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Coordination Mechanisms in a Two-stage Green Supply Chain: Analyzing the Impact of Transportation Decisions on Environment

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Abstract

In this study, the distributor in charge of freight transport is responsible for replenishing the buyer's inventory level, with the government intervening in the supply chain to reduce Greenhouse Gas (GHG) emissions. In the proposed model, a periodic review replenishment policy is applied by the buyer, whereby the distributor is responsible for determining the optimal review period. Therefore, a game theory approach is used to show how government intervention influences the replenishment decisions, transportation, and safety factor. Due to the government constraint imposed to control GHG emissions, the distributor has to set a longer review period involving fewer trucks, resulting in his/her decision leading to more shortage cost for the buyer. The results of four numerical examples indicate that the buyer is not given any incentives to cooperate with the distributor due to his/her reduced revenue. Hence, this study proposes Two-Part Tariff (TPT) and Cost-Sharing (CS) contracts to increase the profitability of both players. Finally, the results show that both coordination mechanisms can effectively coordinate the supply chain, but the TPT contract can also reduce GHG emissions. Furthermore, in all scenarios where the government constraint is implemented, the number of unfilled trucks in each replenishment inventory has been decreased.

Keywords: Periodic review replenishment system; Safety factor; Greenhouse gas emissions; Freight transport; Stackelberg game

1. Introduction

Nowadays, as a result of economic globalization, and the rapid growth in the number of independent industrial enterprises, the level of GHG emissions has increased. Therefore, the need to pay extra attention to environmental issues has become an important challenge for governments and companies worldwide (Madani and Rasti-Barzoki, 2017). In response to this concern, the World Economic Forum reviewed ten global challenges. The results showed that climate change and environmental degradation from GHG emissions account for almost half of the world's problems (Forum, 2018).

Product transportation is strongly related to economic growth, and because it is directly related to GHG emissions, the latter should be considered an integral part of supply chains. Hence, it is necessary to optimize transport activities based on environmental measures (Mallidis et al., 2014). Some retailers such as Walmart and Tesco have imposed their authority on suppliers in the supply chain, forcing them to reduce GHG

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emissions by decreasing the amount of transportation (Basiri and Heydari, 2017). Furthermore, Adidas's global brand has reduced harmful substances in its manufacturing and packaging materials to prevent excessive GHG emissions (Ghosh and Shah, 2012). Hence, nowadays, the entities in the supply chain have come to realize that collaborative decision-making is one of the most important things in the new global business environment (Sarkar et al., 2020).

However, in some cases, enterprises continue to act traditionally, making decisions based on their profitability in a decentralized supply chain, and these self-interested behaviors can cause irreparable damage to the environment (Zhang et al., 2014). In order to align the supply chain's main activities (e.g., inventory replenishment, transportation, production, etc.) with environmental responsibility, the cooperation of all players is required, and all of them should implement one coordination mechanism. The two-part tariff, revenue sharing, cost-sharing, quantity discount, quantity flexibility, sales rebate, and buy-back contracts are some of the mechanisms used to resolve the discrepant objectives of independent supply chain players, and to convince them to engage in collaborative decision-making (Biswas and Avittathur, 2019; Sluis and De Giovanni, 2016). Furthermore, the supply chain coordination in any situation can be effective if the entities enter into an agreement or long-term cooperation (Taleizadeh et al., 2019).

In this study, a two-stage green supply chain under a periodic review replenishment system is examined. GHG is emitted by trucks involved in the distribution of products to replenish the buyer's inventory level. The main purpose of the model presented here is to create a coordination mechanism between the supply chain players by using TPT and CS contracts. It should be noted that the government plays an important role in reducing GHG emissions and protecting the environment in green supply chain management. Therefore, government intervention is applied to ensure that enterprises do not make decisions without considering environmental indicators (Zhang and Liu, 2013). Despite the significant impact of government intervention and its important role in the market, the interactions between government and supply chain players have not been carefully considered in previous studies. Therefore, in this study, the researchers consider the GHG emissions constraint imposed by the government, limiting the emissions caused by the distribution of products and preventing the movement of unfilled, supply chain trucks when delivering buyer's orders. In order to address the gaps in the literature, the following research questions are addressed:

- What are the characteristics of the TPT and CS contracts in the supply chain in terms of the periodic review replenishment policy?
- Can the TPT and CS contracts coordinate simultaneously the distributor's and buyer's decision variables?
- What is the impact of the GHG emissions constraint on freight transport and the key decisions of supply chain players?
- What is the impact of government intervention on supply chain profitability?

To answer the research questions, a distributor-buyer structure with one type of product is considered. In this supply chain, the market demand for the product is stochastic, whereby the buyer as a follower uses a periodic review replenishment policy, and the distributor as a leader is responsible for determining the buyer's review period. In this supply chain, the distributor faces a government-imposed constraint when deciding on the review period, intended to reduce the number of order shipments, especially with unfilled trucks. Therefore, the distributor must consider that the amount of GHG emissions must not exceed a particular threshold limit. This constraint will increase the review period, and it may cause some shortages with partial back-ordering for the buyer and increased holding cost for the distributor. As a result, a mechanism is needed to coordinate simultaneously the decision variables influencing the distributor and the buyer in order to avoid decreasing the profitability of the whole supply chain. Therefore, in this paper, the decentralized and integrated scenarios are formulated and, to coordinate the supply chain players, TPT and CS contracts are used.

Several relevant studies are reviewed in the Research Background section. The Methodology section provides a description of the problem of interest, the notations, and the assumptions used in the study. This is followed by an examination of various supply chain scenarios -decentralized, integrated, and coordinated-modeled- using TPT and CS contracts. In the fourth section, Numerical Examples and Sensitivity Analysis, the data related to the mathematical model are analyzed. Finally, in the Conclusion and Managerial Implications section, the results and several managerial implications are discussed, and suggestions are offered for future research.

2. Research Background

In the supply chain, each player's decision-making affects the profitability of others. Because players have to consider the widespread impact of their decisions, the use of game theory has become one of the most significant issues in research, especially in inventory models (Chen et al., 2017). Periodic review replenishment systems using the game theory approach have attracted much research attention due to their widespread use in supermarkets, the pharmaceutical industry, and pharmacies (Nematollahi et al., 2017).

Nouri et al. (2018) considered the replenishment system in a supply chain involving a manufacturer and a retailer as two independent economic entities. In their proposed model, the retailer's decision on the inventory replenishment level can affect the profitability of the manufacturer. Therefore, if the retailer fails to manage the inventory level properly, there will be a greater shortage of products, and the profitability of the whole supply chain will be decreased. One of the main reasons for using periodic review replenishment systems is the stochastic demand, which makes the quantity of an order different for each demand rate (Eynan and Kropp, 2007). Therefore, in these inventory systems, a mechanism is always needed to coordinate economic entities in order to increase the profitability of the whole supply chain by sharing information about the inventory replenishment level and market demand among all players. In this regard, all players benefit from cooperative decision-making (Chang and Chou, 2013).

Ramandi and Bafruei (2020), surveyed the effect of the government regulations pertaining to subsidies and penalties applied to replenishment decision-making. They considered a bi-objective model in a supply chain with a periodic review inventory system used to coordinate the key decisions of members, the revenue sharing, and where delay-in-payments contracts are used. The results of this study showed that both mechanisms were able to coordinate the supply chain, and government regulations had been effective in reducing GHG emissions. Also, Nematollahi et al. (2018) considered the periodic review replenishment policies with a distributor-retailer structure in a pharmaceutical supply chain. In their model, demand was stochastic and the pharmaceutical product was offered in the supply chain. They sought to optimize the service level and the interval between patients' visits to receive timely medications.

In another study, Ebrahimi et al. (2019) examined the role of a retailer in the supply chain in increasing the customer purchases, and the investments in promotional effort. Furthermore, the periodic review inventory system was used by this retailer, whereby the supplier aimed to specify the multiplier of its replenishment cycle by using a periodic review lot-for-lot policy. In this model, the retailer not only determined the promotional effort but also had to specify the order-up-to-level and visit interval. At first, the centralized and decentralized decision-making were modeled, and then to convince the retailer to participate in the joint decision-making in the supply chain, they used a delay-in-payments contract. Ramandi and Bafruei (2019) investigated a periodic review inventory system with a supplier-retailer pair in the supply chain. What makes their model different from those in other studies is that it separates the shipping costs from the visit cost. Finally, their results indicated that the revenue-sharing contract could coordinate the supply chain.

As evident, studies have used various contracts to create coordination in the supply chain with periodic review replenishment policies. For instance, Johari et al. (2018) firstly considered the decentralized and centralized decision-making structure, and then created coordination between the supplier and the retailer by using a delay-in-payments contract in the supply chain. In another study, Nouri et al. (2018) surveyed a supply chain with two members, in which a retailer used a periodic review replenishment policy. In this instance, a manufacturer sought to innovate the production process in order to secure a greater share of the market along with the promotional efforts of the retailer. They considered a new compensation-based-wholesale-price contract to encourage the supply chain players to participate in the joint decision-making structure.

In this article, we examine the use of TPT and CS contracts in the supply chain as a means of creating coordination between the distributor and the buyer. To date, these contracts have not been used in periodic review replenishment systems although, recently, researchers have considered the TPT contract, especially in green supply chain coordination (Ramandi and Bafruei, 2020).

Similarly, Chen et al. (2017) used the TPT contract in the green supply chain based on the game theory approach involving a manufacturer and a retailer. In their model, the demand function was sensitive to the price and the rate of carbon emissions, and supply chain players needed to decide on wholesale and retail prices. Also, the manufacturer invested in green technology and determined the unit of carbon emissions. Finally, they concluded that the TPT contract could easily coordinate the supply chain with various power structures. Xu et al. (2016) considered a cap-and-trade regulation with sustainable products, and they compared the TPT contract with the revenue-sharing contract in a two-stage supply chain. Their results showed that both contracts could coordinate the supply chain, while the TPT contract would increase the sustainability level and overall profitability more so than would the revenue-sharing contract. Moreover, they concluded that the revenue-sharing contract, by increasing the amount of carbon emissions compared to the TPT contract, resulted in the reduction of profitability due to the environmental sensitivity of demand. In the model presented by Bai et al. (2017), the researchers indicated that when the supply chain members participated in a joint decision-making process, the supply chain's profitability would increase, and the amount of carbon emissions would decrease. Their results showed that the TPT contract performed better than the revenue-sharing and promotional-cost-sharing contract.

The use of the CS contract, whereby supply chain members commit to sharing a portion of supply chain costs, is widely reported in the literature (Heydari and Rafiei, 2020). In this regard, Xu et al. (2017) considered a make-to-order supply chain under a cap-and-trade regulation. This model sought to achieve the optimal value of the selling price and the sustainability level. Here, the cost-sharing contract is used to create coordination between a manufacturer and a supplier to reduce greenhouse gas emissions. In another study with different coordination mechanisms, Qin and Yang (2008) investigated a two-stage supply chain involving a product with a short life cycle. The results of this study indicated that when a revenue-sharing contract is established in the supply chain, that entity should be a leader of the supply chain with a Stackelberg game that holds more than half the revenue. Asgari et al. (2021) investigated the Customers' Environmental Awareness (CEA) in a price- and greenness-sensitive market. They considered two competitive retailers that offer two substitutable products to customers. The demand for each product linearly decreases in price and greenness level and linearly increases in other products' price and greenness level. They presented different scenarios demonstrating the competition between retailers. The general scenarios include strategies related to retailers' price, greenness, and order quantity strategies. The researchers solved the dynamic competition between retailers by taking an analytical approach and presented the optimal solution by using the Nash equilibrium. Finally, important theoretical and managerial insights are derived from the optimal solutions. Moreover, coordination mechanisms are now being used in new technologies such as blockchain. As an example, De Giovanni (2020), considered the smart revenue sharing and wholesale price contract in a supply chain with a supplier and a retailer with a game theory approach, which the supply chain managed through a blockchain.

Nowadays, several strategies are being applied to control and reduce GHG emissions such as the imposition of taxes, offering of subsidies, incentives for carbon footprint reduction, and so on, which have been consistently implemented in different parts of the supply chain (e.g., distribution and production). In this regard, imposing a constraint to prevent an increase in emissions can be very effective (Tao et al., 2018). Moreover, in green supply chain coordination, the government plays a prominent role through interventionist policies intended to reduce GHG emissions and protect the environment. In this regard, Sinayi and Rasti-Barzoki (2018) considered a supply chain under the tax and subsidy policies, in which the government was the leader. In their study, they also modeled environmental, economic, and social issues. Furthermore, they used the TPT contract to achieve coordination among supply chain members in a decentralized structure. Zhang and Wang (2017), investigated the strategy of including corporate social responsibility in a supply chain involving a manufacturer and a retailer under government regulations pertaining to, for example, taxes

Table 1
Review of various coordination contracts used in literature

Authors	Supply chain Players				Demand		Green issues focus	Coordination contract								Government intervention
	Manufacturer	Supplier/Distributor	Single Retailer/Buyer	Multiple Retailers/Buyers	Deterministic	Uncertain		Two-Part Tariff	Delay in Payments	Cost-sharing	Wholesale price	Revenue sharing	Option	Buy-Back	Quantity Discount	
Dong et al. (2016)	*		*			*	*	*				*		*		*
Hu et al. (2016)	*	*	*			*						*				
Wu et al. (2017)		*	*		*			*								
Heydari et al. (2017)		*	*			*			*							
Hu and Feng (2017)		*	*			*						*				
Wan and Chen (2019)		*	*			*					*		*			
Liu and De Giovanni (2019)	*	*			*		*				*	*				
Buratto et al. (2019)	*		*		*							*				
Zheng et al. (2019)		*		*	*										*	
Li et al. (2019)	*		*		*		*			*		*				
Cai et al. (2019)		*	*			*							*			
Liu et al. (2020)	*		*			*								*		
Ji et al. (2020)	*		*		*		*				*	*				*
Zhang and Yousaf (2020)	*		*		*		*	*								*
Wang and Choi (2020)	*		*			*		*		*		*				*
Li et al. (2021)	*			*		*	*	*								
Zhong et al. (2021)	*	*	*			*		*						*		
Xia et al. (2021)	*		*		*		*					*				
The current study		*	*			*	*	*		*						*

or subsidies. The basic model in this paper deploys the Stackelberg game under the condition of incomplete knowledge, and the authors considered the effect of products on the environment and supply chains' profits, and the tariffs.

It should be noted that transportation is also one of the most important factors that must be considered in operation research. In this regard, Aliahmadi et al. (2021) proposed a new bi-objective model to reduce the time and cost of transportation by solving a complex vehicle routing problem. They considered a real network of waste collection in Iran where the trucks and trailers collect the garbage from the urban areas and transfer it to several recycling facilities and a landfill site.

Drawing on the literature review, Table 1 contains a list of other studies that have examined the use of different contract mechanisms. As can be seen in the table, the results of a study carried out by Zhang and Yousaf (2020) showed that strict government interventions under a tax policy in the supply chain do not always reduce GHG emissions which would improve environmental performance. They argued that in these cases, the government should replace tax payments with subsidies. Moreover, Wang and Choi (2020) surveyed a CS contract along with TPT, specifically a revenue-sharing contract in a manufacturer-retailer supply chain. In this paper, government intervention is considered as a cap-and-trade regulation.

The literature highlights the need to consider the issue of freight transport in the delivery of orders for inventory replenishment (Tao et al., 2018). This aspect of the supply chain has not been included in the models for periodic review replenishment systems. Moreover, a model would be more realistic if the role of government intervention in reducing GHG emissions related to product transportations were considered. When the inventory replenishment level is one of the key decisions in the supply chain, and the specified amount of review period affects the number of trucks required for the delivery of orders, it is necessary to consider the GHG emitted by the trucks in the supply chain. Therefore, government authorities and independent economic entities always face a difficult challenge as the government aims to decrease GHG emissions by reducing the amount of transportation in the supply chain, while the players only seek more profitability and fewer additional costs. In this study, the main objective is to investigate this challenge between the government and the players in the supply chain, given that the government imposes a constraint to limit GHG emissions to less than a certain threshold. This constraint forces the distributor to consider environmental issues in his/her decision-making regarding the review period. This study makes several contributions to this research field, as explained below.

- The literature review indicated that few studies have examined the impact of government intervention on decision-making within the supply chain. Moreover, although several studies have investigated social responsibility along with economic goals in a supply chain with a periodic review inventory policy, the literature illustrates that there is a huge gap in the analyses of environmental efforts and the role of the government in controlling GHG emissions, where the supply chain members want to optimize the review period and the base stock quantity. Hence, in this paper, a green supply chain is considered where the relevant players follow a periodic review replenishment system, and the government intervenes in the supply chain by imposing a constraint to reduce GHG emissions.
- In the studies on the periodic review replenishment system, transportation was not investigated in terms of the inventory policy. Despite the fact that the transportation factor and its cost are unavoidable in a periodic review replenishment policy, this issue has been ignored or considered only as a fixed visiting cost in the supply chain. Hence, in this paper, the researchers have taken into account trucks with a maximum fixed capacity used to transport and deliver orders downstream (to the buyer) from upstream (the distributor). This consideration produces a more realistic model.
- As shown in Table 1, the TPT contract is used to coordinate the players' decision-making, and it is applicable in the green supply chain where environmental issues have been considered and addressed. Furthermore, in this paper, the CS contract is examined as one of the effective mechanisms reported in the literature. It should be noted that these two contracts were rarely used to create coordination in the supply chain with a periodic review replenishment system.

3. Methodology

This study examines a two-stage supply chain with a distributor and a buyer as the leader and the follower, respectively. The researchers selected a supply chain that included one type of product according to the market demand, which was stochastic with a normal distribution; also, the shortage could be such as stock-outs and lost sales. In the proposed model, the periodic review replenishment policy is applied by the buyer, and the distributor determines the review period. Furthermore, the distributor uses an independent inventory control system to replenish his/her inventory level. In this supply chain, the distributor first goes to the buyer site, takes orders, and then delivers them after a fixed lead time, which is less than the review period. On the other hand, the buyer determines the safety stock according to the base stock quantity, and this decision can affect the profitability of the whole supply chain.

In the proposed mathematical model, the transportation of products involves delivering orders from the distributor to the buyer using trucks with a maximum fixed capacity, which emit GHG during each round trip. Therefore, the distributor's decision regarding the review period affects freight transport and the number of trucks used for replenishing the buyer's inventory; this decision can lead to an increase/decrease in the total amount of GHG emissions. Since economic issues are the most critical factor for the distributor, he/she chooses the review period that increases his/her profit, without giving any consideration to environmental impacts. Thus, based on the distributor's decision, the number of trucks used for the transport of products can increase, especially if some are not fully loaded, thereby increasing GHG emissions. However, the government imposes a constraint on the supply chain to control emissions caused by freight transport during the process of delivering orders to replenish the inventory. This forces the distributor to determine the review period according to government regulations. The main assumptions made in this study are:

- The market demand is stochastic and follows a normal distribution.
- One type of product is considered.
- One type of truck is used to replenish the inventory of the buyer from the distributor.
- The amount of GHG emissions for each truck per round trip is fixed and equal.
- The review period is fixed and is not stochastic. The distributor delivers the buyer's order after a fixed lead-time.
- The buyer's visiting cost is independent of the review period and the base stock quantity.
- The buyer is facing shortages with partial backordering.
- The review period cannot exceed a specific threshold.

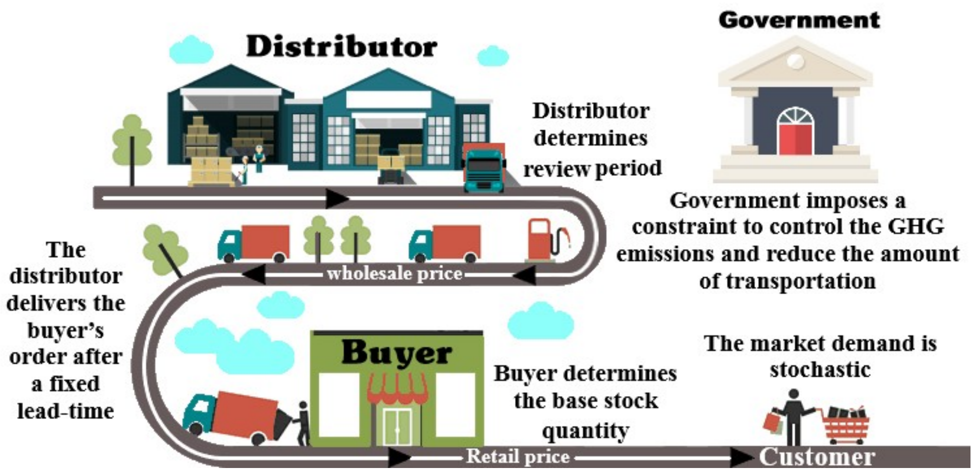

Fig. 1. The proposed model framework.

Details of the supply chain applied in this study are presented in Fig. 1, and all notations for the proposed model are given in Table 2.

In this part, first, the base stock quantity, the expected stock-out, the expected holding inventory in the periodic review replenishment system, the government intervention in freight transport, and the distributor replenishment policy are defined.

Given that the stochastic demand in the supply chain follows the normal distribution (μ, σ^2) per unit time, the buyer uses a periodic review replenishment system (T, S) to control his/her product inventory position. For each replenishment, the distributor goes to the buyer and receives his/her orders; this period between two visits is called the "review period (T)". Also, the buyer's order should be enough to increase the inventory level to the base stock quantity (S). After a fixed lead time (LT), the distributor delivers the order to the buyer. This period (X) (from the review period until delivery) is called the "protection period" and the buyer's demand is stochastic with a normal distribution $(\mu(LT+T), \sigma\sqrt{LT+T})$.

Therefore, the base stock quantity is calculated using equation (1) (Silver et al., 1998):

$$S = \mu(LT+T) + k\left(\sigma\sqrt{LT+T}\right) \tag{1}$$

The first part of equation (1) is related to the expected demand, and the second part is related to the buyer's safety stock. As equation (1) shows, S is a function of k, implying that there is a direct relationship between the base stock quantity and the safety factor. Therefore, in the proposed model, the safety factor is replaced by the base stock quantity and is considered as a decision variable of the buyer.

Due to the demand distribution function in the protection interval, the expected amount of shortage

Table 2
Notations for the proposed model

Indices	
sc,d,b	The indices sc, d, b are used to earmark supply chain, distributor, and buyer, respectively.
D,I,TPT, CS	The indices D, I, TPT, CS are used to earmark decentralized, integrated, two-part tariff contract and cost-sharing contract coordinated supply chain scenarios, respectively.
Decision variables	
S^y	Base stock quantity in scenario y
T^y	Review period between two successive visits in scenario y
Parameters	
w	The unit wholesale price of the product
p	The unit retail price
ϖ	Supply price of the product per unit
μ	Demand rate of product per unit time
σ	Standard deviation of demand per unit time
LT	Lead Time, time between ordering and delivering products
γ_b	The unit shortage cost of the buyer
α	Shortages fraction that will be lost
h_b	Unit inventory holding cost of the buyer per unit time
h_d	Unit inventory holding cost of the distributor per unit time
A_d	Ordering cost of the distributor per order
n	Distributor's replenishment multiplier
θ_d	Visiting cost of the distributor for each review
C	Transport cost per roundtrip
F	Lump-sum fee in the TPT contract
β	Sharing ratio of shortage cost per product allocated to the distributor ($0 < \beta < 1$)
$e\nu$	Amount of emitted GHG related to each truck per roundtrip
$C\nu$	Maximum fixed capacity of trucks
Ue	Certain threshold limit of GHG emissions per roundtrip
$N\nu^y$	Number of used trucks per inventory replenishment in scenario y
Et^y	Amount of total emitted GHG related to all trucks per inventory replenishment in scenario y
k^y	Safety factor in scenario y
π_x^y	Profit function of x in scenario y

between the two consecutive replenishments and the expected holding inventory per unit time are calculated using equations (2) and (3) (Nematollahi et al., 2018):

$$E(X-S)^+ = \sigma\sqrt{LT+T}G(k) = \sigma\sqrt{LT+T}\Big(f_z(k) - k\left(1 - F_z(k)\right)\Big) \tag{2}$$

$$E(S-X)^+ = S - \mu LT - \frac{\mu T}{2} + \alpha E(X-S)^+ = \frac{\mu T}{2} + k\sigma\sqrt{LT+T} + \alpha\sigma\sqrt{LT+T}G(k) \tag{3}$$

In equation (2), $G(k)$ represents the unit normal loss function, $f_z(k)$ the standard normal distribution, and $F_z(k)$ the cumulative distribution function. Equation (3) demonstrates the excess amount of inventory where demand is less than supply.

Given that the distributor uses an independent inventory control system based on the size of the buyer's order, and because the market demand is stochastic, the quantity of the order differs for each review and is equal to $\bar{Q} = \mu T - \alpha E(X-S)^+$. In this system, it is assumed that the distributor replenishes his/her inventory level in each $\bar{T} = nT$ time with the approximate lots of size $n\bar{Q}$. Also, it is assumed that the value of parameter n is chosen according to the distributor's replenishment policy which is predetermined, and the lead time in this system is zero.

On the other hand, the cost and amount of GHG emissions related to each truck used for the freight transport per round trip from the distributor to the buyer's site are equal to C and $e\nu$, respectively, which are fixed and deterministic. Consequently, the number of trucks required for delivering the orders for each replenishment is calculated using equation (4) (Mallidis et al., 2014):

$$N\nu = (\frac{1}{T}).\left\lceil \frac{\mu.T}{C\nu} \right\rceil \tag{4}$$

It should be noted that the value of T in equation (4) affects the number of trucks, and the distributor's decision specifies the amount of GHG emissions in the supply chain. Here, the total amount of GHG emitted by the trucks per replenishment is calculated by using $Et = N\nu * e\nu$. Moreover, the government imposes a constraint to control the range of GHG emissions and reduce the amount of transportation required to prevent the trucks from running without being fully loaded. Under this government constraint, the amount of GHG emissions must not exceed a specific maximum threshold ($Et \leq Ue$). Thus, the distributor is forced to determine the review period as well as take into account the environmental aspects.

According to the aforementioned points, the profit functions of the distributor and the buyer are obtained with:

Profit function of the buyer = Revenues from sales – Inventory holding costs –Stock-out and lost sales costs.

Profit function of the distributor = Revenues from sales – Ordering costs – Inventory holding costs – Visiting cost – Shipping cost.

$$\begin{aligned}\pi_b =&(p-w)\mu - h_b\Big(\frac{\mu T}{2} + k\alpha\sqrt{LT+T} + \alpha\sigma\sqrt{LT+T}G(k)\Big)\\ &- \frac{\gamma_b + \alpha(p-\varpi)}{T}\sigma\sqrt{LT+T}G(k)\end{aligned} \tag{5}$$

$$\begin{aligned}\pi_d =&(w-\varpi)\Big(\mu - \alpha\frac{\sigma\sqrt{LT+T}G(k)}{T}\Big) - \frac{A_d}{nT} - \frac{h_d(n-1)\Big(\mu T - \alpha\sigma\sqrt{LT+T}G(k)\Big)}{2}\\ &- \frac{\theta_d}{T} - CN\nu\end{aligned} \tag{6}$$

The proposed model is presented for decentralized and integrated scenarios, and the TPT and CS contacts are used to coordinate the supply chain. The solution method is based on the derivation of the profit function relative to the decision variable such as obtaining the optimal value of the safety stock (the buyer's decision variable) in all scenarios. However, in order to optimize the value of the review period (the distributor's decision variable), an algorithm is required, which is done by coding in MATLAB software. This algorithm finds all the possible values of the review period and selects the amount that would return the maximum profit. It should be noted that since it was very complex and difficult to take the first and second derivatives of the distributor's objective function from the review period, this search algorithm was used to obtain the distributor's decision variable. This search algorithm is used for all scenarios. The following sections explain in detail how the algorithm works for each scenario.

3.1. Decentralized supply chain scenario

In the literature, this scenario is known as a traditional supply chain, in which each player tries to maximize his/her profit. It should be noted that the relationship between the distributor and the buyer is based on the Stackelberg game. In this scenario, the buyer is the follower of the supply chain and decides on the safety factor within the given review period. Then the distributor, as the leader, determines the review period required to maximize his/her profit. As the review period affects the number of order-delivery trucks sent from the distributor to the buyer, the government constraint is imposed on the distributor to reduce the amount of transportation. The decentralized scenario is modeled as:

$$\begin{aligned} maximize\, \pi_d^D(T^D) =&(w-\varpi)\left(\mu-\alpha\frac{\sigma\sqrt{LT+T^D}G(k^D)}{T^D})\right)-\frac{A_d}{nT^D}\\ &-\frac{h_d(n-1)\left(\mu T^D-\alpha\sigma\sqrt{LT+T^D}G(k^D)\right)}{2}-\frac{\theta_d}{T}-CN\nu^D \end{aligned} \tag{7}$$

s.t.

$$Et^D \leq Ue \tag{8}$$

$$0 \leq T^D \leq T_{max} \tag{9}$$

$$K^D \in arg\, max\, \pi_b^D, T^D \geq 0 \tag{10}$$

In this scenario, the objective of the distributor is to maximize his/her profitability, which is shown in equation (7). Based on ~~the~~ constraint (8) imposed by the government, the GHG emissions for the trucks per round trip for each replenishment must be less than a specific threshold limit. Therefore, the number of trucks used for delivering the orders should be reduced. According to Nematollahi et al. (2018), constraint (9) indicates that the review period in the decentralized scenario must not be negative and it should not be more than the allowed threshold (T_{max}). Constraint (10) specifies the type of decision variables, and equation (11) is applied to present the profit function of the buyer:

$$\begin{aligned} \pi_b^D(k^D) =&(p-w)\mu-h_b\left(\frac{\mu T^D}{2}+k^D\alpha\sqrt{LT+T^D}+\alpha\sigma\sqrt{LT+T^D}G(k^D)\right)\\ &-\frac{\gamma_b+\alpha(p-w)}{T^D}\sigma\sqrt{LT+T^D}G(k^D) \end{aligned} \tag{11}$$

However, firstly, it must be proved that the curve of the buyer profit function over k^D is concave. Thus, **Lemma 1** is presented as:

Lemma 1. *The profit function of the buyer over k^D is concave in the decentralized supply chain scenario.*

Proof. See Appendix A. □

To optimize the value of the safety factor, the derivative of the buyer's profit function over k^D must be zero. So, k^{*D} is equal to equation (12) as follows:

$$k^{*D} = F_z^{-1}\left(1-\frac{h_bT^D}{h_b\alpha T^D+\gamma_b+\alpha(p-w)}\right) \tag{12}$$

Furthermore, to calculate T^{D*} in the decentralized supply chain scenario, ~~the~~ Algorithm 1 is proposed.

Algorithm 1 Outline of the solution approach (D)

$\pi^{*d}_{D} \leftarrow 0$
Input Ue
for T^D:ξ to T_{max} **do**
    $Et^D = N\nu^D * ev$
    if $Et^D \leq Ue$ **then**
        Calculate k^D by using equation(12)
        Calculate π^D_d by using equation (7)
        if $\pi^D_d > \pi^{*D}_d$ **then**
            $T^{*D} = T^D$
            $k^{*D} = k^D$
            $\pi^{*D}_d = \pi^D_d$
        end if
    end if
end for

3.2. Integrated supply chain scenario

In this scenario, all supply chain decisions are made simultaneously by one central decision-maker. These decisions are intended to increase the profitability of the whole supply chain, which is equal to the sum of all players' profits. In this study, the total profit is obtained from the profit functions of the buyer plus the distributor($\pi^I_{sc} = \pi_b + \pi_d$) to determine the safety factor and the review period, simultaneously. The mathematical model proposed below is used in the integrated supply chain scenario:

$$\begin{aligned} maximize\, \pi^I_{sc}(T^I, k^I) =& (p-\varpi)\mu - \frac{1}{T^I}(\theta_d + \frac{A_d}{n}) \\ & - \frac{1}{T^I}\Big(\gamma_b + \alpha(p-\varpi) - \frac{h_d\alpha(n-1)T^I}{2}\Big)\sigma\sqrt{LT+T^I}G(k^I) \\ & - \frac{\mu T^I}{2}\Big((n-1)h_d + h_b\Big) \\ & - h_b\Big(k^I\sigma\sqrt{LT+T^I} + \alpha\sigma\sqrt{LT+T^I}G(k^I)\Big) - CN\nu^I \end{aligned} \tag{13}$$

s.t.

$$Et^I \leq Ue \tag{14}$$

$$0 \leq T^I \leq T_{max} \tag{15}$$

where equation (13) is the objective function of the integrated scenario and maximizes the profitability of the whole supply chain by obtaining the optimal values of T^I and k^I as decision variables. The concavity of the supply chain profit function over k^I is proven in **Lamma 2**. Similar to the decentralized supply chain scenario, two main constraints (14) and (15) indicate the emissions threshold limit constraint and the allowed review period, respectively.

Lemma 2. *The supply chain profit function over k^I is concave in the integrated supply chain scenario.*

Proof. See Appendix B. □

So, at the maximum point of the supply chain profit curve, the best amount of k^I is equal to equation (16):

$$k^{*I} = F_z^{-1}\left(1 - \frac{h_b T^I}{h_b \alpha T^I + \left(\gamma_b + \alpha(p - \varpi) - \frac{h_b \alpha (n-1) T^I}{2}\right)}\right) \tag{16}$$

Equation (16) is obtained from $\frac{\partial \pi_{sc}^I}{\partial k^I} = 0$, which is shown in Appendix B.

To calculate the optimal value of the review period (T^{*I}) in this scenario, Algorithm 2 is proposed:

Algorithm 2 Outline of the solution approach (I)

$\pi_{sc}^{*I} \leftarrow 0$
Input Ue
for T^I:ξ to T_{max} **do**
  $Et^I = N\nu^I * ev$
  if $Et^I \leq Ue$ **then**
    Calculate k^I by using equation (16)
    $\pi_{sc}^I = \pi_d^I + \pi_b^I$
    if $\pi_{sc}^I > \pi_{sc}^{*I}$ **then**
      $T^{*I} = T^I$
      $k^{*I} = k^I$
      $\pi_d^{*I} = \pi_d^I$
    end if
  end if
end for

In this algorithm, first, the decision variables for all the possible review periods ($0 \leq T^I \leq T_{max}$) are calculated. Then, only the decisions that have complied with the government's constraint ($Et^I \leq Ue$) will remain. In the last step, the best T^{*I} under the maximum profit function of the supply chain is determined.

Although the application of T^{*I} and k^{*I} increases the SC profit function, it could incur losses for the buyer. In this regard, the locally optimal decisions, T^{*D} and k^{*D} maximize the buyer profit function to produce globally optimal decisions.

Therefore, the comparison between the integrated and the decentralized scenarios indicates that the profitability of the distributor and the whole supply chain has increased ($\pi_{sc}^{*I} \geq \pi_{sc}^{*D}, \pi_d^{*I} \geq \pi_d^{*D}$) ; however, the buyer in the integrated scenario loses his/her profit, which does not occur when he/she acts independently ($\pi_b^{*I} < \pi_b^{*D}$). Furthermore, there is no incentive for the buyer to shift its local decisions to global decisions and participate in the proposed integrated scenario. As a result, a coordination mechanism is needed to resolve discrepancies in the supply chain to ensure that all players benefit from the proposed mechanism. To this end, the two coordination mechanisms used in this study are described below.

3.3. Supply Chain Coordination Models

A coordination mechanism is a plan to coordinate the activities of independent players to improve the whole supply chain profitability, and includes an incentive scheme to allocate profits resulting from this coordination. These kinds of mechanisms are applied to reward supply chain players for participating in global optimization. On the other hand, in the centralized scenario, supply chain profitability is greater than in a decentralized structure, although this scenario may cause losses for some players. Therefore, since profitability is the priority of supply chain players, they have no interest in aligning their goals with others to participate in global optimization. However, this incentive can be created by sharing, through contracts, any profits resulting from coordination.

3.3.1. Coordinated supply chain scenario based on TPT contract

The main reasons for using the TPT contract in the green supply chain are its simplicity and effectiveness. In this study, the distributor introduced the TPT contract to encourage the buyer to cooperate in order to achieve global supply chain optimization by offering him/her a significant reduction in the wholesale prices ($w^{TPT} = \varpi$). However, in order to obtain the reduced wholesale price as per the contract, the buyer must pay a lump-sum fee (F) to the distributor. The profit functions of the distributor and the buyer can be calculated with:

$$\begin{aligned}\pi_b^{TPT}(k^{TPT}) =&(p - w^{TPT})\mu \\ &- h_b\left(\frac{\mu T^{TPT}}{2} + k^{TPT}\alpha\sqrt{LT + T^{TPT}} + \alpha\sigma\sqrt{LT + T^{TPT}}G(k^{TPT})\right) \\ &- \frac{\gamma_b + \alpha(p - w^{TPT})}{T^{TPT}}\sigma\sqrt{LT + T^{TPT}}G(k^{TPT}) - F\end{aligned} \tag{17}$$

$$\begin{aligned}\pi_d^{TPT}(T^{TPT}) =&(w^{TPT} - \varpi)\left(\mu - \alpha\frac{\sigma\sqrt{LT + T^{TPT}}G(k^{TPT})}{T^{TPT}})\right) \\ &- \frac{A_d}{nT^{TPT}} - \frac{h_d(n-1)\Big(\mu T^{TPT} - \alpha\sigma\sqrt{LT + T^{TPT}}G(k^{TPT})\Big)}{2} \\ &- \frac{\theta_d}{T} - CN\nu^{TPT} + F\end{aligned} \tag{18}$$

It should be noted that the distributor offers this contract when his/her profit is higher than that in the decentralized scenario $(\pi_d^{*TPT} + F_1) \geq \pi_d^{*D}$; also, the buyer cooperates in this coordination mechanism when his/her profitability is greater than it would be if he/she had acted independently $(\pi_d^{*TPT} - F_2) \geq \pi_b^{*D}$. In this case, F_1 is the lower bound and F_2 is the upper bound of the lump-sum fee, in which $F_1 \geq \pi_d^{*D} - \pi_d^{*TPT}$ and $F_2 \leq \pi_b^{*TPT} - \pi_b^{*D}$. Therefore, when the lump-sum fee is within the intended range ($F \in [F_1, F_2]$), the TPT contract will be able to coordinate the supply chain. However, the size of the lump-sum fee depends on the bargaining power of the players involved in the supply chain.

3.3.2. Coordinated supply chain scenario based on CS contract

In the current model, the buyer prefers a more regular and short review period to prevent the shortage cost. However, because the distributor is under the government constraint to decrease GHG emissions, he/she has to extend the review period. On the other hand, the distributor benefits from the centralized scenario and is looking for ways to secure the buyer's participation in global optimization.

Therefore, the distributor offers a CS contract to the buyer, in which he/she undertakes to pay a percentage of the shortage cost. In this coordination mechanism, if the buyer committed to cooperating in the global optimization (T^{*I}, k^{*I}), and made his/her decision based on the whole supply chain profitability (π_{sc}^I), the distributor will undertake $\beta\%$ of the shortage cost, where $0 < \beta < 1$. Furthermore, the buyer bears $(1-\beta)\%$ for his/her shortage cost. Hence, the profit function of the distributor and buyer can be given as:

$$\begin{aligned}\pi_b^{CS}(k^{CS}) =&(p - w)\mu - h_b\left(\frac{\mu T^{CS}}{2} + k^{CS}\alpha\sqrt{LT + T^{CS}} + \alpha\sigma\sqrt{LT + T^{CS}}G(k^{CS})\right) \\ &- (1-\beta)\Big(\frac{\gamma_b + \alpha(p - w)}{T^{CS}}\sigma\sqrt{LT + T^{CS}}G(k^{CS})\Big)\end{aligned} \tag{19}$$

$$\begin{aligned}\pi_d^{CS}(T^{CS}) =&(w-\varpi)\left(\mu-\alpha\frac{\sigma\sqrt{LT+T^{CS}}G(k^{CS})}{T^{CS}})\right)-\frac{A_d}{nT^{CS}}\\&-\frac{h_d(n-1)\Big(\mu T^{CS}-\alpha\sigma\sqrt{LT+T^{CS}}G(k^{CS})\Big)}{2}\\&-\frac{\theta_d}{T}-CN\nu^{CS}-\beta\Big(\frac{\gamma_b+\alpha(p-w)}{T^{CS}}\sigma\sqrt{LT+T^{CS}}G(k^{CS})\Big)\end{aligned}\tag{20}$$

In the CS contract, the sharing ratio of the shortage cost depends on the bargaining power of both players. Moreover, this value should be an amount that exceeds the profits that both the distributor and the buyer would make in the decentralized scenario. Otherwise, this agreement will not be concluded.

Conditions for the buyer to participate in CS contract. The sharing ratio of the shortage cost should be more than enough to compensate for the buyer's losses and encourage him/her to cooperate with the distributor in global optimization. This means that the buyer's profitability after accepting the CS contract should be more than when he/she acts independently. Mathematically, it can be written as:

$$\pi_b^{CS}(T^{*CS},k^{*CS},\beta)\geq\pi_b^{D}(T^{*D},k^{*D})\tag{21}$$

Lemma 3. *The minimum sharing ratio of the shortage cost which the buyer accepts to participate in the CS contract is:*

$$\begin{aligned}\beta^{min}_{(T^*,k^*)} =&\eta*h_b\left(\frac{\mu}{2}(T^{CS}-T^D)+\alpha\Big(k^{CS}\sqrt{LT+T^{CS}}-k^D\sqrt{LT+T^D}\Big)\right.\\&\left.+\alpha\sigma\Big(\sqrt{LT+T^{CS}}G(k^{CS})-\sqrt{LT+T^D}G(k^D)\Big)\right)\\&+\sigma\Big(\gamma_b+\alpha(p-w)\Big)\left(\frac{\sqrt{LT+T^{CS}}G(k^{CS})}{T^{CS}}-\frac{\sqrt{LT+T^D}G(k^D)}{T^D}\right)\end{aligned}\tag{22}$$

$$Where\,\eta=\frac{T^{CS}}{\sigma\Big(\gamma_b+\alpha(p-w)\Big)\sqrt{LT+T^{CS}}G(k^{CS})}$$

Proof. See Appendix C. □

Conditions for the distributor to participate in CS contract. The profitability of the distributor, after accepting a percentage of the shortage cost, should be more than that in the decentralized scenario. Therefore, an upper bound for the sharing ratio of the shortage cost is required to guarantee the distributor's profitability as in the following condition:

$$\pi_d^{CS}(T^{*CS},k^{*CS},\beta)\geq\pi_d^{D}(T^{*D},k^{*D})\tag{23}$$

Lemma 4. *The maximum sharing ratio of the shortage cost which guarantees the distributor's profitability*

Table 3
Parameters of periodic review replenishment system for four investigated examples (Nematollahi et al., 2017)

Parameter	(μ,σ)	p	w	ϖ	h_b	h_d	γ_b	α	n	A_d	θ_d	LT	T_{max}
Example 1	(18000,6000)	20	18	13	9	7	1	0.3	6	250	30	2	16
Example 2	(10000,4000)	40	38	33	10	8	2	0.3	9	500	80	1.5	16
Example 3	(7000,3000)	30	28	24	10	6	1	0.2	7	200	20	1	16
Example 4	(30000,12000)	15	14	12	5	2	0.7	0.1	4	300	30	0.5	16

Table 4
Parameters of transportation and GHG emissions for four investigated examples (Sazvar et al., 2014)

Parameter	C	$e\nu$	$C\nu$	Ue
Example 1	315	1700	900	45000
Example 2	200	1200	500	33000
Example 3	200	1200	500	28000
Example 4	400	2000	1200	55000

in CS contract is:

$$\begin{aligned}\beta^{max}_{(T^*,k^*)} =& \eta * (w-\varpi)\alpha\sigma\left(\frac{\sqrt{LT+T^D}G(k^D)}{T^D} - \frac{\sqrt{LT+T^{CS}}G(k^{CS})}{T^{CS}}\right)\\ &+ \frac{A_d}{n}\left(\frac{1}{T^D}-\frac{1}{T^{CS}}\right) + \frac{h_d\mu(n-1)}{2}\left(T^D - T^{CS}\right)\\ &+ \frac{h_d\alpha\sigma(n-1)}{2}\left(\sqrt{LT+T^{CS}}G(k^{CS}) - \sqrt{LT+T^D}G(k^D)\right)\end{aligned} \tag{24}$$

Proof. See Appendix D. □

As the result, the CS contract can coordinate the supply chain, if the $[\beta^{min}_{(T^*,k^*)}, \beta^{max}_{(T^*,k^*)}]$ is a non-empty interval. From this interval, it can be concluded that the buyer derives more benefit from the CS contract if the sharing ratio of the shortage cost is closer to $\beta^{max}_{(T^*,k^*)}$. Also, if the sharing ratio of the CS contract is closer to $\beta^{min}_{(T^*,k^*)}$, then more benefits are obtained by the distributor.

4. Numerical Examples and Sensitivity Analysis

In this section, firstly, four numerical examples are introduced, then the mathematical model used for all scenarios (decentralized, integrated, and coordinated scenario) is applied to all the examples. Moreover, the relationships between the supply chain decision variables, GHG emissions from product transportation, and the impact of government intervention on the key decisions of the supply chain are examined. Table 3 shows the parameters suggested by Nematollahi et al. (2017), which are used for the periodic review replenishment system to achieve results that are the most realistic. Table 4 shows the parameters related to freight transport which were introduced by Sazvar et al. (2014).

To apply the proposed model in all the supply chain scenarios and to code the introduced algorithms, MATLAB version 9.0 was used. It should be noted that the specifications of the computer used for this study were, 7500 U CPU, Intel Core i7, 12GB RAMDDR4, and 2.70 GHz up to 2.90 GHz. The results for the proposed mathematical models are presented in Table 5.

The results obtained from the supply chain players' profits under the decentralized and integrated scenarios show that the distributor benefits from global supply chain optimization in the four numerical examples. Conversely, according to examples 1, 2, and 3, the buyer's profitability was reduced under

Table 5
Result of four investigated examples for all supply chain scenarios

	Example 1	Example 2	Example 3	Example 4
Decentralized supply chain scenario				
S^{*D}	1835.4	1300.5	675.9	2934.5
k^{*D}	0.8303	1.0956	0.5464	0.6938
T^{*D}	14.04	13.52	15.87	14.60
$N\nu^{*D}$	26	27	23	25
Et^{*D}	44200	32400	27600	50000
${\pi_b}^{*D}$	17138.3	5147.1	4898.8	11308.7
${\pi_d}^{*D}$	62994.9	27351.9	15049.5	42118.7
${\pi_{sc}}^{*D}$	80133.2	32499.1	19948.3	53427.3
Integrated supply chain scenario				
S^{*I}	2298.7	1469.8	856.98	3309.2
k^{*I}	1.1987	1.3043	0.8271	0.8473
T^{*I}	14.04	13.52	15.87	14.60
$N\nu^{*I}$	26	27	23	25
Et^{*I}	44200	32400	27600	50000
${\pi_b}^{*I}$	16180.9	4885.3	4616.6	11130.5
${\pi_d}^{*I}$	65442.5	27956.2	15710.9	42507.3
${\pi_{sc}}^{*I}$	81623.4	32841.5	20327.5	53637.9
Coordinated supply chain scenario based on TPT contract				
S^{*TPT}	2346.8	1509.7	889.46	3229.7
k^{*TPT}	1.2369	1.3534	0.8775	0.8557
T^{*TPT}	14.04	13.52	15.87	14.60
$N\nu^{*TPT}$	26	27	23	25
Et^{*TPT}	44200	32400	27600	50000
${\pi_b}^{*TPT}$	17636.2	5321.02	4968.9	11382.6
${\pi_d}^{*TPT}$	63973.4	27503.5	15347.5	42254.7
${\pi_{sc}}^{*TPT}$	81609.3	32824.5	20316.3	53637.3
Coordinated supply chain scenario based on CS contract				
S^{*CS}	2298.7	1469.8	856.98	3309.2
k^{*CS}	1.1987	1.3043	0.8271	0.8473
T^{*CS}	14.04	13.52	15.87	14.60
$N\nu^{*CS}$	26	27	23	25
Et^{*CS}	44200	32400	27600	50000
${\pi_b}^{*CS}$	17882.8	5318.3	5088.4	11413.7
${\pi_d}^{*CS}$	63740.5	27523.2	15239.1	42224.1
${\pi_{sc}}^{*CS}$	81623.4	32841.5	20327.5	53637.9

the integrated supply chain scenario compared to the decentralized one. Therefore, the buyer refuses to participate in the integrated supply chain.

According to Table 5 and Fig. 2, although the integrated model increases the profits of the whole supply chain and the distributor as a leader compared to those of the decentralized model in all test problems, the buyer incurs losses. Therefore, since the integrated model in all three test problems reduces the follower's profit, he/she refuses to cooperate with the leader in the joint decision-making. It is also clear from the results that, compared to situations where players act independently, under both the TPT and CS contracts, not only do the distributor and the buyer not lose their profit but the profitability of the whole supply chain increases. In other words, the coordination mechanisms proposed in the current study can coordinate the supply chain under government intervention and guarantee members' acceptance of the coordination plan.

Regarding the third research question, "What is the impact of the GHG emissions constraint on freight transport and the key decisions of supply chain players?", Fig. 3 shows the optimal length of the review period and the profit functions before and after the government intervention in the first numerical example (example 1) for all scenarios. As shown in Fig. 3, the curves (a), (c), and (e) represent the integrated,

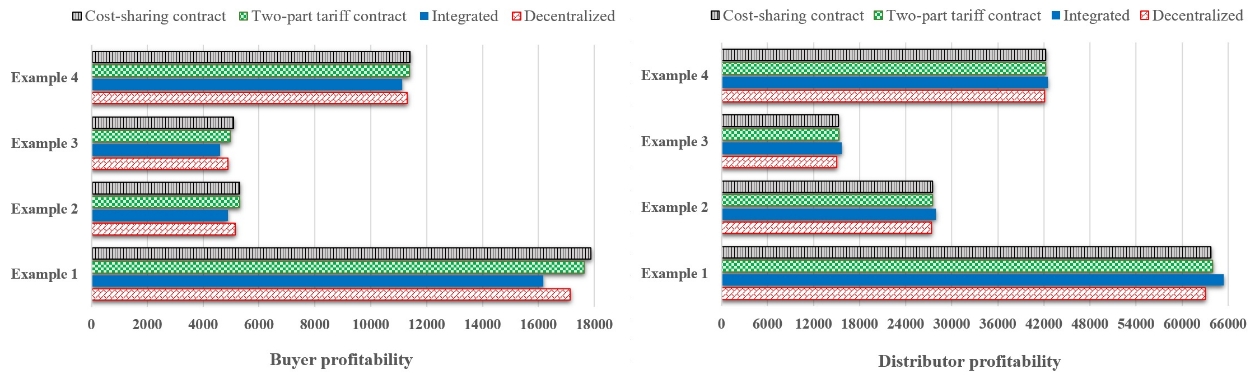

Fig. 2. Comparing profitability of the supply chain members in different scenarios

decentralized, and TPT contract scenarios, respectively, without taking into account the government's constraint. However, parts (b), (d), and (f) in this figure illustrate the effects of government intervention on the key decisions in the supply chain.

Furthermore, when the government does not intervene in the supply chain, the distributor will try to reduce additional costs (e.g., additional holding cost) and make a decision based on his/her profitability. Consequently, when making decisions, the distributor will not consider making attempts to reduce GHG emissions by decreasing the number of unfilled trucks and the amount of transportation required for each inventory replenishment. Hence, the government intervenes in the supply chain to control this environmental issue, and this can affect the distributor's decision-making.

For instance, in the decentralized scenario of example 1, the optimal length of the review period without considering the government constraint is 11.41 days; however, the results show that when the government imposes the maximum threshold limit on GHG emissions in the supply chain, the review period increases to 14.04 days (parts c and d in Fig. 3). Thus, the government constraint forces the supply chain leader to determine the optimal review period according to the allowable range; under this condition, the length of the review period is increased. According to parts (c) and (d) of example 1, when the distributor's decision is based on the government constraint, his/her profit decreases from 63413.5 to 62994.9.

This loss is attributed to the increasing costs associated with inventory holding due to the lengthier review period. In this regard, the proposed TPT and CS contracts will be beneficial as they eliminate the distributor's loss and, more importantly, increase his/her profit, which would not occur if the distributor acted independently. Moreover, Fig. 3 illustrates that the TPT contract has increased the distributor's profit in both cases in the decentralized scenario: the one with the government's constraint (parts d and f) and the other without it (parts c and e). It should be noted that when the distributor uses the TPT contract, his/her profit will be even greater than when there is no government constraint on the supply chain. Therefore, the applied coordination mechanism can reduce the pressure imposed by the government's regulations. Moreover, giving the bargaining power to both the distributor and the buyer is another feature of the TPT contract, which allows the players to compensate for the government's possible adverse effects on their profitability.

Moreover, it is clear from Fig 3 that the profit function follows a sawtooth shape due to the relationship between the review period and the transportation factor. In this regard, according to equation 4, the number of trucks used for transportation depends on the length of the review period. Hence, the number of transport vehicles is obtained in decimals due to the equation fractions; to calculate the exact number of trucks being used for transportation, the numbers are rounded up. As the value of T decreases, the number of trucks increases, which can reduce the profit function and vice versa. In this regard, because the review period is ~~the~~ decision variable, when the distributor makes a minor change to the review period, the number of trucks changes. Because this process continues to the end, the profit function has a sawtooth shape. To illustrate,

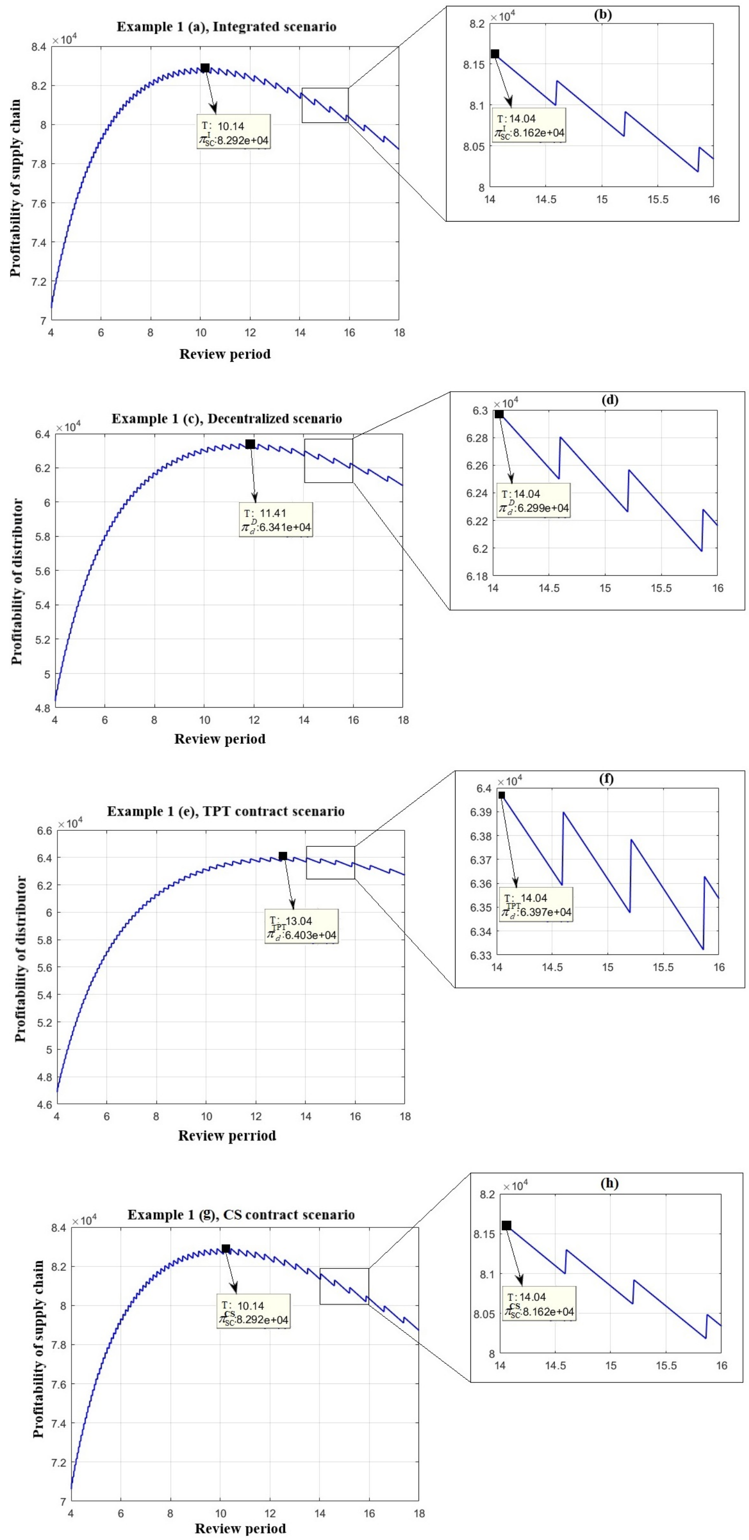

Fig. 3. The effect of the government's constraint on the review period for all supply chain scenarios of example 1.

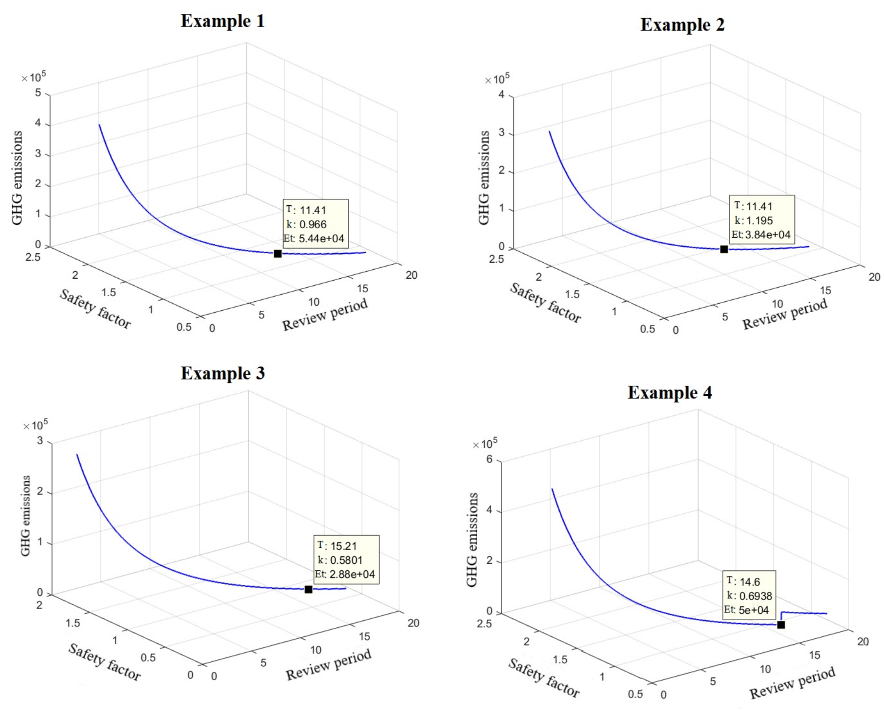

Fig. 4. Relationship between supply chain decision variables and the GHG emissions in the decentralized scenario.

according to example 1, when the value of T is between 14.04 and 14.59, the number of trucks engaged in transportation is 25, but with a minute change in the review period (an increase from 14.59 to 14.60), the number of trucks transported increases to 26. Therefore, the amount of profit function with $T = 14.59$ and $T = 14.60$ are 79481.91 and 79785.09, respectively.

As shown in Fig. 4, the relationship between decision variables and GHG emissions caused by freight transport in the supply chain is examined. The optimal number of decision variables is shown in Fig. 4 is calculated without considering government constraint in the model. The results show that the number of shipments required for the delivery of orders per inventory replenishment decreases due to the increase in the length of the review period; thus, the amount of GHG is reduced. In other words, the government imposes the constraint that results in a decrease in the number of trucks required for delivering the buyer's orders. Due to the government constraint, the distributor is not allowed to move most of the unfilled trucks, thereby reducing the amount of transportation required for each inventory replenishment.

One important factor in the periodic review replenishment system is the review period established in the inventory replenishment policy of the supply chain. If environmental issues are not considered and unfilled trucks are sent on the road by the distributor, this will produce more GHG emissions during the delivery of orders to the buyer. This endangers the environment and the government has to prevent additional GHG emissions by imposing some regulations. In this paper, the government has to reduce GHG emissions by imposing a constraint on the distributor. So, in order to demonstrate the behavior of supply chain members before (the blue curve) and after (the red curve) the government's constraint, Fig. 5 shows the effect of this constraint intended to reduce GHG emissions. As shown in Fig. 5 and Table 5, after government intervention, the amount of GHG emissions in all the scenarios is less than or equal to the situation where the environmental issue is not considered by decision-makers in the supply chain. Hence, when the government does not intervene in the supply chain to control the amount of GHG emissions, supply chain members are reluctant to consider the environmental factor in their decision-making. The blue curve in Fig. 5 indicates the increase in emissions due to the increase in the number of freight trucks. For instance, in the decentralized

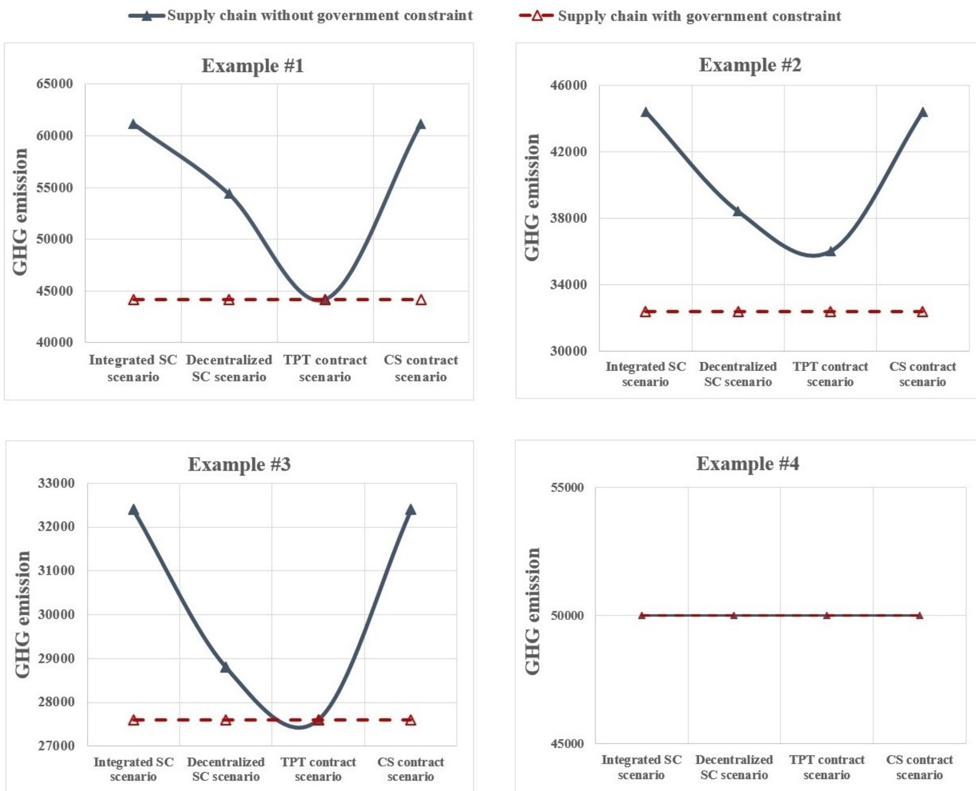

Fig. 5. The effect of government intervention on GHG emissions in all supply chain scenarios.

scenario in the four numerical examples, the GHG emissions decreased by 18.75%, 15.62%, 4.16%, and 0%, respectively.

Also, the amounts of GHG emissions in example 4, before and after the government intervention, are equal since the amount of emissions from trucks transported before applying this constraint is less than the specific threshold limit set by the government. Also, one of the most important results, which can be seen in this figure, is the effect of the TPT contract on the reduction of GHG emissions. This indicates that this contract, apart from its role in coordinating the supply chain, can reduce GHG emissions. As seen with the four numerical examples, the implementation of this coordination mechanism has resulted in the reduction of GHG, even without the government's constraint. However, the CS contract can coordinate only the supply chain; it cannot reduce GHG emissions. Therefore, it can be concluded that the TPT contract is very useful in green supply chain management even without the government pressures to reduce GHG emissions.

4.1. Sensitivity analysis on lump-sum fee of TPT contract

Fig. 6 shows the analysis of the sensitivity of F in regard to the profit function of the players. As shown in Fig. 6, the supply chain became coordinated in the specified intervals; in other words, the profitability of all players shown between the dashed lines is greater than in the decentralized scenario. The interval $[F_1, F_2]$ is equal to $[84822, 86298]$, where for the minimum amount of F , the distributor's profit is equal to the decentralized scenario ($\pi_d^{TPT} = \pi_d^D = 62995$) and when the maximum value of F is determined, the buyer's profit is equal to ($\pi_b^{TPT} = \pi_b^D = 17138$).

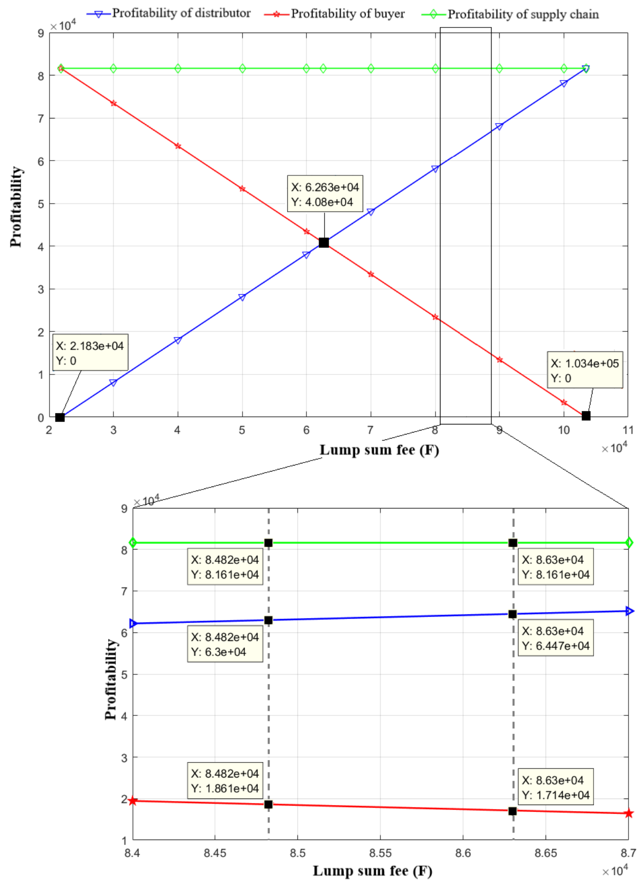

Fig. 6. The effect of lump-sum fee of TPT contract on the profit functions of supply chain players.

4.2. Sensitivity analysis on sharing ratio of the CS contract

Fig. 7 illustrates the impact of the sharing ratio of the shortage cost on the profit function of the players and the whole supply chain. As expected, by increasing β, the buyer's profitability has increased, and there has been a reduction in the distributor's profit function. As mentioned, the supply chain players accept a CS contract as long as their profitability is guaranteed. In this regard, the interval in which both players benefit from this contract in examples 1 to 4 are [32.51%,83.15%], [10.19%,23.5%], [11.86%,27.8%], and [3.3%,7.2%], respectively. It should be said that each sharing ratio of the shortage cost selected in these intervals can create coordination between the distributor and the buyer.

4.3. Changes in shortage fraction and its impact on the supply chain

To examine the proposed model from the perspective of inventory management, another sensitivity analysis is performed on the parameter of shortage fraction that will be lost (α) and its effect on the decision variables of supply chain and buyer's profit function. According to Fig. 8, when the shortage fraction increases, the buyer holds more safety stock to avoid shortages. Moreover, holding the safety stock in the coordination mechanism is greater than in the decentralized scenario. However, this inventory level is the reason that the cost of inventory has increased and the profitability of the buyer has decreased. As illustrated in Fig. 9, by increasing α, the buyer's profit function in the coordination mechanism is decreased more than in

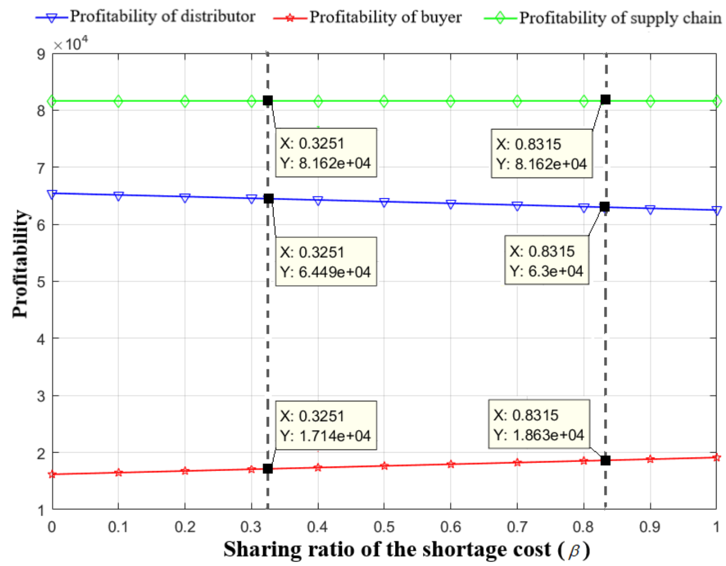

Fig. 7. The effect of the sharing ratio of the CS contract on the profit functions of supply chain players.

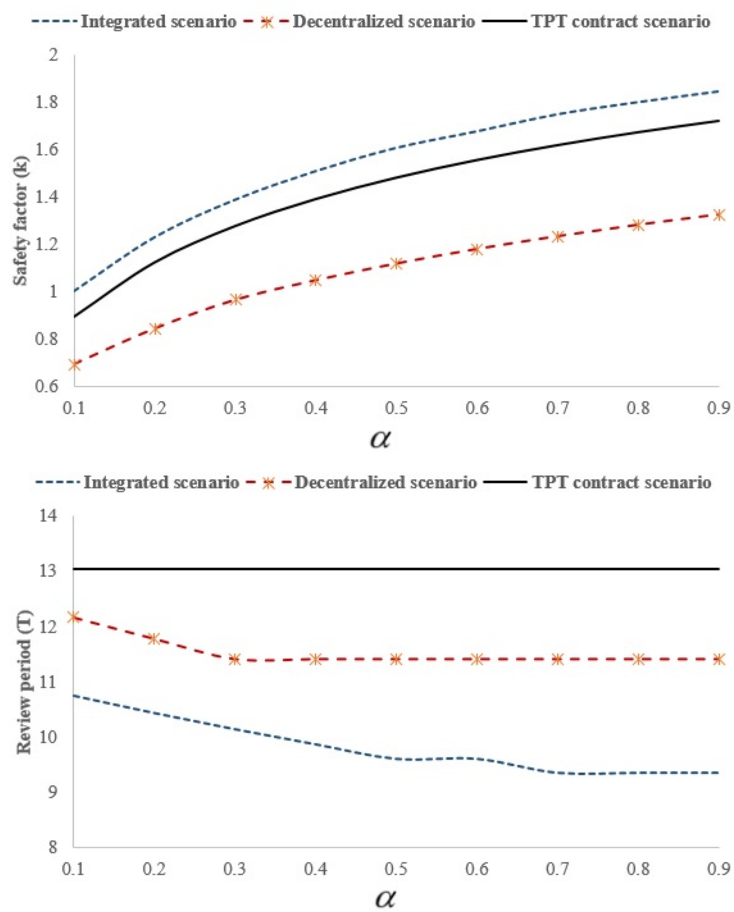

Fig. 8. The effect of shortage fraction α on the supply chain decision variables.

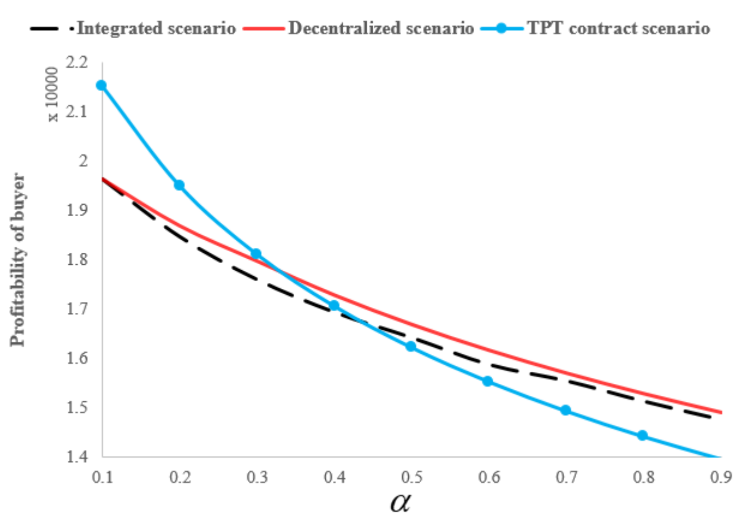

Fig. 9. The effect of shortage fraction α on the buyer's profit functions.

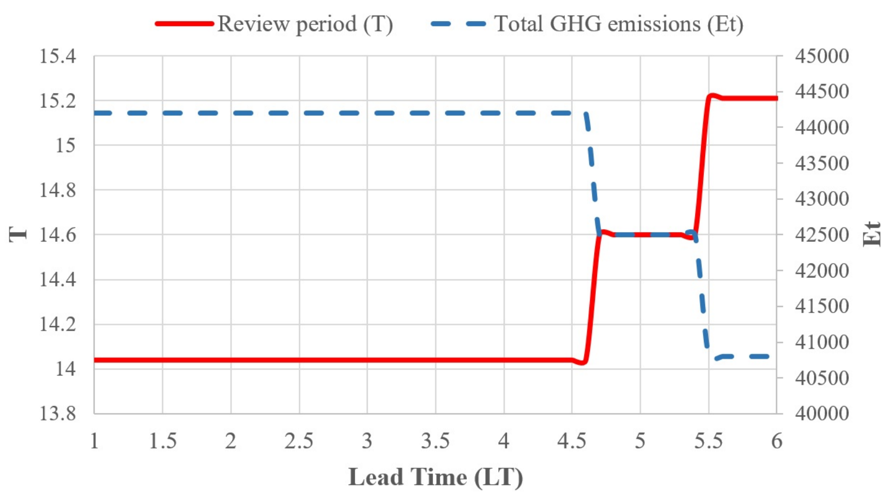

Fig. 10. Values of the review period and total GHG emissions by increasing lead time in decentralized supply chain scenario (Example 1).

the decentralized scenario. In other words, the buyer prefers a shorter T if the amount of α increases, and the review period under the TPT contract is longer than for the decentralized scenario. Therefore, the TPT contract with a lower α will produce better results for the buyer and increases his/her profitability. For this reason, when the distributor chooses a longer review period due to the government's constraint, the buyer cooperates with the distributor only if the coordination mechanism is applied.

4.4. Lead time-sensitive demand

The time between ordering and delivering products is one of the most important factors in supply chain management which can affect the market demand.

In this regard, since the reduction or increase of lead time may cause costs for members and change affect in the supply chain, it is necessary to conduct a thorough sensitivity analysis of this factor (Moon and Cha,

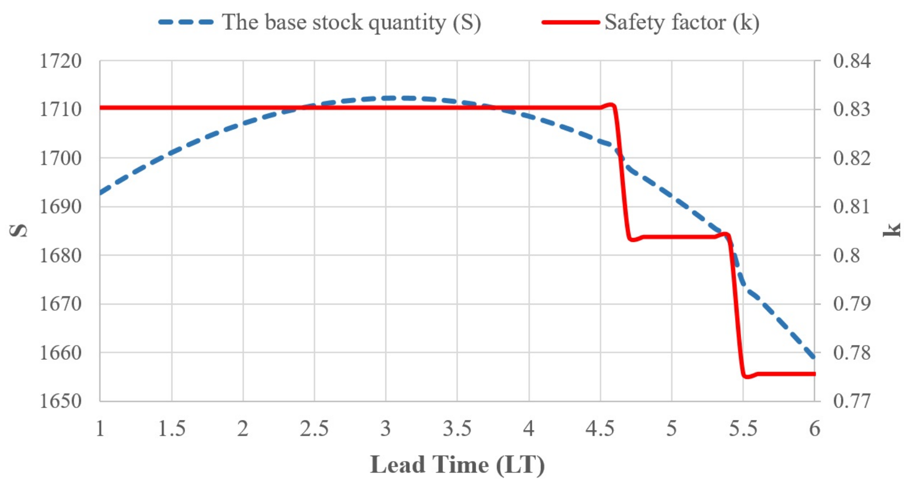

Fig. 11. Values of the base stock quantity and safety factor by increasing lead time in decentralized supply chain scenario (Example 1).

2005; Sarkar and Mahapatra, 2017). Therefore, in this subsection, in order to analyze the impact of this parameter on the key decisions of supply chain members and profitability, it is assumed that market demand is sensitive to lead time (Albana et al., 2018; Zhu, 2015). In this regard, the customer's demand follows a normal distribution $(D(LT), \sigma)$ in which the expected demand is considered to be stochastic and a linear function of the lead time is:

$$D(LT) = \mu_0 - \delta * LT \tag{25}$$

where μ_0 is the size of the potential market demand, and $\delta > 0$ is the lead time sensitivity factor. Fig. 10 and Fig. 11 are considered to examine the effect of the new demand function from the perspective of inventory management, and the impact of increasing lead time on the decision variables and the total amount of GHG emissions.

It is clear from Fig. 10 that the review period remains constant at 14.04 from $LT = 1$ to $LT = 4.5$, and then increases sharply to 15.21 in $LT = 6$. The main reason for this growth is that when lead time increases, the market demand reacts negatively, and is lost. Thus, as shown in Fig. 11, S declines, and the buyer orders less, which makes the distributor lengthen T. Moreover, as mentioned previously, the leader of the supply chain is constrained by government policy to ensure that the truck is fully loaded. Therefore, as shown in Fig. 10, the number of trucks engaged in transportation and the amount of GHG emissions declines from 44,200 to 44,800 as customer demand decreases. It should be noted that since there is a direct relationship between the base stock quantity and the safety factor, as illustrated in Fig. 11, there is a simultaneous decrease in the value of S (from 1692.81 to 1658.68) and k (from 0.8303 to 0.7755).

For the second part of this analysis, Fig. 12 is presented in order to compare the effect of increasing the time between ordering and delivering products on the profitability of members and the entire supply chain with and without the lead time-sensitive demand function. The first column shows that when the lead time increases from $LT = 1$ to $LT = 6$, the amount of supply chain profit function falls significantly from $\pi_{sc}^{*D} = 71800.59$ to $\pi_{sc}^{*D} = 23796.10$. The main reason for this sharp decline is the decrease in market demand and the imposition of high shortage costs on supply chain members. This growth in shortage cost directly affects the buyer's profitability and reduces it to the extent that his/her profit function is negative in $LT = 6$. Therefore, since the market demand is sensitive to lead time (normal distribution $(D(LT), \sigma)$), customers might not want to wait to purchase the product, and demand is lost, which can substantially decrease the distributor's revenue, with profitability falling from $\pi_d^{*D} = 56830.88$ to $\pi_d^{*D} = 24602.36$. The second chart demonstrates that when the customer's demand follows a normal distribution (μ, σ), increasing

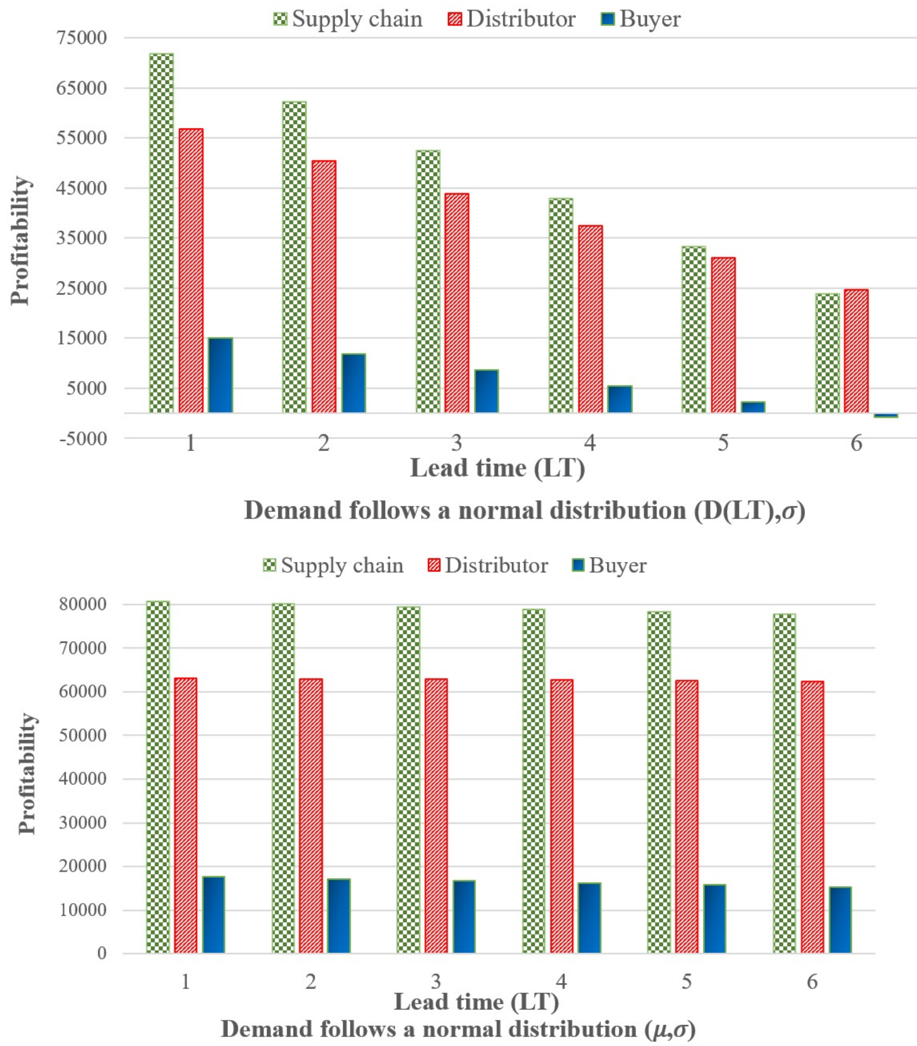

Fig. 12. Comparison of decreasing in profit functions by increasing lead time in decentralized supply chain scenario (Example 1) with and without the lead time-sensitive demand.

LT leads to a slight decline in the profits of the distributor, the buyer, and the entire supply chain.

The main reason for this small decrease is that large numbers of potential demands remain in the supply chain and are backordered when it is not sensitive to the lead time. The results extracted from these figures are shown in Table. 6 and Table. 7.

Table 6
Result of example 1 for decentralized supply chain scenario with lead time-sensitive demand

Notations	$LT = 1$	$LT = 2$	$LT = 3$	$LT = 4$	$LT = 5$	$LT = 6$
S^{*D}	1692.81	1707.04	1712.26	1708.55	1692.08	1658.68
k^{*D}	0.8303	0.8303	0.8303	0.8303	0.8037	0.7756
T^{*D}	14.04	14.04	14.04	14.04	14.6	15.21
Et^{*D}	44200	44200	44200	44200	42500	40800

Table 7
Result of example 1 for decentralized supply chain scenario with lead time-sensitive demand with and without the lead time-sensitive demand

Demand follows	Profits	$LT=1$	$LT=2$	$LT=3$	$LT=4$	$LT=5$	$LT=6$
A normal distribution $(D(LT),\sigma)$	π_b^{*D}	14969.71	11803.69	8652.997	5516.29	2326.8	-806.263
	π_d^{*D}	56830.89	50360.54	43894.9	37433.55	30988.74	24602.37
	π_{sc}^{*D}	71800.6	62164.23	52547.89	42949.84	33315.54	23796.11
A normal distribution (μ,σ)	π_b^{*D}	17636.99	17138.25	16654.84	16185.41	15728.82	15284.08
	π_d^{*D}	63148.09	62994.94	62846.5	62702.35	62562.14	62425.57
	π_{sc}^{*D}	80785.08	80133.19	79501.33	78887.76	78290.96	77709.65

5. Conclusions and Managerial Implications

This study has investigated the issue of supply chain coordination by applying TPT and CS contracts, in which the key decisions made by the supply chain players are determined under several conditions which are related to freight transport, and constraints imposed by the government to reduce GHG emissions. The proposed model in the supply chain uses the periodic review replenishment policy via the buyer (follower), whereby the distributor (leader) is responsible for determining the review period. Therefore, the distributor goes to the buyer's site and receives his/her orders, and then delivers them by using trucks after a fixed lead time, and the buyer decides only on the base stock quantity.

The distributor's decisions regarding the review period can affect the number of trucks used for replenishing the buyer's inventory level. Hence, the distributor's decision-making can increase/decrease the total amount of GHG emissions. In this situation where the main objective of the distributor is to increase profitability, he/she will not consider environmental issues when determining the review period. Therefore, the government imposes a constraint on GHG emissions in the supply chain.

In the proposed model, firstly, the decentralized scenario is modeled, in which the supply chain players seek only to increase their profitability and the Stackelberg game is used to find the optimum value of decision variables in the supply chain. After that, the integrated scenario is examined, where the optimization is based on the profitability of the whole supply chain. However, although the global optimization of the integrated scenario increases the profitability of the whole supply chain, it may cause a loss for the buyer, thereby discouraging him/her from cooperating with the distributor. Therefore, the TPT and CS contracts have been proposed to guarantee the profitability of all the supply chain players. These coordination mechanisms can achieve some significant results:

1. The buyer and the distributor have the bargaining power in these contracts, so coordination within the supply chain can be achieved easily.
2. Both the TPT and CS contracts have been able to facilitate effective coordination among supply chain players.
3. The results of modeling indicate that even if the government constraint intended to reduce the amount of transportation in the supply chain is not applied, the TPT contract will be able to reduce the amount of GHG emissions in the supply chain. Hence, this contract is a very effective means of implementing green supply chain management.

Therefore, when the government intervenes in all supply chain scenarios, the model involves fewer transportation trucks and less GHG emissions. The government's constraint increases the length of the review period to prevent the movement of unfilled trucks in the supply chain. So, increasing the review period increases the distributor's holding cost and the buyer's shortage cost, which can reduce their profitability. However, the results show that the TPT and CS contracts will largely compensate for this reduction in the profitability of the supply chain players. Furthermore, the findings from this study have several important implications for managers:

- From an economic perspective, the cooperation of the supply chain players during the review period, coupled with the safety factor, can improve individual profitability and increase the efficiency of the entire supply chain. Also, it can be said that the establishment of coordination mechanisms between players can significantly decrease any possible negative effects that government regulations could have on profitability. Hence, managers can benefit from the coordination models proposed in this paper (TPT and CS contracts) to improve the profitability of the whole supply chain and its players, rather than adhering to a decentralized scenario.
- In terms of the environment, the TPT contract as one of the coordination mechanisms proposed in this current study is capable of decreasing transportation to improve environmental performance, even without considering the government regulations. Due to its strong bargaining power, this contract can easily facilitate coordination between supply chain members and also reduce GHG emissions. This will mean that the supply chain managers who, in addition to increasing profitability, are also concerned with environmental issues, can take advantage of this contract.
- From a governmental regulation viewpoint, it can be said that if the environmental issues are not considered in the supply chain decision-making, one of the ways to decrease GHG emissions will be by government intervention. This problem can be seen in supply chains with a periodic review replenishment policy where players may cause an increase in freight transport by using unfilled trucks to increase profitability. So government authorities could use the model proposed in this paper to control freight transport and reduce GHG emissions.

For future studies, researchers are advised to use ~~a~~ more realistic supply chain scenarios by including the manufacturer in the decision-making process. Moreover, studies could be conducted to determine whether the implementation of government regulations via a transportation tax can effectively decrease GHG emissions in the supply chain.

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Appendix A

In this part, equation (11) represents the buyer's profit function, and the second derivative of this function over k^I must be negative ($\frac{\partial^2 \pi_b^D}{\partial k^{D2}} \leq 0$) .

$$\begin{aligned}\frac{\partial \pi_b^D}{\partial k^D} =& - h_b\left(\alpha\sqrt{LT+T^D} - \alpha\sigma\sqrt{LT+T^D}(1-F_z(k^D))\right)\\ &- \frac{\gamma_b+\alpha(p-w)}{T^D}\sigma\sqrt{LT+T^D}(1-F_z(k^D))\end{aligned} \tag{A1}$$

$$\frac{\partial^2 \pi_b^D}{\partial k^{D2}} = -f_z(k^D)\sigma\sqrt{LT+T^D}\left(h_b\alpha + \frac{\gamma_b+\alpha(p-w)}{T^D}\right) \tag{A2}$$

Because all the parameters of the problem are positive and $p > w$, it is clear that the second derivative in the decentralized SC scenario is negative.

Appendix B

To prove Lemma 2, the second derivative of the supply chain profit function over k^I must be negative ($\frac{\partial^2 \pi_{sc}^I}{\partial k^{I2}} \leq 0$) .

$$\begin{aligned}\frac{\partial \pi_{sc}^I}{\partial k^I} =& \frac{\alpha\sqrt{LT+T^I}(1-F_z(k^I))}{T^I}\left(\gamma_b+\alpha(p-\varpi)-\frac{h_d\alpha(n-1)T^I}{2}\right)\\ &-h_b\left(\sigma\sqrt{LT+T^I}-\alpha\sigma\sqrt{LT+T^I}(1-F_z(k^I))\right)\end{aligned} \tag{B1}$$

$$\frac{\partial^2 \pi_{sc}^I}{\partial k^{I2}} = \Big(\frac{h_d\alpha(n-1)T^I}{2} - \big(\gamma_b+\alpha(p-\varpi)+\alpha T^I h_b\big)\Big)\frac{\alpha\sqrt{LT+T^I}(f_z(k^I))}{T^I} \tag{B2}$$

Due to the condition below, the second derivative of the SC profit in the integrated scenario is negative.

$$\frac{h_d\alpha(n-1)T^I}{2} < \gamma_b+\alpha(p-\varpi)+\alpha T^I h_b \tag{B3}$$

Appendix C

To calculate the minimum value of the sharing ratio of the shortage cost ($\beta_{(T^*,k^*)}^{min}$), the buyer's profit function in the coordinated supply chain scenario based on the CS contract must be more than or equal to his/her profit function in the decentralized scenario, and can be proved easily with equation (C1) below:

$$\begin{aligned}&\pi_b^{CS} \geq \pi_b^D\\ &\quad\Rightarrow (p-w)\mu - h_b\left(\frac{\mu T^{CS}}{2}+k^{CS}\alpha\sqrt{LT+T^{CS}}+\alpha\sigma\sqrt{LT+T^{CS}}G(k^{CS})\right)\\ &\quad(1-\beta_{(T^*,k^*)}^{min})\frac{\gamma_b+\alpha(p-w)}{T^{CS}}\sigma\sqrt{LT+T^{CS}}G(k^{CS})\\ &\quad\geq (p-w)\mu - h_b\left(\frac{\mu T^D}{2}+k^D\alpha\sqrt{LT+T^D}+\alpha\sigma\sqrt{LT+T^D}G(k^D)\right)\\ &\quad-\frac{\gamma_b+\alpha(p-w)}{T^D}\sigma\sqrt{LT+T^D}G(k^D)\end{aligned} \tag{C1}$$

Appendix D

Also, the maximum value of the sharing ratio of the shortage cost ($\beta_{(T^*,k^*)}^{max}$), by using the distributor's profit function in the coordinated supply chain scenario based on the CS contract and his/her profit function in the decentralized scenario is calculated easily as shown in the equation (D1) below:

$$
\begin{aligned}
\pi_b^{CS} &\leq \pi_b^D \\
&\Rightarrow (w-\varpi)\Big(\mu-\alpha\frac{\sigma\sqrt{LT+T^{CS}}G(k^{CS})}{T^{CS}}\Big)-\frac{A_d}{nT^{CS}} \\
&-\frac{h_d(n-1)\Big(\mu T^{CS}-\alpha\sigma\sqrt{LT+T^{CS}}G(k^{CS})\Big)}{2}-\frac{\theta_d}{T}-CN\nu^{CS} \\
&-\beta^{max}_{(T^*,k^*)}\frac{\gamma_b+\alpha(p-w)}{T^{CS}}\sigma\sqrt{LT+T^{CS}}G(k^{CS}) \\
&\geq (w-\varpi)\Big(\mu-\alpha\frac{\sigma\sqrt{LT+T^{D}}G(k^{D})}{T^{D}}\Big)-\frac{A_d}{nT^{D}} \\
&-\frac{h_d(n-1)\Big(\mu T^{D}-\alpha\sigma\sqrt{LT+T^{D}}G(k^{D})\Big)}{2}-\frac{\theta_d}{T}-CN\nu^{D}
\end{aligned}
\tag{D1}
$$