) For the second model, find Q_2^* by substituting $\psi(k_0)$ into Eq. (34).

Step 4   Calculate actual shipping weight, $(W_y = Q^* w)$. If $(W_y \leq W_x)$ is satisfied go to Step 5. Otherwise, go to Step 6 if truckload constraint is not satisfied $(W_y > W_x)$.

   (Step 4.1) For the first model, $(W_{y1}^* = Q_1^* w)$.

   (Step 4.2) For the second model, $(W_{y2}^* = Q_2^* w)$.

Step 5   Revised the optimal lot size and go to Step 6.

   (Step 5.1) For the first model, $\left(Q_1^* = \frac{W_x}{w} \right)$.

   (Step 5.2) For the second model, $\left(Q_2^* = \frac{W_x}{w} \right)$.

Step 6   Determine of $\Phi(k_i^*)$ then find k_i from $\Phi(k_i)$ by checking the normal table.

   (Step 6.1) For the first model using Eq. (31).

   (Step 6.2) For the second model using Eq. (35).

Step 7   Repeat Step 2 – 6 until no change occurs in the values of Q and k. The result is denoted by (Q^*, k^*) for both models.

Step 8   Compute the cost functions.

   (Step 8.1) For the first model using Eq. (22).

   (Step 8.2) For the second model using Eq. (27).

Step 9   Set $n = n + 1$, repeat step 2 for both models.

Step 10   Check and evaluate the cost function.

   (Step 10.1) If $JTC_1\left(Q_{1(n_1)}^*, k_{1(n_1)}^*, n_1 \right) \leq JTC_1\left(Q_{1(n_1-1)}^*, k_{1(n_1-1)}^*, n_1 - 1 \right)$, then go to Step 9, otherwise go to step 11 on the first model.

   (Step 10.2) If $JTC_2\left(Q_{2(n_2)}^*, k_{2(n_2)}^*, n_2 \right) \leq JTC_2\left(Q_{2(n_2-1)}^*, k_{2(n_2-1)}^*, n_2 - 1 \right)$, then go to Step 9, otherwise go to step 11 on the second model.

Step 11   The optimal decision variables.

   (Step 11.1) For the first model, $(Q_1^*, k_1^*, n_1^*) = \left(Q_{1(n_1)}^*, k_{1(n_1)}^*, n_1 \right)$, then (Q_1^*, k_1^*, n_1^*) is a set of optimal, therefore the optimal of total emission is $TE_1^* = \Delta_{T1} \gamma (2d_m + d_b) + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co}) L_r + (\Delta_{T2} w + \Delta_{I2} n_1^*) Q_1^*$.

   (Step 11.2) The second model, $(Q_2^*, k_2^*, n_2^*) = \left(Q_{2(n_2)}^*, k_{2(n_2)}^*, n_2 \right)$, then (Q_2^*, k_2^*, n_2^*) is a set of optimal, therefore the optimal of total emission is $TE_2^* = \Delta_{T1} \gamma (2d_m + d_b) + \Delta_{I1}(e_{co} + s_{co} + h_{co} + c_{co}) L_r + (\Delta_{T2} w + \Delta_{I2} n_2^*) Q_2^*$.

5. Numerical example

This section demonstrates of the models to obtain the optimal solution. Table 2 shows the set data for our example. Implementing two models by optimizing the cost function, we found the optimal solutions as given in Table 3. The minimum joint total cost for the first model (without penalty and incentive policies) is \$95,998.58/year with the optimal order quantity, $Q^* = 677{,}67$ units; actual weight, $W_y^* = 14{,}908.77$ lbs; safety factor, $k^* = 2.25$; number of delivery, $n^* = 3$ times, total transport emission quantity, $E_T^* = 37.67$ ton CO_2 and total industrial emission quantity, $E_I^* = 107.10$ ton CO_2. The emissions results show that the total transport emission quantity is below the ELV_T (50 ton CO_2) and the total industrial emission quantity is higher than the ELV_I (100 ton CO_2). With the same parameters, the optimal solutions of the second model (involving the penalty and incentive policies) yields a minimum joint total cost of \$92,586.91/year with $Q^* = 438{,}05$ units; $W_y^* = 9{,}637.17$ lbs; $k^* = 2.42$; $n^* = 4$ times, $E_T^* = 24.50$ ton CO_2 and $E_I^* = 104.39$ ton CO_2. Due to the transport emission quantity below the ELV_T and the industrial emission quantity above the ELV_I, then the impact is the provision of incentives and penalties by the Government to the buyer and the manufacturer, respectively. So, the penalty and incentive policies have contributed in reducing emissions. The second model gives an impact to a decreased transport emission quantity with a saving of 13.18 ton CO_2 (34.98%). It is affected from the actual weight on the second model that is smaller than the actual weight on the first model (9,637.17 < 14,908.77), because the actual

weight is direct emission ($W_y{}^* = Q^*w$). The saving of the industrial emission comes from production quantity (direct emission) on the second model $Q_2{}^*n_2{}^* = 1,752.20$ units that are smaller than the first model of $Q_1{}^*n_1{}^* = 2,033.01$ units with a saving of 2.71 ton CO_2 (2.53%). The saving of total emission quantity is 15.89 ton CO_2 (10.97%). The joint total cost saving on both models is \$3,411.67 (3.55%).

Table 2
Parameters and values for numerical example

	Parameters	Unit	Values
General	1. Average of demand (D)	units/year	10,000
	2. Production rate (P)	units/year	40,000
	3. Standard deviation of demand (σ)	unit/week	7
	4. Lead time (L)	days	56
	5. Buyer's ordering cost per order (S_b)	\$	30
	6. Manufacturing setup cost per setup (S_m)	\$	3,600
	7. Buyer's holding cost (h_b)	\$/unit/year	45
	8. Manufacturer's holding cost (h_m)	\$/unit/year	38
	9. Carbon emission tax (C_{GHG})	\$/ton CO_2	20
	10. Penalty (ρ)	\$/year/ton CO_2	300
	11. Incentive (η)	\$/year/ton CO_2	125
	12. Transport emission limit value (ELV_T)	ton CO_2	50
	13. Industrial emission limit value (ELV_I)	ton CO_2	100
	14. Buyer's surcharge of pick-up per shipment (θ)	\$	14
	15. Weight of a unit part (w)	lbs/unit	22
	16. Discount factor for LTL shipment (α)	-	0.11246
	17. Freight rate (F_x)	\$/lb/mile	0.000040217
	18. Full truckload shipping weight (W_x)	lbs	46,000
	19. Backorder cost (π_x)	\$	100
	20. Marginal profit (π_0)	\$	300
	21. Backorder ratio (β)	-	0.25
Transport sector	1. Fuel price (δ)	\$/liter	1.02
	2. Fuel consumption (γ)	liters/mile	0.63569
	3. Distance from the freight to the buyer (d_b)	miles	600
	4. Distance from the manufacturer to the freight (d_m)	miles	50
	5. Transport indirect emission factor (Δ_{T1})	ton CO_2/liter	0.01268
	6. Transport direct emission factor (Δ_{T2})	ton CO_2/lb	0.00250
Industry sector	1. Electricity energy consumption (e_{co})	Kwh	154,556
	2. Steam energy consumption (s_{co})	Kwh	115,917
	3. Heating energy consumption (h_{co})	Kwh	38,639
	4. Cooling energy consumption (c_{co})	Kwh	77,278
	5. Energy loss rate (L_r)	-	1 %
	6. Industrial indirect emission factor (Δ_{I1})	ton CO_2/Kwh	0.02264
	7. Industrial direct emission factor (Δ_{I2})	ton CO_2/unit	0.00965

Table 3
The comparison of model 1 and model 2

	Model 1	Model 2
Order quantity (units)	677.67	438.05
Actual weight (lbs)	14,908.77	9,637.17
Safety factor	2.25	2.42
Number of delivery	3	4
Total transport emission quantity (ton CO_2)	37.67	24.50
Total industrial emission quantity (ton CO_2)	107.10	104.39
Total emission (ton CO_2)	144.77	128.88
Total cost of buyer (\$/year)	45,222.49	37,454.28
Total cost of manufacturer (\$/year)	50,776.08	55,132.63
Total cost (\$/year)	95,998.58	92,586.91
[a]Saving of total emission [ton CO_2, (%)]		15.89; (10.97%)
[b]Saving of total cost [\$/year, (%)]		3,411.67; (3.55%)

[a] ($TE_1 - TE_2$) / TE_1 x 100%   [b] ($JTC_1 - JTC_2$) / JTC_1 x 100%

We compared and analyzed the results of independent and integrated policies. Table 4 shows that the total emission for an integrated policy is higher than the independent policy on the first model. A high value on total emission on an integrated policy is contributed from increasing of transport and industry decision variables simultaneously. It can be understood that the optimal actual weight transported on integrated policy (14,908.77 units) is higher than independent policy (12.903.51 lbs) in which both are derived from the optimal order quantity. It is the same in production quantity of integrated policy that is higher than independent policy. The integrated policy generates higher order quantity, aiming to reduce joint total cost. The total cost of independent and integrated policies are $96,784.60/year and $95,998.58/year, respectively. Therefore, the integrated policy gives total cost saving of $786.03/year or 0.81%. The second model has a similar discussion with cost saving in the amount of 0.24%.

Table 4
The comparison of independent and integrated policies for model 1 and model 2

	Model 1		Model 2	
	Independent	Integrated	Independent	Integrated
Order quantity (units)	586.52	677.67	409.23	438.05
Actual weight (lbs)	12,903.51	14,908.77	9,003.04	9,637.17
Safety factor	2.31	2.25	2.44	2.42
Number of delivery	3	3	4	4
Total transport emission quantity (ton CO_2)	32.66	37.67	22.91	24.50
Total industrial emission quantity (ton CO_2)	104.46	107.10	103.27	104.39
Total emission (ton CO_2)	137.12	144.77	126.19	128.88
Total cost of buyer ($/year)	44,949.96	45,222.49	37,368.00	37,454.28
Total cost of manufacturer ($/year)	51,834.64	50,776.08	55,441.04	55,132.63
Total cost ($/year)	96,784.60	95,998.58	92,809.03	92,586.91
[a]Saving of total emission [ton CO_2, (%)]		-7.66; (-5.58%)		-2.7; (-2.14%)
[b]Saving of total cost [$/year, (%)]		786.03; (0.81%)		222.13; (0.24%)

[a] $(TE_{ind} - TE_{int}) / TE_{ind}$ x 100%   [b] $(TC_{ind} - JTC) / TC_{ind}$ x 100%

In the next case, we included the freight schedule data and illustrated the above solution procedure. Table 5 presents the actual freight rate schedule data by considering shipping weight and distance. The data were adopted from Swenseth and Godfrey (2002) and Leaveano (2014b). The freight rates were redefined from the freight rate per pound to freight rate per pound per mile. For instance, we assume FTL can be delivered 600 miles with weight equal and more than 18,257 lbs and freight cost is a constant charge ($1,110/shipment). Therefore, the freight rate per pound per mile is obtained by dividing freight rate per shipment with the highest break point and distance. Unlike the case of 10,000 - 18,000 lbs, the freight rate per pound is a variable rate based on the load transported by the LTL. The freight rate per pound per mile can be obtained by dividing freight rate per pound with distance.

Table 5
The freight rate schedule data

Weight break	F_x / lb	F_x / lb/ mile
1 – 227 lb[*]	$40	$0.000293685
228 – 420 lb	$0.176/lb	$0.000293333
421 – 499 lb[*]	$74	$0.000247161
500 – 932 lb	$0.148/lb	$0.000246666
933 – 999 lb[*]	$138	$0.000230230
1,000 – 1,855 lb	$0.138/lb	$0.000230000
1,856 – 1,999 lb[*]	$256	$0.000213440
2,000 – 4,749 lb	$0.128/lb	$0.000213333
4,750 – 9,999 lb[*]	$608	$0.000101343
10,000 – 18,256 lb	$0.0608/lb	$0.000101333
18,257 – more[*]	$1,110	$0.000040217

[*] the fixed logistic rate

We discussed the effect of various full truckload capacities (W_x) from 25,000; 20,000, 15,000; 10,000; 7,500 and 5,000 lbs. The results for this example are summarized in Table 6. The results obtained for various values of the full truckload capacity are lower total emission, especially emission from the transport sector. However, the opposite effect on the total cost will increase. The increase in the total costs is due to an increase in the manufacturer's setup and emission. If the full truckload capacity is decreased gradually then it will give an opportunity for the manufacturer to increase its production setup. For instance on the 2nd model, $W_x = 7,500$ and 5,000 lbs, the results $n^* = 5$ times and 8 times, respectively. Hence, the impact is the manufacturer's emission also increased (103.93 to 105.02 ton CO_2). Because the emission has exceeded from ELV_I, then the penalty will be given to the manufacturer.

Table 6
The resulted and compared of $W_x = 25,000$; 20,000; 15,000; 10,000; 7,500; and 5,000 lbs

	$W_x = 25,000$ lbs		$W_x = 20,000$ lbs	
	Model 1	Model 2	Model 1	Model 2
Order quantity (units)	668.77	431.06	666.64	429.38
Actual weight (lbs)	14,713.04	9,483.35	14,666.05	9,446.36
Safety factor	2.26	2.42	2.26	2.42
Number of delivery	3	4	3	4
Total transport emission quantity (ton CO_2)	37.19	24.11	37.07	24.02
Total industrial emission quantity (ton CO_2)	106.84	104.12	106.78	104.05
Total emission (ton CO_2)	144.03	128.23	143.85	128.07
Total cost of buyer ($/year)	44,180.69	35,875.94	43,929.21	35,493.95
Total cost of manufacturer ($/year)	50,830.32	55,181.02	50,844.73	55,195.06
Total cost ($/year)	95,011.01	91,056.96	94,773.94	90,689.01
[a]Saving of total emission [ton CO_2, (%)]		15.8; (10.97%)		15.78; (10.97%)
[b]Saving of total cost [$/year, (%)]		3,954.06; (4.16%)		4,084.93; (4.31%)
	$W_x = 15,000$ lbs		$W_x = 10,000$ lbs	
	Model 1	Model 2	Model 1	Model 2
Order quantity (units)	674.21	435.33	454.55	431.13
Actual weight (lbs)	14,832.60	9,577.37	10,000.00	9,484.80
Safety factor	2.26	2.42	2.40	2.42
Number of delivery	3	4	4	4
Total transport emission quantity (ton CO_2)	37.48	24.35	25.40	24.12
Total industrial emission quantity (ton CO_2)	107.00	104.28	105.02	104.12
Total emission (ton CO_2)	144.48	128.63	130.43	128.24
Total cost of buyer ($/year)	53,171.58	45,195.90	52,704.96	44,244.31
Total cost of manufacturer ($/year)	50,796.09	55,149.55	52,943.57	55,180.48
Total cost ($/year)	103,967.67	100,345.45	105,648.53	99,424.80
[a]Saving of total emission [ton CO_2, (%)]		15.86; (10.97%)		2.2; (1.68%)
[b]Saving of total cost [$/year, (%)]		3,622.22; (3.48%)		6,223.74; (5.89%)
	$W_x = 7,500$ lbs		$W_x = 5,000$ lbs	
	Model 1	Model 2	Model 1	Model 2
Order quantity (units)	340.91	340.91	227.27	227.27
Actual weight (lbs)	7,500.00	7,500.00	5,000.00	5,000.00
Safety factor	2.51	2.51	2.65	2.65
Number of delivery	6	5	9	8
Total transport emission quantity (ton CO_2)	19.15	19.15	12.90	12.90
Total industrial emission quantity (ton CO_2)	107.22	103.93	107.22	105.02
Total emission (ton CO_2)	126.37	123.08	120.12	117.93
Total cost of buyer ($/year)	54,711.70	43,828.47	61,226.03	47,686.54
Total cost of manufacturer ($/year)	53,992.56	56,034.52	55,072.11	57,237.92
Total cost ($/year)	108,704.27	99,862.98	116,298.14	104,924.47
[a]Saving of total emission [ton CO_2, (%)]		3.29; (2.6%)		2.2; (1.83%)
[b]Saving of total cost [$/year, (%)]		8,841.29; (8.13%)		11,373.68; (9.78%)

[a] $(TE_1 - TE_2) / TE_1$ x 100%   [b] $(JTC_1 - JTC_2) / JTC_1$ x 100%

6. Analysis and discussion

In this section, we studied and analyzed the effect of various parameters to determining the optimal decision variables such as the optimal order quantity, safety factor, the number of deliveries and total

emission and subsequently on joint total cost for both models. The parameter dividing 3 categories, there are the general parameter, transport sector and industrial sector (Table 7).

Table 7
Categories of sensitivity parameter

General parameter	Transport sector	Industrial sector
1. Penalty	1. Fuel price	1. Loss rate (%)
2. Incentive	2. Fuel consumption	2. Indirect industry emission factor
3. Carbon emission tax	3. Distance	3. Direct industry emission factor
4. Emission limit value	4. Indirect transport emission factor	
5. Production rate	5. Direct transport emission factor	
6. Average of demand		
7. Standard deviation of demand		

6.1 Sensitivity of general parameters

6.1.1 Effect of changing in the Government's penalties and incentives

We analyzed the effect of changing in the penalty on total emissions and total costs. From the assumptions used in the development model that has been described earlier, the Government's penalty should be larger than the Government's incentive. We use incentive \$125/year/ton CO_2. So, the penalties used in this analysis are 125, 150, 200, 250, 350, 500, 700, 1000, 1200 and 1500 (\$/year/ton CO_2). The effects of changing in the penalty on the decision variables and total costs are shown in Table 8.

Table 8
The effect of changing in penalties and incentives on decision variables and total cost

Penalty	Model 1					Model 2					Saving	
	Q_1^*	k_1^*	n	TE_1^*	JTC_1	Q_2^*	k_2^*	n_2^*	TE_2^*	JTC_2	TE [a)]	JTC [b)]
125	677.67	2.25	3	144.77	95,998.58	577.24	2.31	3	136.34	94,863.29	8.44 (5.82%)	1,135.3 (1.18%)
150	677.67	2.25	3	144.77	95,998.58	569.47	2.32	3	135.69	94,644.58	9.09 (6.27%)	1,354 (1.41%)
200	677.67	2.25	3	144.77	95,998.58	458.08	2.40	4	130.76	94,082.97	14.02 (9.68%)	1,915.61 (2%)
250	677.67	2.25	3	144.77	95,998.58	447.73	2.41	4	129.79	93,358.36	14.99 (10.35%)	2,640.22 (2.75%)
350	677.67	2.25	3	144.77	95,998.58	428.97	2.42	4	128.03	91,771.59	16.74 (11.56%)	4,227 (4.4%)
500	677.67	2.25	3	144.77	95,998.58	404.79	2.44	4	125.77	89,087.84	19.01 (13.13%)	6,910.74 (7.2%)
700	677.67	2.25	3	144.77	95,998.58	378.10	2.47	4	123.27	85,031.39	21.51 (14.85%)	10,967.19 (11.42%)
1000	677.67	2.25	3	144.77	95,998.58	302.58	2.55	5	119.12	77,987.52	25.65 (17.72%)	18,011.06 (18.76%)
1200	677.67	2.25	3	144.77	95,998.58	288.07	2.56	5	117.62	72,706.51	27.15 (18.75%)	23,292.07 (24.26%)
1500	677.67	2.25	3	144.77	95,998.58	269.74	2.59	5	115.73	64,272.62	29.04 (20.06%)	31,725.96 (33.05%)

| Incentive	Model 1					Model 2					Saving	
	Q_1^*	k_1^*	n	TE_1^*	JTC_1	Q_2^*	k_2^*	n_2^*	TE_2^*	JTC_2	TE [a)]	JTC [b)]
5	677.67	2.25	3	144.77	95,998.58	462.43	2.40	4	131.17	94,358.97	13.61 (9.4%)	1,639.61 (1.71%)
10	677.67	2.25	3	144.77	95,998.58	461.33	2.40	4	131.06	94,290.74	13.71 (9.47%)	1,707.85 (1.78%)
15	677.67	2.25	3	144.77	95,998.58	460.24	2.40	4	130.96	94,221.99	13.82 (9.54%)	1,776.59 (1.85%)
25	677.67	2.25	3	144.77	95,998.58	458.08	2.40	4	130.76	94,082.97	14.02 (9.68%)	1,915.61 (2%)
50	677.67	2.25	3	144.77	95,998.58	452.82	2.40	4	130.27	93,726.72	14.51 (10.02%)	2,271.86 (2.37%)
75	677.67	2.25	3	144.77	95,998.58	447.73	2.41	4	129.79	93,358.36	14.99 (10.35%)	2,640.22 (2.75%)
100	677.67	2.25	3	144.77	95,998.58	442.81	2.41	4	129.33	92,978.30	15.45 (10.67%)	3,020.29 (3.15%)
125	677.67	2.25	3	144.77	95,998.58	438.05	2.42	4	128.88	92,586.91	15.89 (10.97%)	3,411.67 (3.55%)
250	677.67	2.25	3	144.77	95,998.58	416.36	2.43	4	126.85	90,472.12	17.92 (12.38%)	5,526.47 (5.76%)
300	677.67	2.25	3	144.77	95,998.58	408.54	2.44	4	126.12	89,558.24	18.66 (12.88%)	6,440.34 (6.71%)

[a)] $(TE_1 - TE_2) / TE_1$ x 100%   [b)] $(JTC_1 - JTC_2) / JTC_1$ x 100%
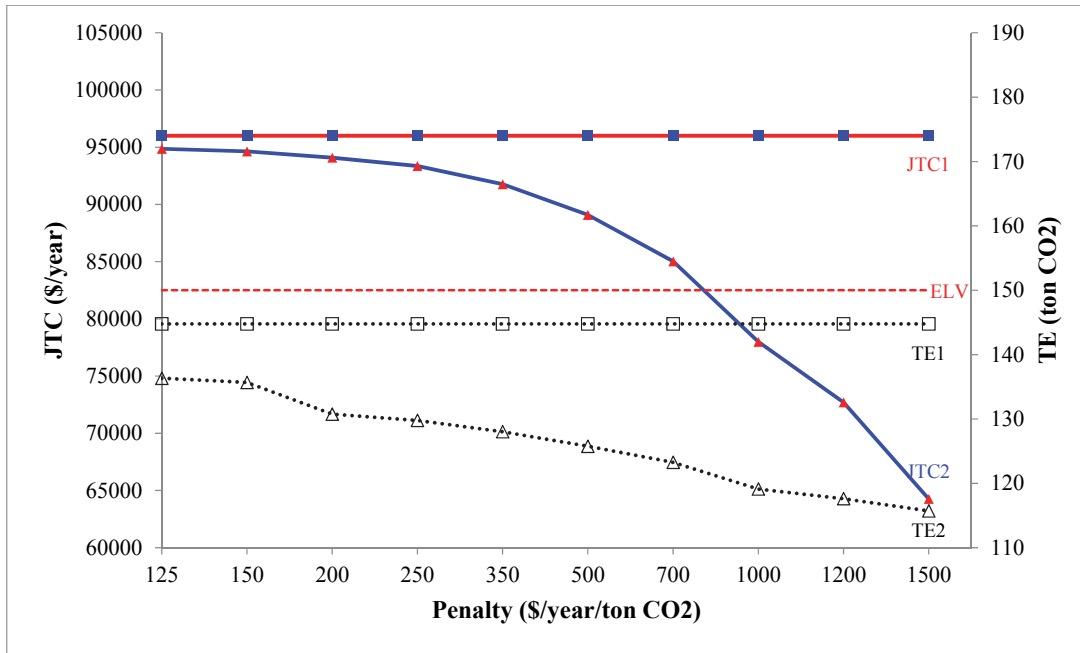
Fig. 4. The effect of changing in penalty on total cost and total emission

In Fig. 4, it can be observed that the penalty policy can reduce total emission and total cost on the second model. As we know, the first model is not considered as the penalty policy; hence the results show that the total emission and total cost are the constant rates. The comparison of these models produces total emission saving from 5% to 20% and total cost saving from 1% to 33%. So, we conclude that the Government's penalty will give impact on the reduction in total emission and total cost of the parties.
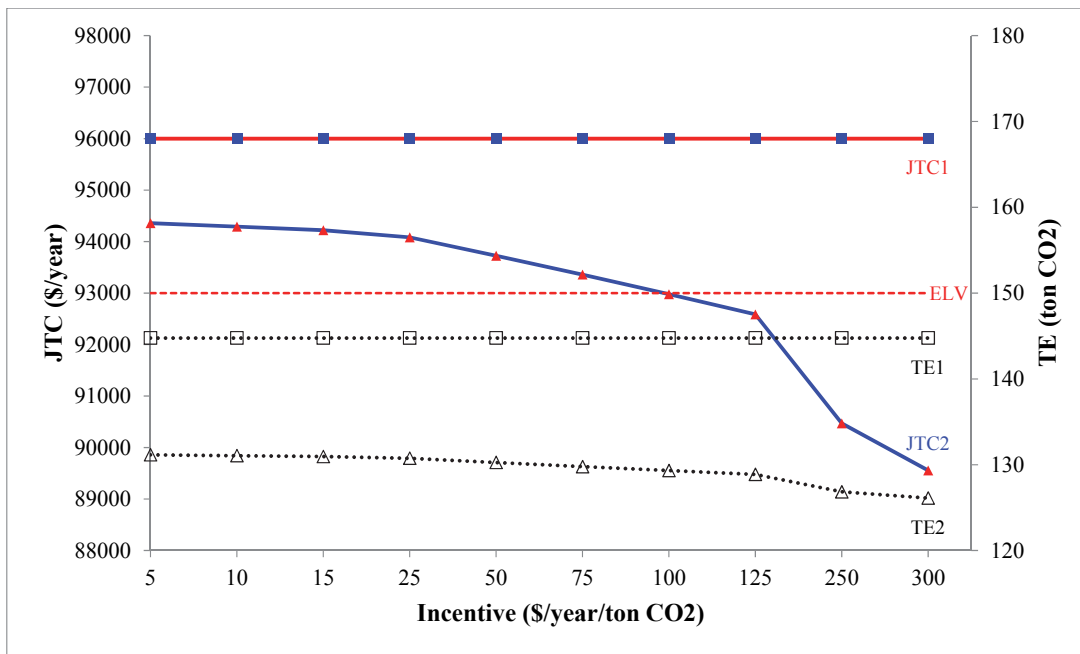
Fig. 5. The effect of changing in incentive on total cost and total GHG emission

Table 8 shows the effect of varying the incentives to determine the decision variables and total costs. In contrast to the penalty policy, the incentive should be lower than the penalty. The penalty, in this case, is $300/year/ton CO_2. Hence, the incentives used in this analysis are 5, 10, to 300. Fig. 5 shows that the second model produces the total emission, and the total cost is lower than without penalty and incentive policies. Thus, we conclude with the same penalty conclusion that the Government's incentive can reduce the total emission and the total cost with saving on total emission and total cost of 9% - 13% and 1% - 6%, respectively.

6.1.2 Effect of changing in carbon emission tax

Carbon emission tax has an impact to determining the amount of transport and industrial emissions and total costs on both the models. The parties will pay a carbon emission tax ($/ton CO_2) on how much GHG emission produced by transport and industrial sectors. In this case, we used the initially of a carbon tax of $20/ton CO_2 and total ELV of 150 ton CO_2 (ELV_I = 100 ton CO_2 and ELV_T = 50 ton CO_2). The behavior of the total emission and total cost for both models is shown in Figure 6. In this experiment, the carbon tax is associated with the optimal order quantity, and it affects the total cost and total emission. In the case when carbon taxes are more $20/ton CO_2, the impact is the increase in the total emission and total cost, simultaneously. The carbon tax is $55/ton CO_2 will cause the second model to be inefficient compared to the first model. Furthermore, the increase in carbon tax also leads to a large gap of the total emission between the first and second model (saving of 11% - 17%). It is affected by penalty and incentive imposed on the second model. Finally, we noted that the carbon emission tax influences the total emission and total cost.
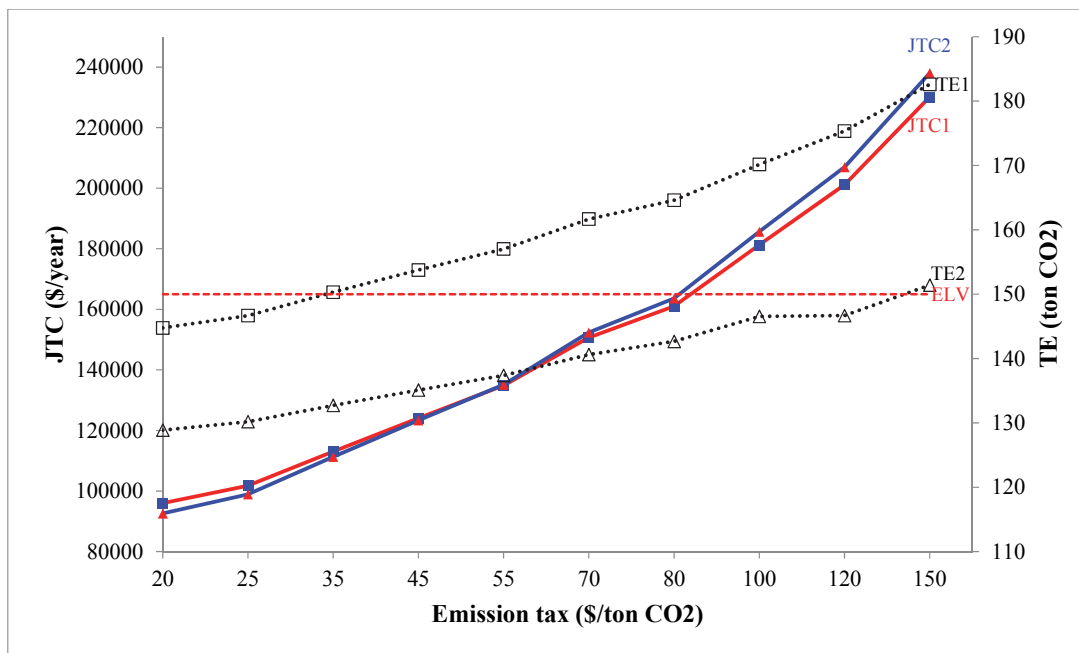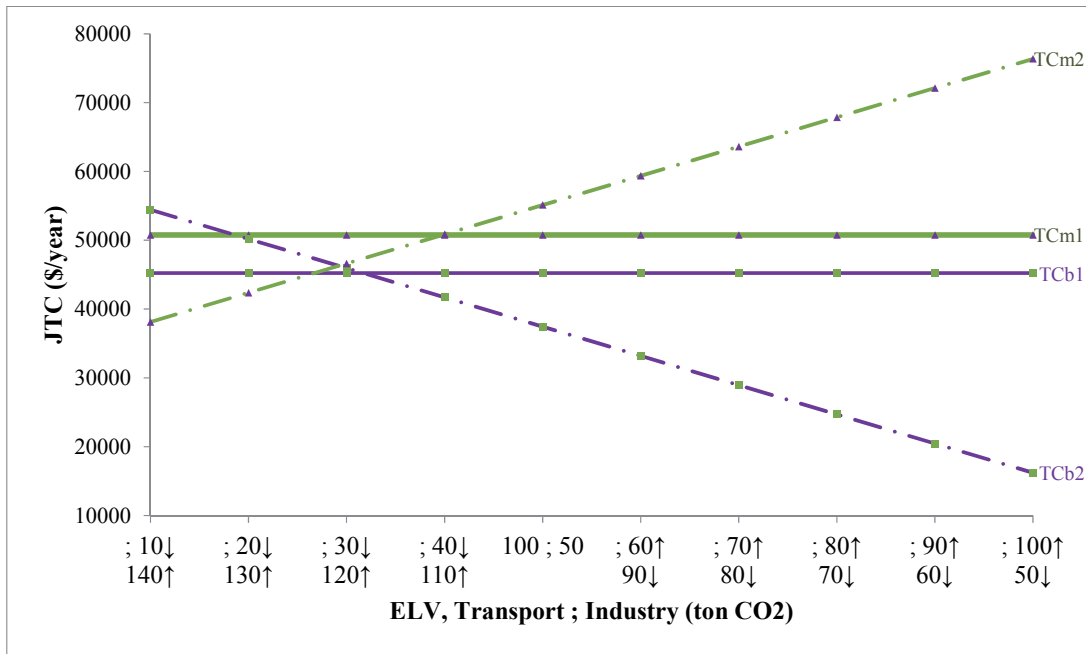

Fig. 6. The effect of changing in carbon emission tax on total cost and total GHG emission

6.1.3 Effect of changing in Emission Limit Value

Here, we studied the effect of varying ELV from transport and industry sectors. In this case, we set total ELV by 150 ton CO_2. The values of ELV transport start from 10 to 100 ton CO_2 (low to high) and contrary to the values of ELV industry start from 140 to 50 ton CO_2 (high to low). Figure 7 portrays a simple relationship between total cost and two ELVs. Based on the ELV transport low value and the ELV industry high value, the impact is the total cost of the buyer and the manufacturer will be increased and decreased, respectively. However, for a high value of ELV transport and low value of ELV industry, the impact is the total cost of the buyer and the manufacturer will be decreased and increased, respectively. There is a

cutting point representing the trade-off among total cost of the buyer and the manufacturer and the values of *ELV*.

Fig. 7. The effect of changing in ELV on total cost and total emission

6.1.4 Effect of changing in production rate

In this example, we discussed and investigated the varying values of production rate. As shown in Figure 8, the increase in production rate will make the total cost of the both models increase. Likewise, the total emission will also increase. The increase in the total emission is influenced by a large increase in the transport emission while the industrial emission declines. It affects to an increase in the buyer's holding cost, carbon emission cost, and penalty, but the manufacturer's holding cost and carbon emission cost and penalty will be decreased.
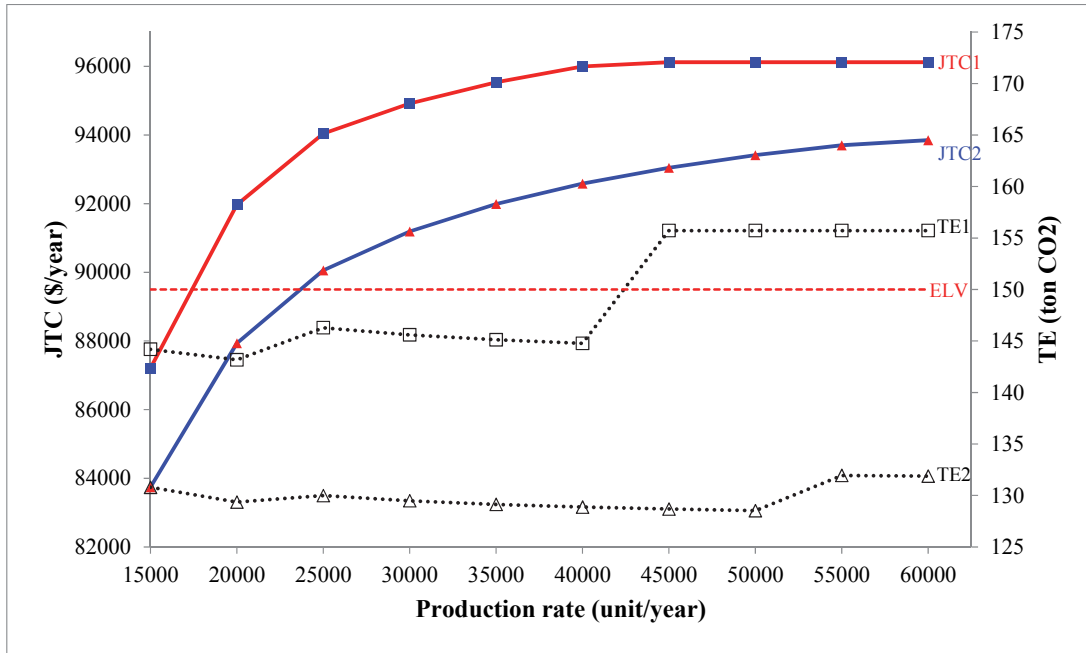
Fig. 8. The effect of changing in production rate on total cost and total emission

6.1.5 Effect of changing in average and standard deviation of demand

In the Fig. 9 and Fig. 10 show the behavior of the stochastic environment. We may see that if the average and standard deviation rises, then the total cost will also elevate in both models. If the demand average increase, the buyer's holding cost, carbon cost and safety stock on the both models will also increase. In contrast to demand standard deviation, having more demand standard deviation will affect to reduce the buyer's holding and carbon costs, and safety stock is pretty much to handle demand variation.
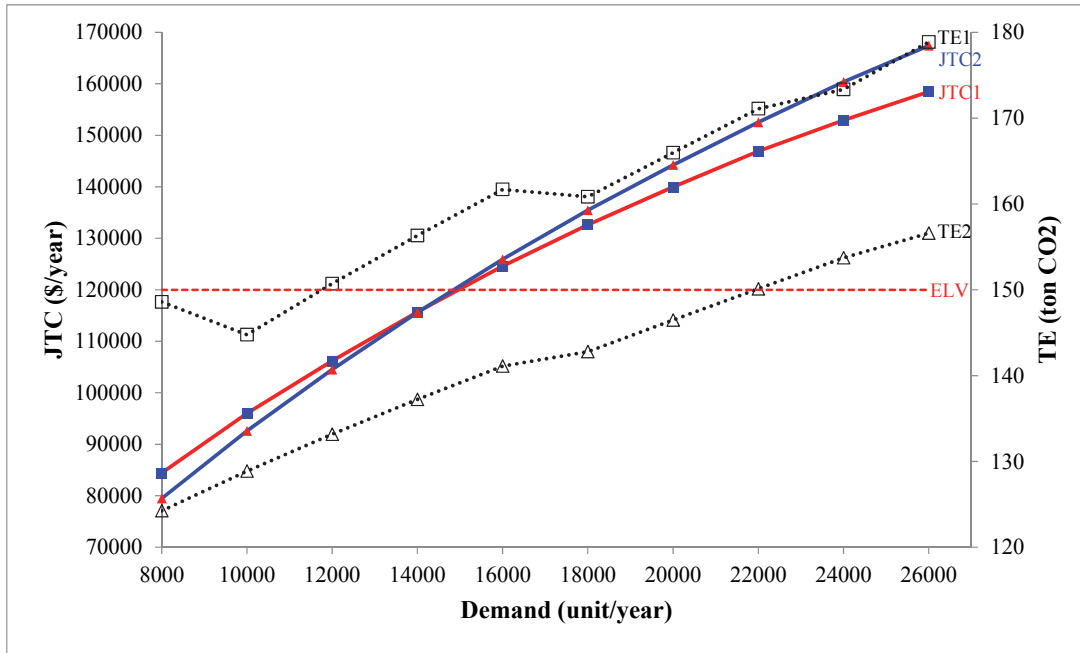
Fig. 9. Effect of changing in demand average on total cost and total emission
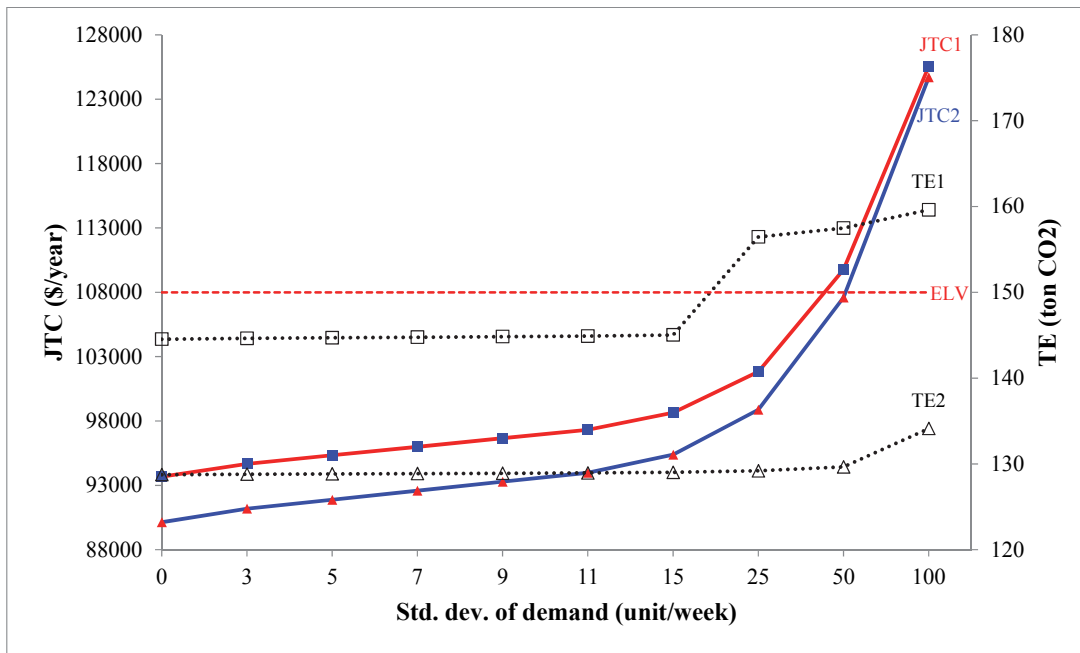
Fig. 10. Effect of changing in demand standard deviation on total cost and total emission

6.2 Sensitivity parameter from the transport sector

Figs. (11-15) show the effect of varying parameters from the transport sector, such as fuel price and consumption, distances, transport direct and indirect factors on total emissions and total cost of a supply chain. In the second model, the penalty and incentive policies are considered. The graphs show that the cost can be significantly increased by distances and direct emission factor and the second model can reduce total cost and total emission. The increase in total cost comes from the buyer's cost, otherwise the manufacturer's cost.
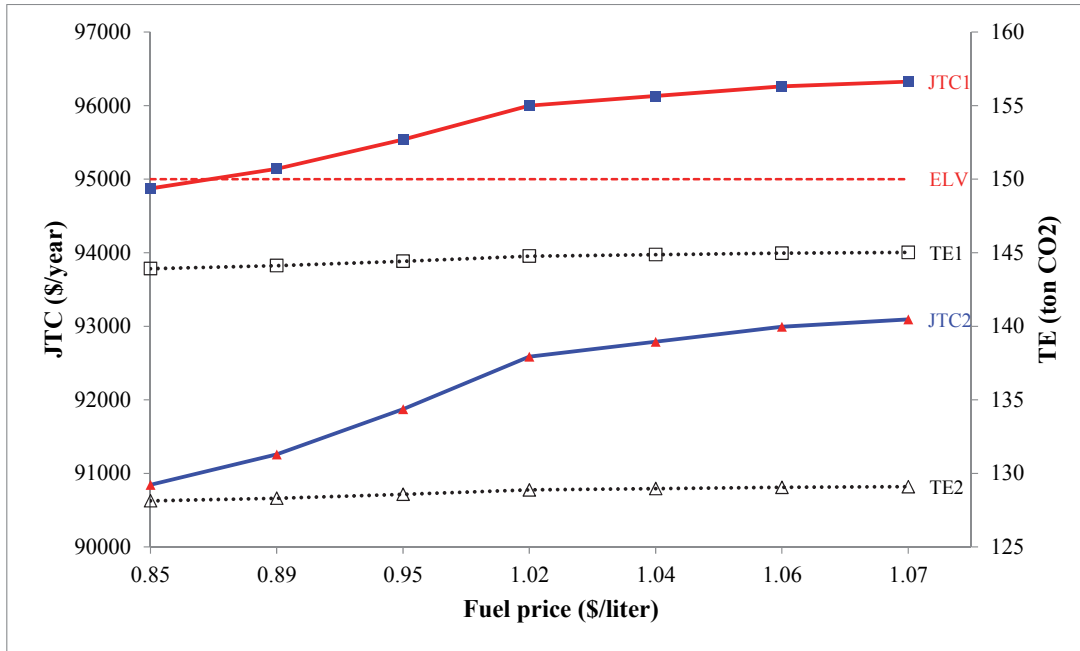
Fig. 11. Effect of changing in fuel price on total cost and emission
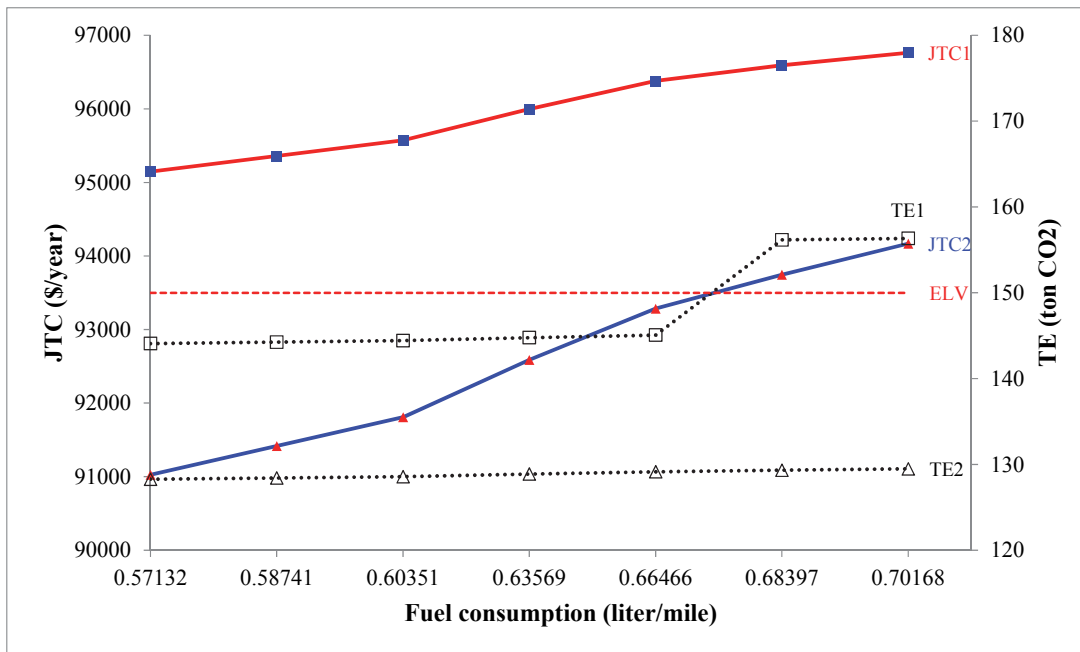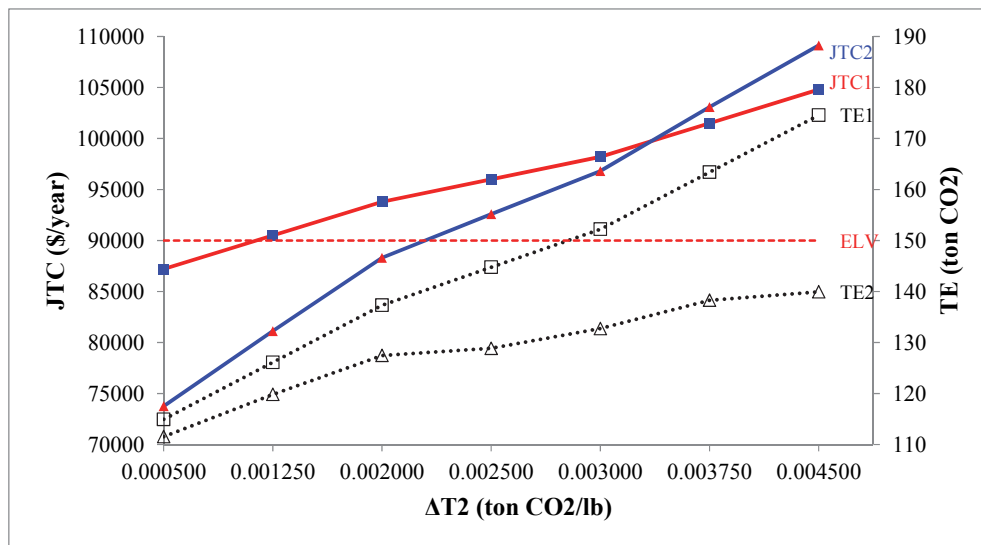

Fig. 12. Effect of changing in fuel consumption on total cost and total emission
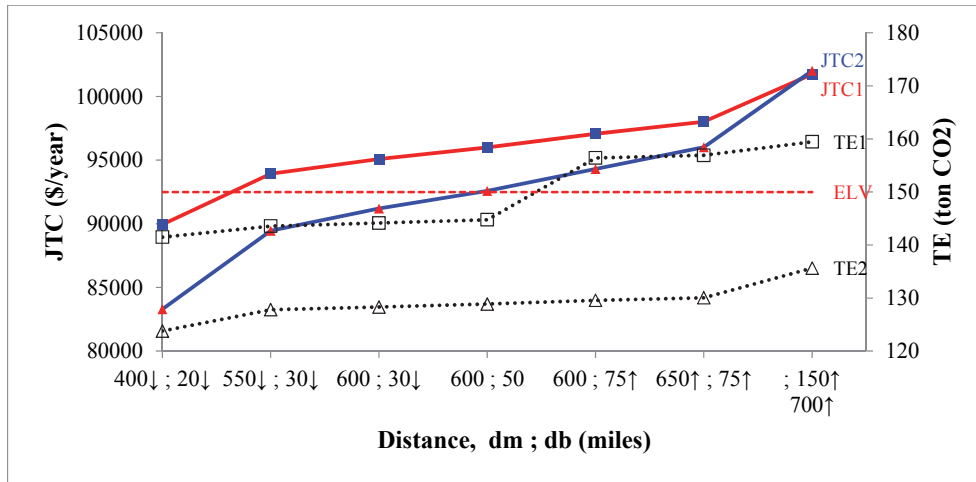
Fig. 13. Effect of changing in distance on total cost and total emission
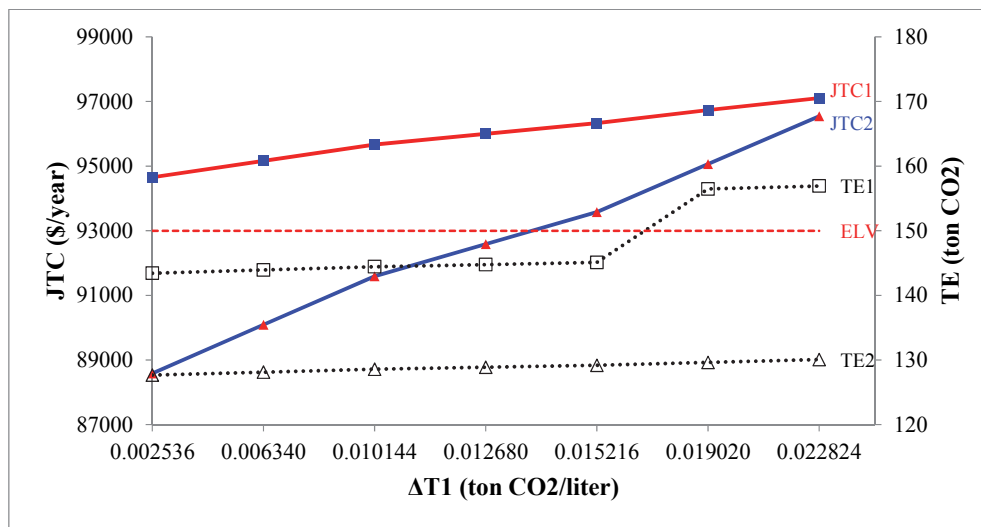
Fig. 14. Effect of changing in transport indirect emission factor on total cost and total emission

Fig. 15. Effect of changing in transport direct emission factor on total emission

6.3 *Sensitivity parameter from the industry sector*

The observations of the varying parameter from industrial parameters, an especially loss rate of energy (electricity, steam, heating, and cooling), industrial indirect and direct emissions factors on total cost and total emission are illustrated in Figs. (16-18. In this case, the total cost is affected by the increase in the optimal production quantity and total industrial emission; hence the impacts on the total cost of the manufacturer are the manufacturer's holding cost, setup cost, carbon emission cost and penalty cost. As we can see, the total cost can be significantly increased by the industrial direct emission factor. Finally, we concluded that these parameters contributed to the increase in total emission and total cost.
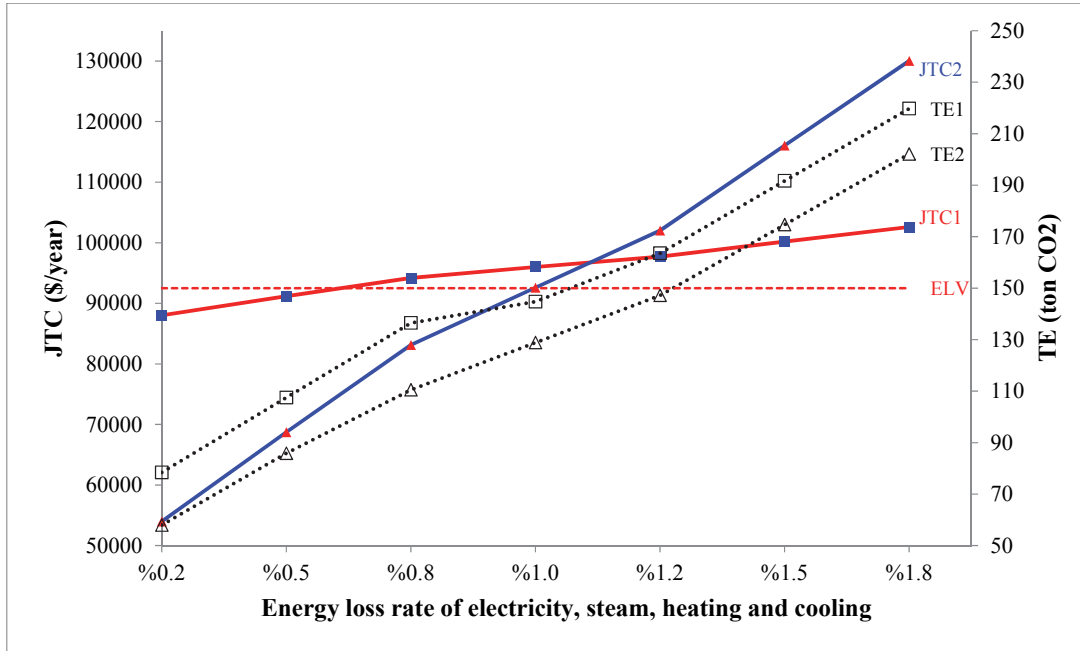

Fig. 16. Effect of changing in loss rate of electricity, steam, heating and cooling on total cost and total emission
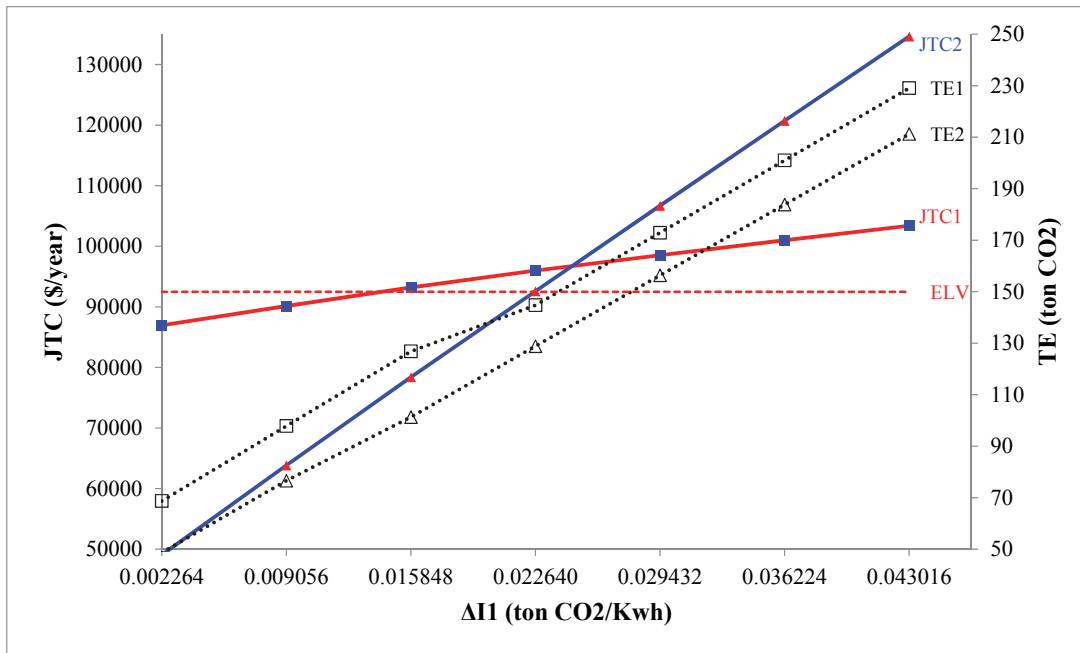

Fig. 17. Effect of changing in industrial indirect emission factor on total cost and total emission
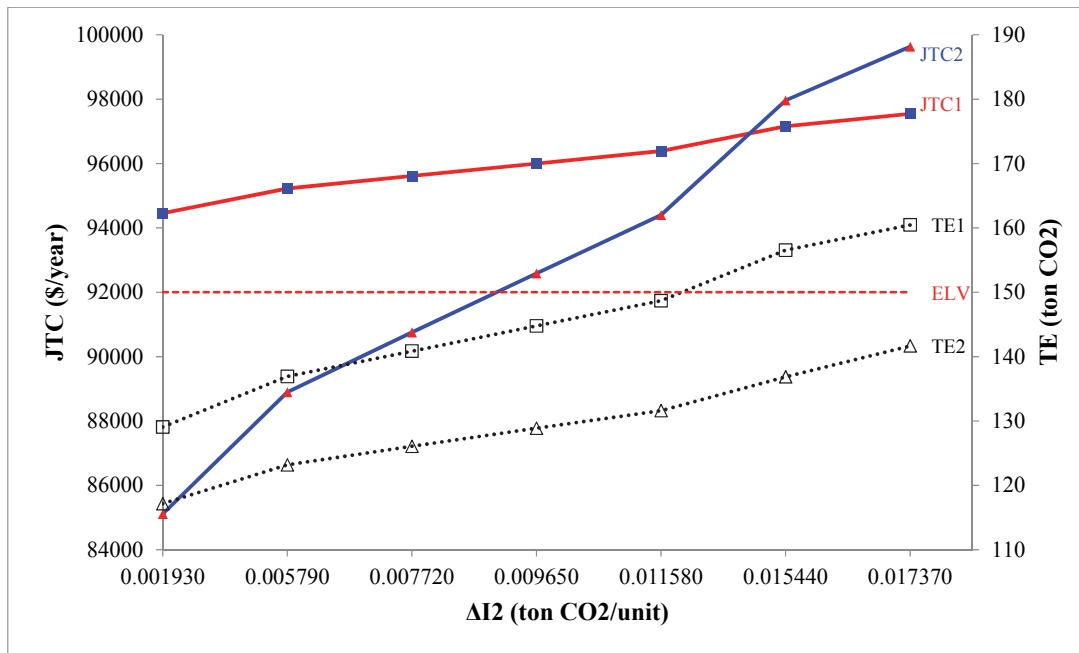
Fig. 18. Effect of changing in industrial direct emission factor on total cost and total emission

7. Conclusion

In this study, we formulated a supply chain inventory model considering carbon emission tax, the penalty and incentive policies. Here, we also considered stochastic demand and industrial and transport GHG emissions. The numerical example and analysis showed that these policies and stochastic environment can influence the decision-makers in determining the optimal order quantity and reduce total emission resulting from transport and industrial sectors. We also examined the relationship between relevant parameters of these sectors and the total emission associated with total cost. Significant cost savings on total cost of the entire supply chain can also be achieved by considering the penalty and incentive policies. Our findings provided some useful insights to practitioners. This paper contributed to an integrated inventory literature with GHG emission.

The proposed models have limitations. The proposed model in this paper could be extended in various directions. Future research may consider multi-manufacturer and multi-buyer. The other indirect emission may be involved such as waste disposal. In addition, other policies to reduce GHG emissions can be incorporated into inventory models such as investment cost of emission reductions, recycling, remanufacturing, cleaner production or green manufacturing etc.

Acknowledgement

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