

## Assessing the economic and environmental benefits of horizontal cooperation in delivery: Performance and scenario analysis

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### ABSTRACT

The growing environmental and economic concerns oblige logistics operations managers to look for simple solutions to optimize their processes and to incorporate sustainability in logistics networks. Logistics collaboration is one of the management practices to foster the sustainability of freight transport. This paper presents an 'ex ante' decision support tool to evaluate the economic and ecologic impacts of shippers' horizontal collaboration in urban freight delivery. Optimization model as a two-echelon location routing problem (2E-LRP) is exploited to demonstrate the benefits of joining facility location and vehicle routing decisions under multi-objective optimization approach. Numerical instances reproducing the real urban network are regenerated to test the proposed mechanism. Scenario analysis is conducted to analyze and discuss the effect of parameters' changes in generated gains.

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## 1. Introduction

The transport sector contributes to 14% of global greenhouse gas emissions<sup>1</sup>. Global Sustainable Transport Conference (2016) stated that without undertaking the transport sector the world will not be able to reach his goals under the Paris Agreement (2015). Accordingly, governments are under pressure to decarbonize the transport activities. Logistics collaboration is one of the adopted practices to develop sustainable transport and to adduce new efficiency and cost reduction to supply chain. Juvien (2011) defined the supply chain collaboration (SCC) as “two players (or more) of the Supply Chain seek to optimize together the logistics of the distribution circuit in which they are linked”. As stated by Palmer et al. (2018), collaboration is different from just sharing transport, or using a logistics service provider (LSP) as it requires a level of communication between partners to create value with more efficient transport, through orchestration and sequencing of freight. The most expanded classifications for SCC is referred to its direction. When members of the same chain value (industrial and distributor)

<sup>1</sup><https://cop24.gov.pl/presidency/initiatives/driving-change-together-partnership/>

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collaborate, this represents the vertical collaboration. In Horizontal collaboration, companies in the same level in supply chain collaborate (carriers, shippers or customers) (Taieb & Affes 2013). Lateral cooperation aims at gaining more flexibility by combining and sharing capabilities in vertical and horizontal channels (Simatupang & Sridharan 2002). CSC has gained increased attention in the field of supply chain management with the number of published articles over the last years. Although, horizontal collaboration has received little attention compared to vertical collaboration (Leitner et al., 2011; Moutaoukil et al., 2013; Amer & Eltawil, 2015; Soysal et al., 2018; Vos & Raa, 2016; Pan et al., 2019). Therefore, this paper focuses on horizontal collaboration.

Janjevic et al. (2018) identified three horizontal collaboration schemes according to the type of actors involved: (i) shipper collaboration with the goal of reducing transportation costs by making the use of the company's fleet more efficient, (ii) logistics service providers collaboration with the goal of decreasing operational costs or with the goal of improving delivery time and (iii) network collaboration where shippers and LSPs collaborate with the goal of decreasing operational costs simultaneously at both ends.

The network optimization is one of the several issues that need to be addressed for achieving successful horizontal collaborative transportation. From the transportation management's point of view, the recent literature reviews on logistics horizontal collaboration appeared in (Amer & Eltawil, 2014; Amer & Eltawil, 2015; Okdinawati & Simatupang, 2015; Gansterer & Hartl, 2018; Pan et al., 2019) and most recent studies proposing quantitative models for establishing horizontal collaboration and reveal that:

- Most of papers in horizontal collaboration were interested in cost and profit allocation (Frisk et al., 2010; Vanovermeire & Sörensen 2014; Defryn et al., 2016).
- Optimization of horizontal collaborative supply chain was principally consisting of single objective mathematical modeling approach dealing with economic occupation (Lozano et al., 2013; Adenso-díaz et al., 2014; Pérez-Bernabeu et al., 2015, Danloup et al., 2015; Tang et al., 2017; Quintero-Araujo et al., 2017).
- There are few studies on the problem of shippers' collaboration in comparison with carriers' collaboration. Related references (Gansterer et al., 2017).
- Most studies have focused on inter-urban transport problem (Pan, 2010).
- Larger part of papers on the subject established vehicle routing models to tackle the operational level of the supply chain and supposing that strategic facility location decisions have met in a prior step and cannot be modified (Gonzalez-feliu et al., 2010; Moutaoukil et al., 2013; Pérez-Bernabeu et al., 2015; Montoya-torres et al., 2016; Soysal et al., 2018).

To overcome this drawback and clarify the outcome of joining facility location and vehicle routing issues in the design of sustainable collaborative distribution network in urban area, we focus, in this paper, on the case of numerous shippers who choose to collaborate to serve their customers located in urban area. These shippers manage their fleets of vehicles. We suppose that large vehicles are forbidden to go inside inner-city and so, merchandise transit through intermediate points (depots or satellites) where it is unloaded and loaded in smaller vehicles assuring multi-drop deliveries to different customers. The common goals are to minimize, simultaneously, the transportation cost and the carbon emissions beside to determine the depots to open, the assignment of customers to these depots and routes assuring the delivery of goods.

This problem was modeled as a Two Echelons Location Routing Problem (2E-LRP) in our previous work (Ouhader & El kyal, 2017) where we studied the economic, ecologic and social impacts of joining facility location and vehicle routing problems in urban road freight transportation under horizontal collaboration. The problem was mostly analyzed under single-objective approach and trade-offs between the three metrics was presented. We confirmed that horizontal collaboration can contribute to a reduction in transportation costs and carbon emissions in such coalitions. However, collaboration has

a negative impact on the social dimension presented by the created job opportunities. To enhance our previous analysis, we focus, in the current paper, on how to balance the economic concern and environment protection in a collaborative coalition by adopting a multi-objective approach to copy with trade-offs among the two conflicting objectives. To the best of our knowledge and from the literature of shippers' horizontal collaboration in freight transport, very few papers have modeled a horizontal collaborative distribution network using location routing problem. Quintero-Araujo et al. (2017) and Nataraj et al. (2019) discussed the use of horizontal collaboration concepts in integrated routing and location decisions but using single echelon location routing problem (LRP) under single-objective approach to optimize distribution cost. Wang et al. (2018) proposed a bi-level programming model to solve multi-depot LRP for optimizing total cost and balance profits between upper and lower decision makers under single-objective approach.

Also, we note that there are very few papers that analyzed horizontal cooperation using multi-objectives approaches. Works like Pan et al. (2014), Ballot and Fontane (2010), Soysal et al. (2018) and Stellingwerf et al. (2018) focused on the optimization of the two objectives, transportation cost and emissions, but separately. Ballot and Fontane (2010) approved the ecologic performance of horizontal collaboration, used real data. Pan et al. (2014) presented models based on P-hub median problem and VRP to optimize independently the transportation cost and carbon emission. Soysal et al. (2018) studied a perishable food supply chain to assess the outcomes of horizontal collaboration in energy use (carbon emissions) and logistics cost based on Inventory Routing Problem (IRP) under single objective approach. Stellingwerf et al. (2018) quantified, separately, the economic and environmental benefits of implementing Joint Route Planning and Vendor Managed Inventory employing vehicle routing and an inventory routing models.

The works of Muñoz-villamizar et al. (2017), Arango-serna et al. (2018), Wang et al. (2018) and Defryn and Sörensen (2018) were the only studies found evaluating the impact of shippers horizontal collaborative transport network considering multi-objective approach. Arango-serna et al. (2018) proposed a genetic multi-objective model for the goods distribution optimization through collaborative inventory and transportation between several suppliers and customers. The Inventory routing problem (IRP) was used to optimize food distribution process in the downtown area of Medellín City in Colombia. The objective was the simultaneous optimization of inventory and transportation costs, service level, and the number of required trips. Muñoz-villamizar et al. (2017) studied the implementation of an electric fleet of vehicles in collaborative urban distribution of goods, in order to reduce environmental impacts while maintaining a level of service. They proposed an approach using mathematical modeling with multiple objectives, for tactical and operational decision-making to explore the relationship between the delivery cost and the sustainability impact. Wang et al. (2018) were interested in the collaborative multiple centers vehicle routing problem with simultaneous delivery and pickup (CMCVRPSDP) to optimize operating cost and the total number of vehicles in Chongqing city's logistics. Defryn and Sörensen (2018) proposed a multi-objective optimization models for the travelling salesman problem with horizontal cooperation to combine the coalition economic objectives with individual partner ones. These cited works were studied using variants of Vehicle routing problem (VRP) supposing that facility location decisions have met in a prior step and cannot be modified.

The main contribution of this current study is to develop, for decisions makers, a preliminary (ex-ante) decision mechanism to evaluate the economic and ecologic impacts of collaborative freight delivery in urban areas prior to shippers' acceptance to participate in a horizontal cooperation. We are interested in, simultaneously, quantifying how cooperation among suppliers, firms can lead to reduce delivery costs and carbon emission in different scenarios. The particularity of the proposed quantitative analysis is: **First**, the adoption of two-objective mathematical model to deal with the conflicting interests of stakeholders by a simultaneous optimization of cost and CO<sub>2</sub> emissions related to collaborative transportation rather than post estimation of CO<sub>2</sub> emissions after cost optimization as done by the

majority of similar works. **Second**, the exploitation of (2E-LRP) to study the effect of combining facility location and vehicle routing decisions in the design of sustainable collaborative supply chain under multi-objective approach. **Third**, the analysis is based on the regeneration of extended known instances for the 2E-LRP (Sterle 2009) which reproduce a reel schematic representation of a multi-level urban area but seldom analyzed example of horizontal collaboration. **Four**, the proposed mechanism has the advantage in showing explicitly how a change in parameters affects the performance and the configuration of the collaborative network with a single model to be developed and run for various scenarios. After this introductory part, the paper is organized as follows: The second section describes the adopted analysis approach and discusses the obtained results, whereas the last section deals with our conclusions for the sake of providing a new perspective.

## 2. Computational experiments

### 2.1. Description of the Approach

Our modeling approach is based on the 2E-LRP formulation proposed in our work (Ouhader & El kyal, 2018). The first objective function minimizes carbon emissions induced by trucks and vehicles. We referred to the European studies as Moutaoukil et al. (2013), Pan et al. (2013) and Moutaoukil et al. (2015) to estimate CO<sub>2</sub> emissions. These emissions depend on the weight carried by the vehicle, on the capacity of the vehicle that is used, on the travelled distance and the average speed of the vehicle.

To evaluate the impact of simultaneous consideration of economic and ecologic concerns besides joining location and routing decisions in collaborative urban transport networks, the proposed approach was tested using Sterle's instances (Sterle, 2009) which reproduce a reel schematic representation of a multi-level urban area. The performance of the developed model is addressed using 8 data sets ranging from small-scale instances to large ones. Each set includes 10 instances generated according to the following features: number of customers {15,25,40,75,100,150,200}, number of factories {2,3,4,5}, number of satellites {3,4,5,8,10,15,20}, demands in the range [1,100], capacities of satellites in the range [550; 950], opening costs are in the range [45; 75] and transshipment costs are in the range [0.02; 0.07], the transportation costs correspond to the Euclidean distances and they are doubled in the first level. A homogeneous fleet of vehicles and trucks is used. Their characteristics are summarized in Table 1. For the base case, the maximum route time T for urban route was fixed at 8h.

**Table 1**

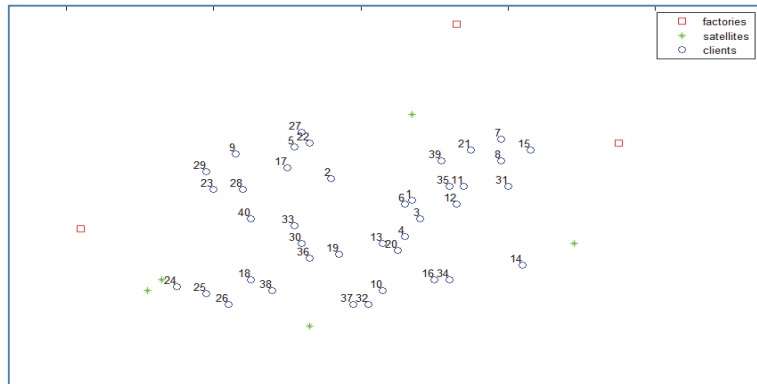
Truck and vehicle characteristics

	Trucks (regional routes)	Vehicle (urban routes)
Capacity	800	200
Fixed cost	100	50
Average speed (km/h)	45	20
$E_{(empty)}$ (g/CO <sub>2</sub> )	479.82	58,6
$E_{(full)}$ (g/CO <sub>2</sub> )	532.6	59

Origin-destination matrixes are regenerated according to the specifications of instances I1 explained in (Crainic et al., 2011) (see Fig. 1). For interested readers, the original instances are available in <http://claudio.contardo.org/instances/>. The model is tested using commercial solver (MATLAB 2014) on a 4.2 GHz Core i7 desktop with 16 GB RAM under Windows 10 environment desktop. In order to replicate the experiments, full origin-destination matrices, demand sets and the other parameters are available upon request to the corresponding author of this paper. The Two following scenarios are evaluated:

- Non collaborative scenario (NCS): the real scenario, which assumes that no collaboration exists and each supplier serves all its customers independently from the other suppliers. Quantification of economic and ecologic performance of this scenario is obtained summing up the individual costs and carbon emissions of all the suppliers. Here, we solve separately the model for each supplier.

- Collaborative scenario (CS): all suppliers are cooperating. Each factory has unshared customers with other partners. The anticipation of the coalition's performance implies that partners share some logistical information (demands, delivery dates, and locations of all the customers). Here we solve the model for the entire coalition.



**Fig. 1.** Nodes distribution in the 11 instances

For the considered scenarios, three cases are studied:

- C\_min case: an optimal solution, obtained when minimizing cost individually.
- Em\_min case: an optimal solution, obtained when minimizing carbon emissions individually
- C\_St\_Em case: Pareto optimal solutions, obtained when the bi-objective model is solved.

To generate a set of efficient solutions, we opt for the  $\epsilon$ -constraint method. The objective with higher priority is considered as the objective function (Transportation cost) while others are written as constraints (carbon emissions). The  $\epsilon$ -constraint is a posteriori articulation of preference method. The solution process is divided in two steps: first, generation of the efficient solutions. By following the same demarche as Khalili-Damghani et al. (2015), in epsilon constraint method, the range of minor objective function has been divided into 10 equal intervals after finishing the calculation of the payoff table. The right hand side of minor objective function, which has been a constraint, is set equal to one of the break points in each run (See Eq. (1)).

$$\Delta\epsilon = \text{Emissions (Em\_min case)} + \left( \frac{\text{Emissions(C\_min case)} - \text{Emissions(Em\_min case)}}{11} \right) \quad (1)$$

The optimum value of the main objective function is obtained while the minor objective function is equal to a feasible solution. This will cause generating non-dominated solutions. Iterating this procedure will result in generating the Pareto front. In the second step, the decision maker selects one of these solutions based on his/her preferences and priorities (Sadjadi & Heidari, 2014). In this problem, we evaluate the performance of the model in terms of the generated gains after horizontal collaboration under multi-objective approach for each set of instances. We consider as a benchmark, the total transportation cost resulting of carbon emissions that should not exceed a predefined admissible value. This value was defined to be slightly higher than the optimum emission level obtained in Em\_min case as a very strict environmental constraint. For each studied set, the averages of the obtained results are illustrated in columns 3,4,5 and 6 of Table 2. We compare partners' stand-alone cost and carbon emissions with those of constructed coalitions in the three cases. In C\_St\_Em case, the synergy value is measured by quantifying the minimum cost's gains that can be generated in the worst case. Here we compare the two costs of C\_min under NCS scenario and C\_St\_Em under CS scenario. Also, we quantify the maximum emissions' gains that can be generated in the most optimistic case by comparing the two amounts of CO<sub>2</sub> emissions of Em\_min under NCS scenario and C\_St\_Em under CS scenario. For each set, the averages of obtained results after running ten instances are presented in columns 7, 8 and 9 of Table 2 and in Table 3.

**Table 2**

Comparison of studied metrics between collaborative and non collaborative scenarios

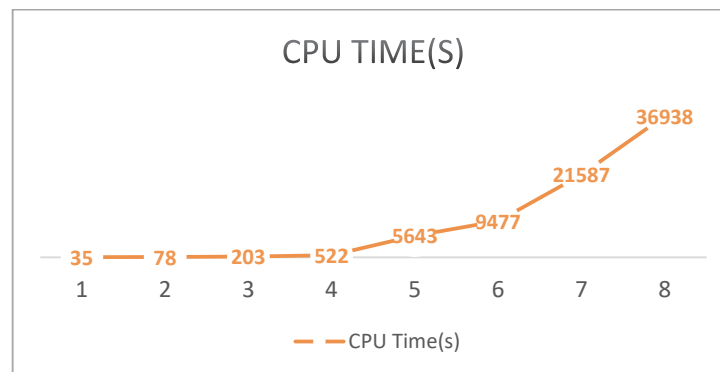
Samples	Sets	Non collaboration (NCS)				Collaboration (CS)					
		C_min		Em_min		C_min		Em_min		C_st_Em	
		Cost	(€)	CO2 (g/km)	Cost	(€)	CO2 (g/km)	Cost	(€)	CO2 (g/km)	CPU Time(s)
1	2-3-15	517		5576	465		3687	509		4389	35
2	3-4-25	1383		48740	1143		25803	1306		30309	78
3	3-5-40	2442		74436	1726		31422	2227		41187	203
4	4-6-60	3784		115438	2608		50634	3404		61234	522
5	4-8-75	5319		190213	3535		73118	4659		92890	5643
6	5-10-100	9088		359401	5846		109725	7595		130768	9477
7	5-15-150	16856		1420367	10600		400000	13600		485300	21587
8	5-20-200	22934		1740580	13765		375095	17954		554890	36938

A review of the CPU time for epsilon-constraint method shows that as the size of the problem is increased, CPU time increases (Fig. 2). As the problem is NP-Hard, the exact method, epsilon-constraint, cannot solve the large size instances in a reasonable time. For sample 8, the CPU time exceeds 10 hours. Computational results confirm that the collaborative cost and CO<sub>2</sub> emissions are always smaller than stand-alone values (see Table 2 and Fig. 3). Therefore, the gaps between collaborative and noncollaborative scenarios are positive. Regarding cost, these gaps ranged in [10,10%; 39,98%] for C\_min case and, at least, in [1,55%; 21,71%] for C\_St\_Em case. Regarding CO<sub>2</sub> emissions, the gaps ranged in [33,88%;78,45%] for Em\_min case and, at best, in [21,29%;68,12%] for C\_St\_Em case. Results confirm that jointly and optimally deciding on the location of depot and route of distribution can reduce total logistics costs and have a positive environmental impact under the scenario of collaboration. Numerical examples also show that gains improve as the number of partner's coalition increase meaning that more partners create more synergy value.

**Table 3**

The synergy value of collaborative scenario

Sample	Set	Gains			
		C_min Cost	Em_min CO2	C st Em Cost CO2	
1	2-3-15	10.10%	33.88%	1.55%	21.29%
2	3-4-25	17.37%	47.06%	5.57%	37.81%
3	3-5-40	29.33%	57.79%	8.82%	44.67%
4	4-6-60	31.08%	56.14%	10.04%	46.96%
5	4-8-75	33.54%	61.56%	12.41%	51.17%
6	5-10-100	35.67%	69.47%	16.43%	63.62%
7	5-15-150	37.11%	71.84%	19.32%	65.83%
8	5-20-200	39.98%	78.45%	21.71%	68.12%



**Fig. 2.** Runtime's evaluation of multi-objective solution based on network configuration (samples) in collaborative scenario

2.2. Numerical example

In practice, the majority of horizontal coalitions are formed with two or three partners (Senkel & Durand, 2013). Therefore, to perform our analysis and to provide a more illustrative discussion, we focus on the example of a network of 3 possible partners, 5 satellites and 40 costumers (Sample 3). We assume that partners, next referred to as F1, F2 and F3, have different sizes in terms of the volume of shipped products and number of customers (see Table 4).

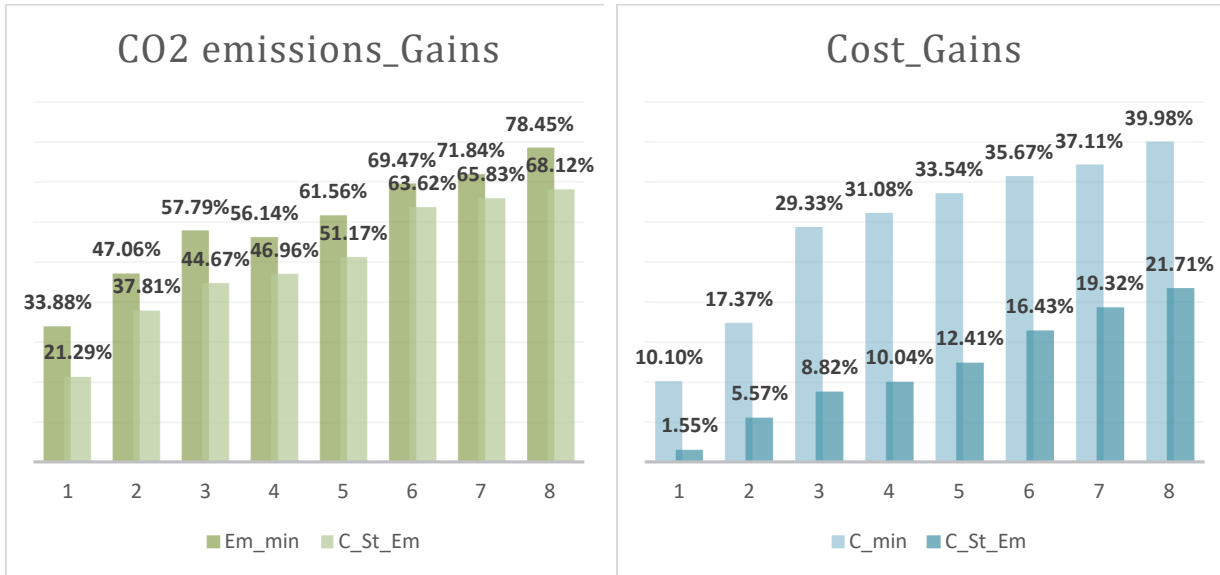


Fig. 3. Cost and emissions gains classified by samples and cases in collaborative scenario

Table 4

Partners' characteristics

Partner	Number of customers	% of the total shipped volume of the coalition
F1 (big size)	20	60%
F2 (medium size)	12	29%
F3 (small size)	8	11%

The studied set includes 10 instances generated according to the specifications described, previously. The averages of obtained results under mono-objective approach in collaborative scenario, are used to create the payoff table (Table 5).

Table 5

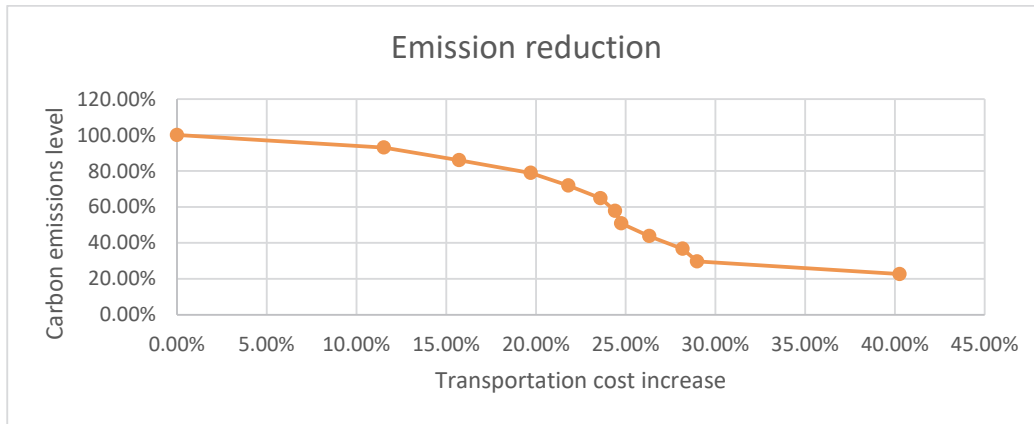
Payoff table of collaboration scenario

Objective function	Cost(€)	Emissions (g/CO2)
C min	1726	138836
Em min	2422	31422

By applying the  $\epsilon$  constraint method, we minimized the transportation cost of the coalition under transportation CO<sub>2</sub> emissions in a predefined admissible value  $\epsilon$  (C\_St\_Em case). We generated 10 instances by lowering  $\epsilon$  value by 7,03% from the highest emission level at each instance. Based on Eq. (1) and the payoff table, the amount of  $\epsilon$  for Pareto chart is calculated by the equation:

$$\epsilon = 138836 - \left( \frac{138836 - 31422}{11} \times \text{counter} \right). \tag{2}$$

The model is solved for different values of upper bounds of total carbon emissions. The tradeoff between Carbon emissions reduction and transportation cost increase is illustrated in Fig. 4.

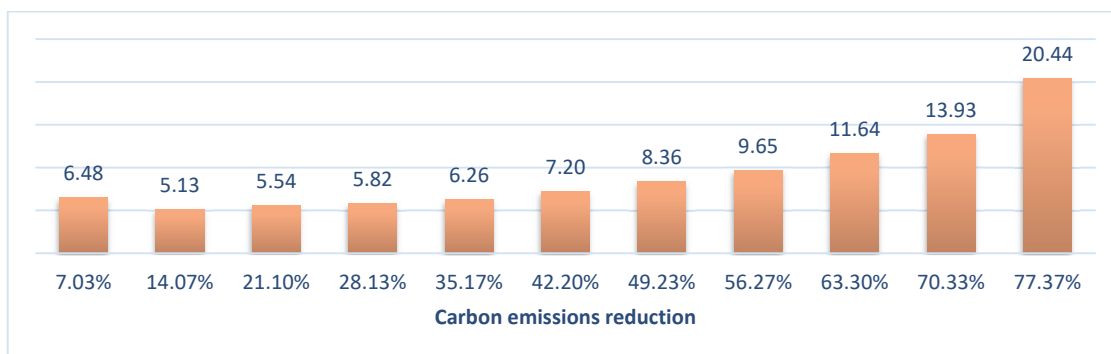


**Fig. 4.** Carbon emissions reduction Vs Transportation cost increase

From Fig. 4, we remark that the slope of the chart is decreasing. The total logistics cost increase as the upper bound of CO<sub>2</sub> emissions decreases. When CO<sub>2</sub> emissions level is around 29,67%, slop starts decreasing greatly. Therefore, the cost of achieving the same percentage of emissions reduction is increasing. This result has motivated us to calculate, for each instance, the Average Abatement Cost (AAC). For simplification, AAC is the average cost of reducing 1×Kg of CO<sub>2</sub> emissions. As observed in Fig. 5, the AAC increases when percentage of emissions reduction increases until the level 63,30% where the AAC increases greatly. This level corresponds to the point where the slop of the Pareto frontier is decreasing clearly. The AAC helps decision makers decide which abatement measures to implement in function of CO<sub>2</sub> emission reduction. For example, if the goal is to reduce carbon emissions by 28,13%, then the average abatement cost is equal to 5,82€/kgCO<sub>2</sub>.

We conclude that the transportation cost and CO<sub>2</sub> emissions are two conflicting objectives. Thus, the multi-objective optimization helps decision makers decide about the best trade-off by determining the cost of being sustainable from the point of reducing transportation emissions. Each one of the obtained solutions has to be evaluated by considering aspects not included in the model and taking into consideration aspects that might be predefined such as a budget for distribution or national laws that establish maximum allowable limits for CO<sub>2</sub> emissions.

To analyze and compare different scenarios of collaborative supply chain, one of the solutions in Fig. 4 can be selected. Emission level of 29,67% on the chart, equivalent to a reduction of 70,33% of CO<sub>2</sub> emissions, seems to be an ambitious ecologic solution. The AAC increased greatly in this level. For this solution other parameters can be assessed. Summary results for the three cases are presented in Table 6. The third to last columns show the total of travelled distances by trucks and vehicles, the number of used trucks, number of used vehicles (City freighters), the open satellites and number of assigned customers to these satellites, the average load rate of the tracks and the average load rate of the vehicles.



**Fig. 5.** Average abatement cost Vs carbon emissions reduction in collaborative scenario



Over all the three cases, these results show that the observed differences related to generated gains are linked to the change of travelled distances and number of vehicles due to the reallocation of customers to open satellites in each case.

**Table 6**

Summary results of comparison between different cases in collaborative scenario

Cases	Travelled distance (Km)	Trucks number	vehicles number	satellites number: opening satellites /number of assigned customers	TLR	VLR
C_min	648	5	10	3:S1/20;S3/14;S5/6	53,33%	92,92%
Em_min	351	5	11	3: S1/4;S3/20;S4/16	53,33%	79,00%
C_St_Em	438	6	10	3: S1/17;S3/14;S5/9	47,13%	92,83%

TLR: Average Load Rate of tracks VLR: Average Load Rate of vehicle

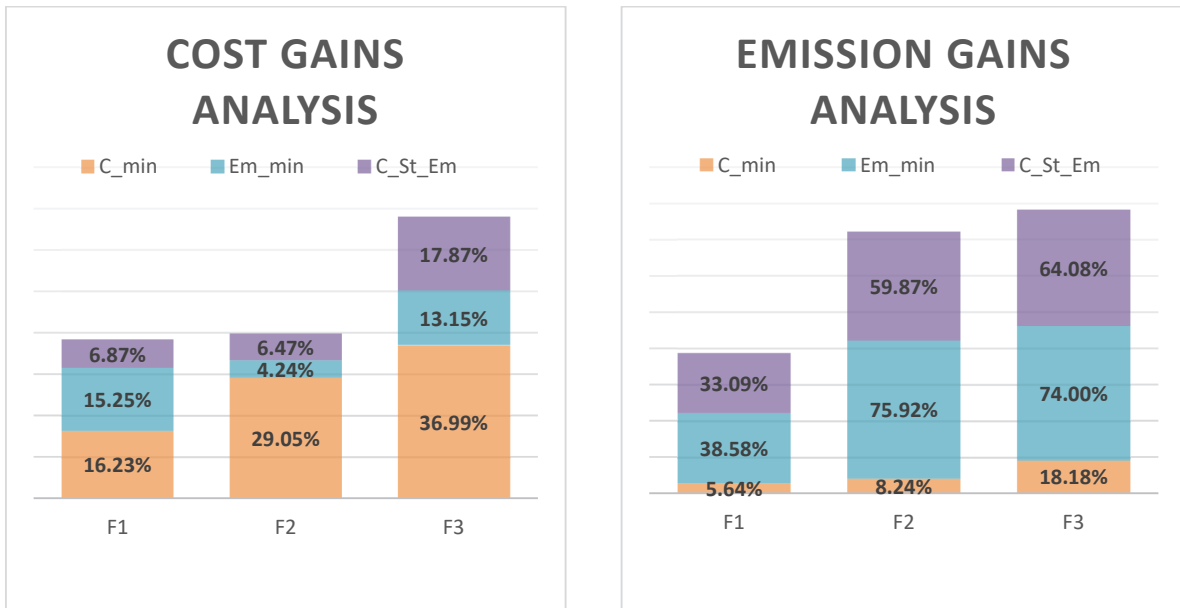
As in any collaboration, dividing the coalition gains in a fair manner between the participants constitutes a key issue (Verdonck et al., 2016). It is critical that each individual partner has a lower cost performance in collaboration compared to its stand- alone performance to have incentive to join the coalition. Therefore, an agreement must to be made to re-distribute the joint costs of the collaboration (Valeria et al., 2016). Recently, Guajardo (2016) provided a survey on cost allocation methods found in the literature on collaborative transportation and also described the theoretical basis for the main methods as well as the cases where they are used. The allocation methods are primarily formulated to distribute gains (cost) among members in collaborative scenarios but they are in principle useful for allocating emissions (Kellner & Otto 2012).

We investigate the well-known Shapley value, commonly considered as a possible best practice by the industry (Krajewska et al., 2007), especially, after that the method is gaining popularity as it was put forward by the European CO3-project (Defryn et al., 2016; Cruijssen & BV, 2012). As explained by Vanovermeire et al. (2014), for each player, this value is calculated as the weighted average of the marginal contributions of this player to any possible coalition that can be formed given the game at hand. This implies that the cost effect that each player generates when he is added to the coalition as well as the different sub-coalitions is used to determine the allocated profit. The cost allocated to partner  $p$  can be calculated by using (Eq.23). Given a player  $i$ , a coalition  $N$ , which consists of sub-coalitions  $S \subseteq N$ , that each generates a cost  $c(S)$ , the Shapley value is:

$$c_i^{Shapley} = \sum_{S \subseteq N \setminus i} \frac{|S|!(n-|S|-1)!}{n!} \times (c(S \cup i) - c(S)). \quad (3)$$

To be able to divide the two metrics according to the Shapley value, we created some lists that contain orders of all sub-coalitions and repeating precedent calculation for the three bases cases. First step, we evaluate the obtained solutions when each supplier stands alone in C\_St\_Em case. We minimize the total transportation cost by adding a constraint limiting the transportation CO<sub>2</sub> emissions in predefined value. This value was defined to be slightly higher than the optimum emission level obtained in Em\_min case. In second step, we compare between generated collaborative gains in the three base cases: C\_min, Em\_min and C\_St\_Em.

Fig. 6 demonstrates that horizontal collaboration is still beneficial to all partners in the C\_St\_Em case but not with the same importance in comparison with cases of mono-objective optimization. In fact, due to high fixed target for emissions reduction, the collaborative cost gain declined with more than one half in comparison to C\_min case for all the suppliers. Also, emission gains decreased compared to Em\_min case but they are relatively close to optimal target. We can also remark that when the supplier size increases, CO<sub>2</sub> emissions gains decrease. Supplier F3 (small size company) is always the largest beneficiary from collaboration in term of cost and emissions gains.



**Fig. 6.** Gain analysis of base cases in collaborative scenario

### 2.3. Scenarios analysis

The parameter values and assumptions of any model are subject to changes. Scenario analysis is adopted to evaluate the effect of changing parameters on model conditions and measuring the flexibility of model. To enhance our decision support tool, we study the effect of the changes in some factors on the attained synergy by the collaboration. We are interested in learning the effects of network structure, number of common customers, vehicles' speed and time deadline.

For the studied numerical example, we simulate each scenario in C\_St\_Em case under collaboration. In each studied scenario includes 10 instances generated according to the specifications described previously. The averages of obtained results are used to perform the analysis. E-constraint method was used to solve the problem. To perform the analysis, we compare the obtained results with a benchmark. The C\_St\_Em case in collaboration scenario, studied in previous section, was considered. Especially, emission level of 29,67% on the chart of Fig. 4, was the selected solution. Here the value of  $\epsilon$  was defined to be slightly higher than the optimum emission level obtained in the case of only minimization of carbon emissions.

#### 2.3.1. Impact of satellites localization

In our previous work (Ouhader & El kyal, 2018), we study the impact of satellites localization within the distribution area and the interdependency with the collaboration strategy. The idea was carried away from (Sterle, 2009). The analysis, in the cited work, was based on the impact of this localization on the aggregated benefits of horizontal collaboration without any mentioning of impact on individual performance of each supplier. Therefore, we studied two additional configurations I2 and I3 which differ in the location of the satellites according to the configurations presented with green stars in Fig.7. In addition to the initial configuration I1, the two configurations I2 and I3 were simulated in standalone and collaborative scenarios following the same simulation process described in precedent section.

Concerning the individual gains allocated to each supplier, Fig. 8 shows that configuration I2 and I3 are, respectively, the most beneficial for F1 and F2 in terms of cost and carbon emissions. For F3, the most advantageous configuration was I2 considering cost and I1 considering carbon emissions. We

conclude that decision making about the location of depots is of great importance and can affect the performance of the coalition. The relocation of the open depots and customers can lead to further economic and ecological savings.

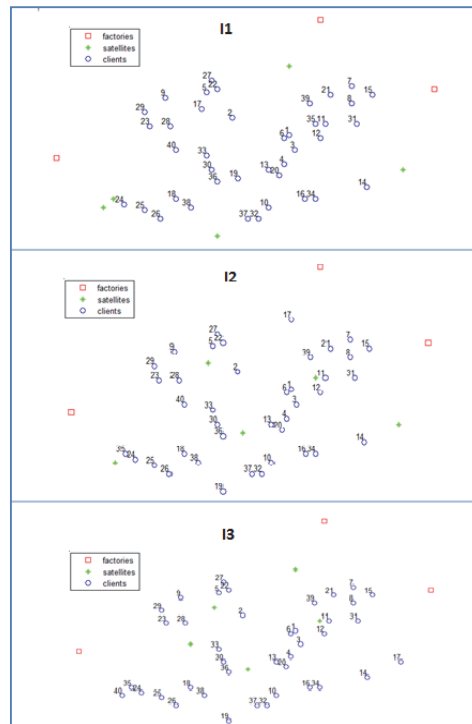


Fig. 7. Satellite distribution in the three set instances

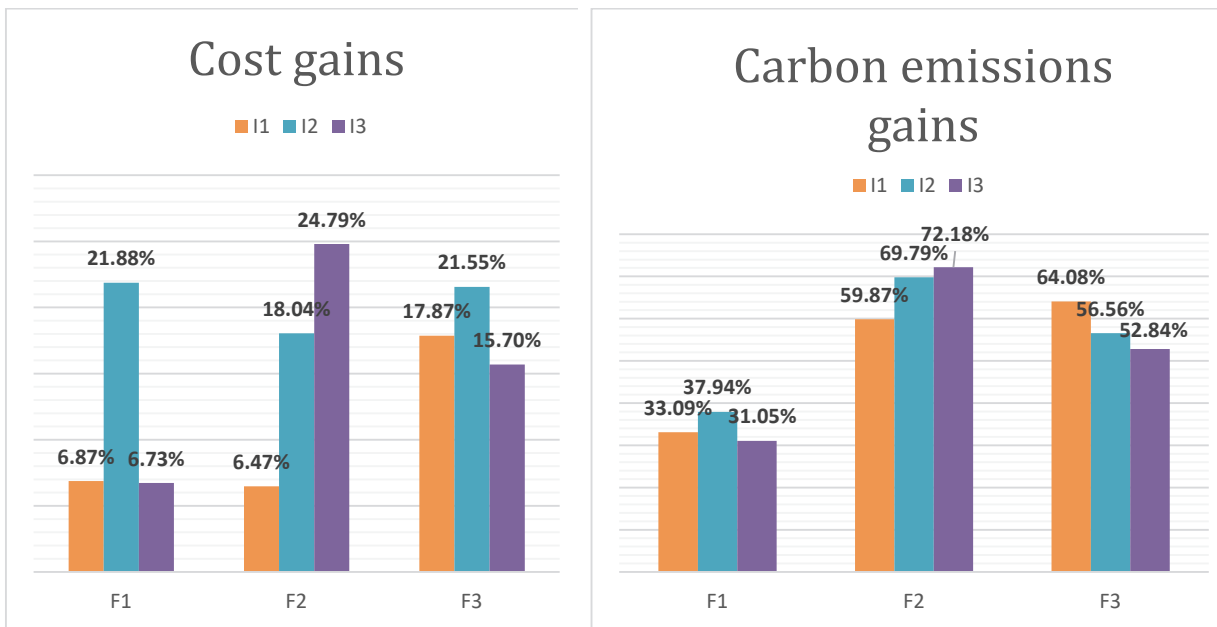


Fig. 8. Comparison between gains allocated to each supplier in configuration I1,I2 and I3

2.3.2. Impact of increasing the number of partners' customers

We analyze, in this section, the effect of increasing the number of each supplier's customer. Three additional scenarios have been simulated where we augment by ten the customers' number of one

supplier: Increase\_F1, Increase\_F2 and Increase\_F3. Fig.9 shows that the number of customers influences the attained gains in a positive way. Serving 50 customers instead of 40 adds 4.49% and 14.16%, respectively, to the collaborative aggregated cost and carbon emissions gains. The increase of F1 customers' number is more beneficial for the coalition. Focusing in the individual allocated gains, Fig.10 shows that, when a supplier integrates more customers to the coalition, he increases his cost and carbon emissions savings to the detriment of other suppliers.

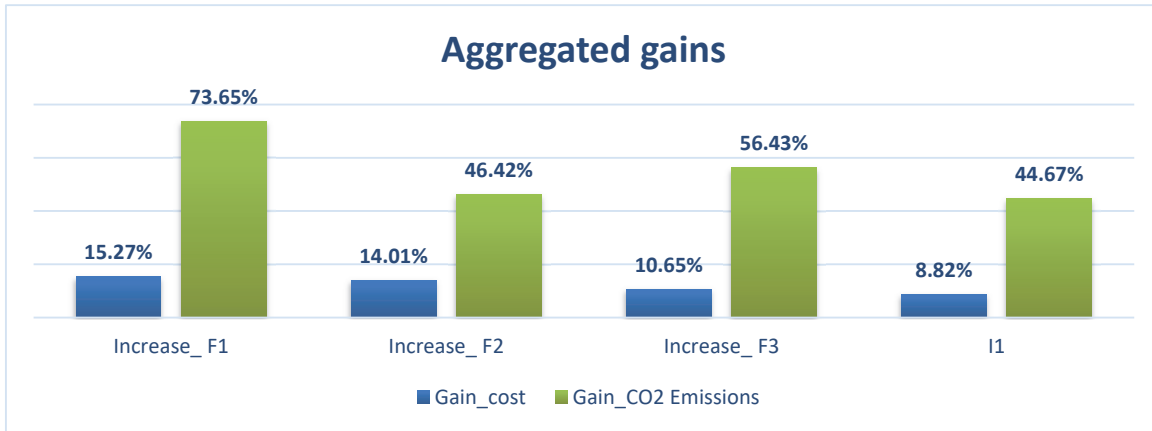


Fig. 7. Comparison of aggregated gains in the scenario of increasing the customers' number

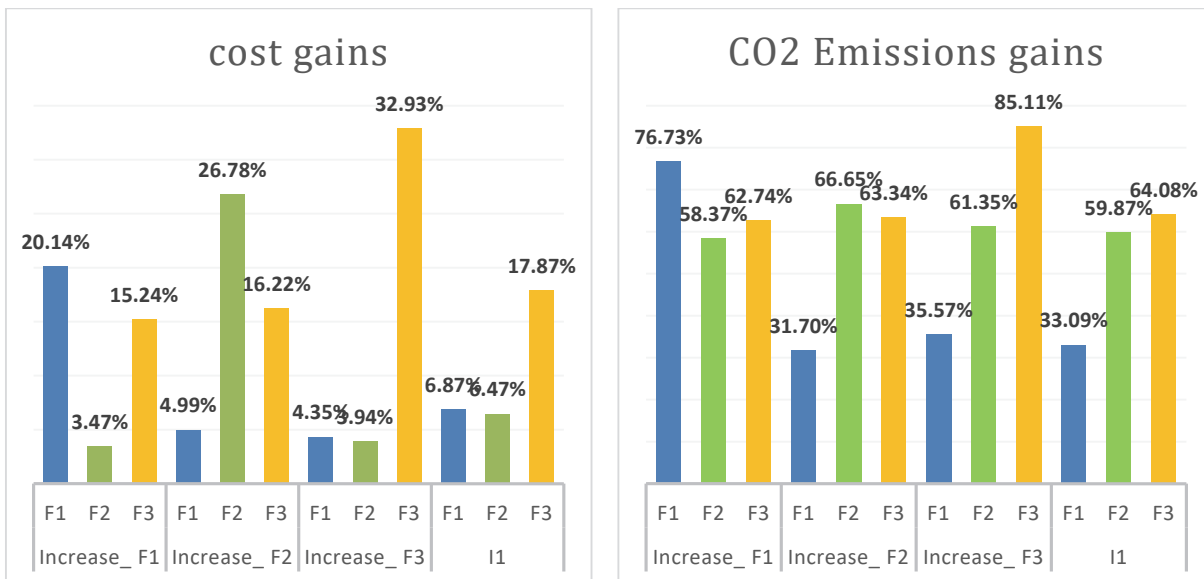


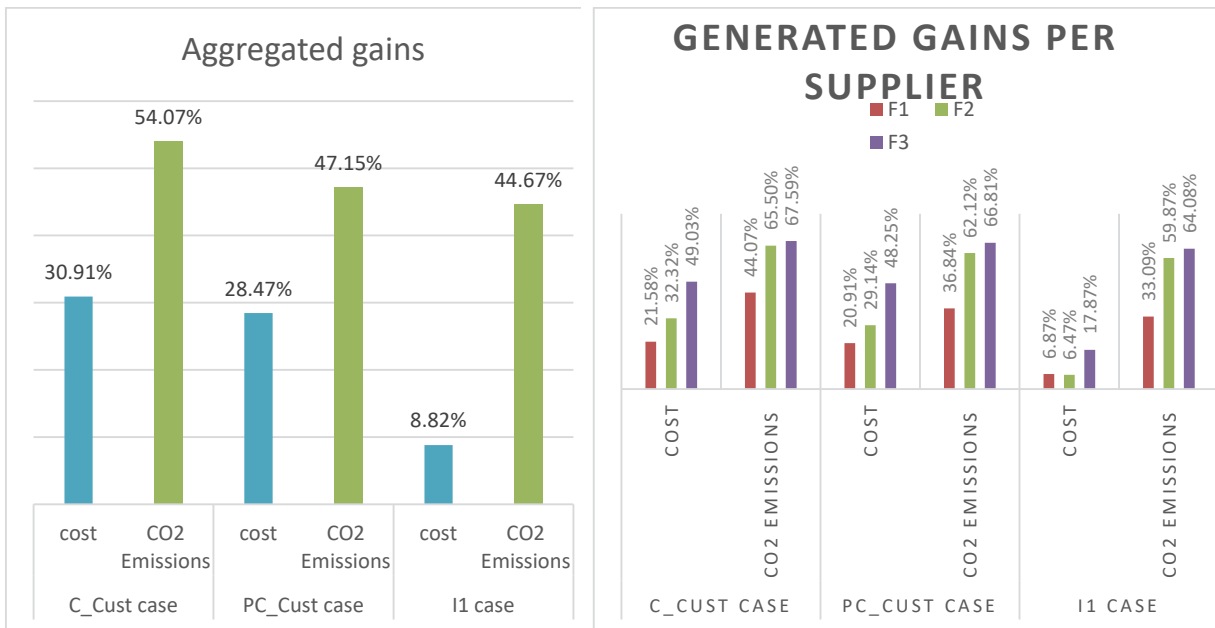
Fig. 8. Comparison between allocated gains to each supplier in the scenario of increasing the customers' number

2.3.3. Impact of the number of common customers

Here, we study the effect of common or shared customers between coalition's partners (customers have request goods from more than one shipper) on the attained synergy by the collaboration in the economic and environmental benefits to assess the opportunities offered by the horizontal collaboration. In the base case I1, all customers were non-common. Each supplier has his own and unshared customers with other partners. Customers could, also, be common and they necessarily order from all suppliers (C\_Cust case) or partially common and they are not forced to order from all suppliers (PC\_Cust case). To

highlight to effect of the number of common customers in collaboration, we analyzed the three cases: I1, C\_Cust case and PC\_Cust case.

The summary results, presented in Fig 11, show that sharing more common customers, influences the generated cost and carbon emissions savings in a positive way. Aggregated cost and carbon emissions gains have gone up, respectively, from 8.82% to 30.91% and from 44.67% to 54.07% in the scenario where all customers were common. The same trend was observed for individual gains allocated to suppliers. For example, for F1, cost and carbon emissions gains have increased, respectively, from 6.87% to 21.58% and from 33.09% to 44.07%, in C\_Cust case. These findings can be explained by the reduction in the travelled distances and the number of open depots besides the new allocation of customers to depots. We also note that the computing time decreases as the percentage of shared customers increase. This is due to the size of instances that increases as the number of customers that cannot be shared increases.



**Fig. 11.** Comparison between aggregated and allocated gains in the scenario of increasing the common customers' number

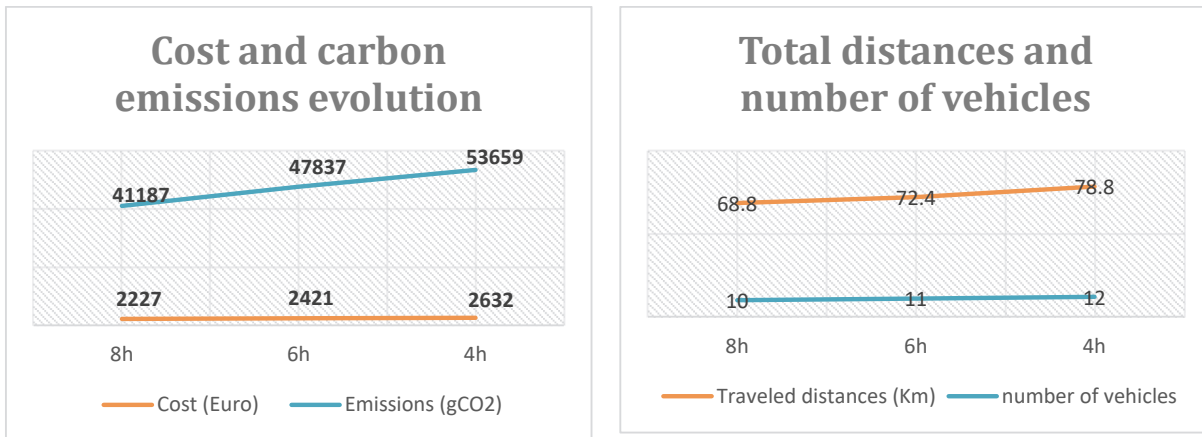
#### 2.3.4. Impact of changes in other parameters

We can evaluate the effects of the changes in several parameters in the model. As is stated by Figliozzi (2010), the travel distance of a vehicle is an important element in tactical and strategic models to solve problems such as location and network design. In the base case I1, the maximum route time  $T$  was 8h. In practice, local authorities can impose a restriction or rules to limit the time duration for distribution. To investigate the effect of this restriction, we analyze two additional scenarios:

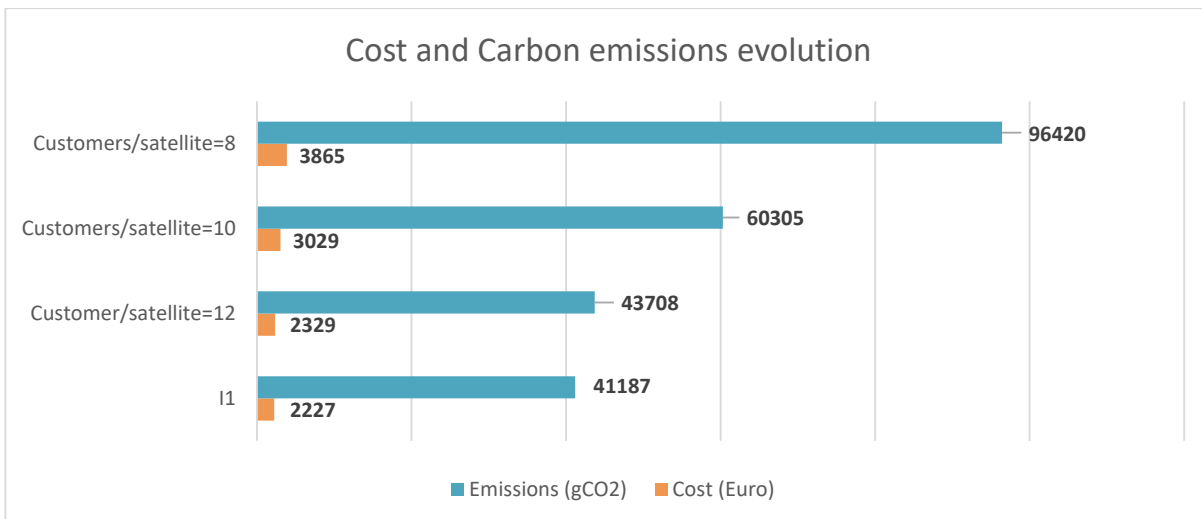
(1) Time 6 ( $T=6h$ ) and (2) Time4 ( $T=4h$ ). From Fig.12, when the time deadline became shorter, total cost and carbon emissions have increased, respectively, from 2227 Euros to 2632 Euros and from 41187g ( $CO_2$ ) to 53659 g( $CO_2$ ). In this case, total travelled distances augment and the network has used more vehicles to satisfy customer's demands.

Also, we can analyze the effect of adding restrictions on the maximum number of customers assigned to each opened satellite. Fig. 13 shows that decreasing this number from 12 to 8, increases aggregated

cost and total carbon emissions. This is due to the increase of open satellites, the reallocation of customers and therefore the increase of travelled distances.



**Fig. 9.** Evolution of cost, carbon emissions, total distances and number of vehicles in function of maximum time deadline in collaborative scenario



**Fig. 13.** Evolution of cost and carbon emissions in function of customers' number per satellite under collaborative scenario

### 3. Conclusion

In this research we have presented to decision makers a quantitative mechanism to preliminary evaluate the economic and environmental effects of collaborative freight delivery in urban areas before that companies agree to participate in a horizontal cooperation scheme. In particular, 17 scenarios have been formulated for the analysis (Table 9). This quantitative analysis was based on multi-objective mathematical model for a two-echelon location routing problem (2E-LRP). Extended known instances reflecting the real distribution in urban area were regenerated to evaluate several goods' delivery strategies. Shapley value method, belonging to the field of cooperative game theory, was used to allocate cost and CO<sub>2</sub> emissions to partners of the coalition. The obtained results confirm that horizontal collaboration leads to a reduction in transport costs and enhances the ecologic performance of partners in such coalitions. We have also shown that the combination of facility location and vehicle routing provides significant gains on studied metrics than separate decisions. Therefore, decision making about the location of depots and the routes of distribution is of great importance and can affect the

collaborative supply chain. Referring to the multi-objective analysis, the incorporation of environmental concern in addition to economic one impacted the generated gains. Scenario analyses have shown that the obtained gains were dependent on several modeling parameters as number of partner, network structure, number of common customers, vehicles speeds and route time.

This research can be beneficial to many distribution network design problems in different industries, and obtains lots of benefits in real cases. For further extensions and improvement, we can apply the proposed approach in real cases such e-commerce, drug distribution and retail. Another extension of the model could be incorporated the individual preference of each partner or consider additional objectives as customer service level. It is important to note that the model can be easily extended to consider multi-period planning framework. The complexity of the adopted model requires choosing a heuristic resolution, especially for instances with a large number of served points.

**Table 7**  
Analyzed scenarios

Scenarios	Description
1 C min	minimizing cost under single objective approach
2 Em_min	minimizing emissions under single objective approach
3 C St Em	cost minimization versus CO2 emissions reduction
4 I2	Network Configuration I2
5 I3	Network Configuration I3
6 Increase_F1	augmentation of the F1 customers' number
7 Increase_F2	augmentation of the F2 customers' number
8 Increase_F3	augmentation of the F3 customers' number
9 C Cust case	Total common customers
10 PC Cust case	partially common customers
11 Time4	Route time equal to 4 hours
12 Time6	Route time equal to 6 hours
13 Costumers/satellite=8	Max 8 customers assigned to each opened satellite
14 Costumers/satellite=10	Max 10 customers assigned to each opened satellite
15 Costumers/satellite=12	Max 12 customers assigned to each opened satellite

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