A fuzzy rule-based multi-criterion approach for a cooperative green supplier selection problem

Parisa Rafigh1 · Ali Akbar Akbari1 · Hadi Mohammadi Bidhendi1 · Ali Husseinzadeh Kashan2

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Abstract
Multi-criterion decision-making models are widely used in supplier selection problems. This study contributes to a green supplier selection problem considering the green manufacturing, green transportation, and green procurement. This study contributes to reverse logistics, eco-design, reusing, recycling, and remanufacturing with their high impact on the industries. In addition to the logistics costs and transportation costs, the carbon emissions are considered. With regard to the game theory, this paper uses a cooperative green supplier selection model. If transportation requirements of two or more companies are combined, it will help manufacturers to have less CO₂ emissions with lower cost. After creating the optimization model to consider the uncertainty, this cooperative game theory model is established in a fuzzy environment. In this regard, a fuzzy rule-based (FRB) system is deployed and the set of fuzzy IF–THEN rules is considered. The proposed FRB model is contributed for the first time in the area of green supplier selection problem. Finally, some sensitivity analyses are conducted in a numerical example to evaluate the proposed model. With regard to the findings, although the cost of CO₂ emission of horizontal cooperation is increased, the cost saving of companies is increased. It means our total cost is optimal in a logistic network using the cooperative game theory. The results also indicate that horizontal cooperation in logistic network causes less cost and benefits for each company.

Keywords Fuzzy rule-base system · CO₂ emissions · Cooperative game theory · Green supplier selection

Introduction
A supply chain (SC) consists of a large variety of collaborative contracts and facilities integrating them into a collaborative system (Lozano, et al., 2013; Lozano, 2012). A conceptual model to manage a supply chain network is done by the supply chain management (SCM) (Sarkis et al., 2011). The SCM includes different sectors from supplier selection, transportation, manufacturing, recycling, and disposal (Dulebenets, 2018; Abioye, et al., 2019; Yazdani et al., 2021; Gholizadeh et al., 2021). A forward SC network design focuses on the selection of suppliers, manufacturing and transportation of products to customers, while a reverse SC network design collects the retuned products from customers to do the recycling and disposal activities. In both types of SCM, the greenhouse gases (GHG) are generated by the shipping of products among facilities. This concept shifts the SCM to the green SCM (GSCM) contributing to the recycling technology, clean production, and green design, with the goal of minimization of energy and resources consumption and environmental emissions especially CO₂ emissions (Sarkis et al., 2011; Fatollahi-Fard, et al., 2020a; Song et al., 2020). Due to the importance of GSCM, this study motivates an optimization model and a game theory approach as the main tools to address supply chains and logistics challenges.
The cooperative game theory (CGT) can be used for modeling of SCM and GSCM to address the cooperation among suppliers (Li, & Zhang, 2015). The CGT is mainly used to maximize the benefits for distribution when two or more companies are cooperated together (Hafezalkotob, 2015). In addition to the supply chains, the CGT has many other applications to scheduling, cost saving, negotiation and bargaining (Khalili-Damghani, & Sadi-Nezhad, 2013a; 2013b). In each game, two or more players are contributed and cooperated by forming such coalitions (Li, & Zhang, 2015; Tippayawong, et al., 2016). The transportation of products creates the GHG emissions and the GHG volumes can be allocated to different objects with regards to different parts of a supply chain network (Fathollahi-Fard et al., 2021; Ali et al., 2021). This study aims to address all objects of GHG volumes and establishes the CGT model to address a green supplier selection model in a supply chain network.

With regard to recent reports, many efforts are done to engage in development of green economy in the developed countries, e.g., USA, Denmark, UK, France, Austria, and Japan (Mojtahedi, et al., 2021; Pasha et al., 2021). The trade among these countries is facing with several uncertain factors based on environmental issue (Wang, & Kopfer, 2015; Ummalla, & Samal, 2018; Fallahpour et al., 2021). For example, the depletion of the ozone layer and climate changes are highly concerned by international committees and governments (Wang et al., 2021; Yu et al., 2021). However, in a supply chain network from suppliers to customers, many logistics activities and industrial processes have been linked to an increase in the GHG through CO₂ emissions (Andersson, et al., 2018; Nejatian et al., 2021; Mohammadi et al., 2021; Zhou, et al., 2020). This study proposes a comprehensive framework to address CO₂ emissions based on the green manufacturing, green transportation, and green procurement.

The proposed CGT method has some advantages in comparison with majority of studies in the area of GSCM. First, it follows a hierarchy process to make the decisions for suppliers. It goes without saying that facilities must be allocated to ship the products using vehicles in an efficient way. For transportation of products, there are many operations such as air plane and oil pipeline that have used in a few supply chain network models. Concerning to CO₂ emissions, this study aims to maximize the flow of products to reduce CO₂ emissions to have a lower cost. Generally, the atmospheric CO₂ levels can be stabilized through climate change policies. This study contributes to different CO₂ levels in our CGT model as local markets gets involved in the global trading market (Fallahpour, et al., 2021; Mojtahedi et al., 2021). Generally, in the proposed cooperative green supplier selection problem, a comprehensive cooperation is done to reduce the CO₂ emissions while optimizing the total cost and flow of products.

All in all, this study contributes a novel fuzzy rule-based (FRB) approach for a cooperative green supplier selection problem. This study aims to respond to the following research questions:

- RQ1: How can the transportation cost be reduced when the suppliers are cooperated together?
- RQ2: How can the CO₂ emission be reduced in a cooperative supplier selection system?
- RQ3: How can we choose the green suppliers with regards to the GSCM concept and FRB model?

The rest of this paper is organized as follows. The literature review is evaluated in the “Literature review” section. The “Proposed framework” section defines assumptions and develops the multi-objective optimization model. The proposed FRB approach to tackle the proposed problem in the “Proposed FRB system” section. The “Numerical example” section tests a numerical example and does some sensitivity analyses. Finally, the “Conclusion” section provides a summary of this research and future research works.

**Literature review**

Relevant studies to this paper are in the area of supply chain network design, supplier selection and CGT for the distribution network. For example, Lozano (2012) represented a cooperative data evolution analysis (DEA) based on the CGT to increase the economic share. Kellner and Otto (2012) considered the allocation of CO₂ emissions to shipments in road freight transportation. Lozano et al. (2013) proposed the CGT to measure the benefits for reduction in the transportation. Khalili-Damghani, & Sadi-Nezhad, (2013a) developed a decision support system for the supplier selection accommodated in a fuzzy environment. The developed decision support system consisted of two major modules. The first one was a fuzzy programing with several set of constraints about budget and other required resources in the fuzzy environment and the second module of this system was an FRB system. Khalili-Damghani, & Sadi-Nezhad, (2013b) solved a multi-objective supplier selection problem considering both financial/non-financial and internal/external factors. The proposed decision support system contained two main modules. The first module was formed through TOPSIS based on goal programing. This uncertain preference was modeled using linguist term and parameterized through liner fuzzy relation. Li and Zhang (2015) considered cooperation through capacity sharing between competing forwarders. Hafezalkotob (2015) proposed the competition of two green and regular supply chains for both government and enterprises’ benefits. Üçler, et al., (2015) combined a CGT with fuzzy programming approach for a
bi-objective supply chain network in Turkey to make an interaction between economic and environmental factors. Zhao et al., (2018) proposed evolutionary algorithms for a CGT to model interaction between distributors and customers based on strategic and environmental decisions to reduce CO₂ emissions.

Recently, Safaeian et al., (2019) proposed a multi-objective supplier selection and order allocation problem considering incremental discount in a fuzzy environment. This model optimizes the total cost, price of products, quality level and the environmental pollution. Al-Sheyadi et al., (2019) evaluated different strategies for implementation of green supply chain management in Oman. A data driven approach is developed to handle their simulation model. Peng et al., (2019) developed a system dynamic model to construct the stock-flow graph to introduce a CGT between government and enterprises. Fathollahi-Fard et al., (2020a) proposed a sustainable supply chain network design for recycling, and reusing wastewater in the west Azerbaijan province. Zhang et al., (2020) developed an interval-valued intuitionistic uncertain approach for the risk-based supplier selection management. Fathollahi-Fard et al., (2020b) developed three heuristics for a healthcare network design to do the routing and scheduling of nurses. In another study, they (Fathollahi-Fard et al., 2020c) introduced an adaptive Lagrangian relaxation algorithm for a supply chain network design problem. Collins, & Kumral, (2020) developed a CGT based on a multi-criterion analysis for implantation of economic and environmental criteria in the mining industry in Turkey. Loganathan, et al., (2020) proposed the environmental Kuznets curve hypothesis to estimate bootstrap quantile to assess the productivity, carbon taxes and natural resources in Malaysia from 1970 to 2018. Javad et al., (2020) implemented a green supply chain management in the Khuzestan steel company. A fuzzy TOPSIS method is analyzed to select the green suppliers with regards to demand fluctuations.

More recently, Fallahpour et al., (2021) offered both sustainability and resiliency criteria to propose a supplier selection decision-making model and addressed it by a hybrid heuristic fuzzy decision-making model. Mojtahedi et al., (2021) proposed a sustainable logistics for coordinated solid waste management using an adaptive memory search. Ali et al., (2021) proposed a decision-making approach based on fuzzy analytic hierarchy process based on the Delphi method to evaluate criteria and factors to achieve the supply chain resiliency. Pasha et al., (2021) considered the green emissions and environmental pollution for the liner shipping in the offshore logistics and simulated this problem by a comprehensive optimization model. Theophilus, et al., (2021) proposed an optimization of truck scheduling for the distribution network in the case of Walmart Company in the USA. Dong, et al., (2021) evaluated an energy-efficient production system using an adaptive fuzzy logic-based model and applied a novel metaheuristic algorithm based on evolutionary searches. Lin et al., (2021) developed a multi-stage CGT model for analyzing the long-term green supply chain management. The first stage selects the green suppliers. The second stage decides the prices for suppliers with regards to a green competition among them. Finally, the green shipping lines are selected to satisfy the demand of customers and retailers. The latest study is Rafigh et al., (2021) who developed a sustainable closed-loop supply chain network design including allocation, inventory and pricing decisions for a healthcare logistics network. They proposed a possibilistic-stochastic programming approach to simulate a case study in Iran during the COVID-19 pandemic.

Generally, the aforementioned papers can be classified into two groups. One group focuses on the development of new optimization and game theories for the supply chains and supplier selection management. Another group tries to develop new solutions in this field. This paper is classified into the first group. Although there are many similar models in the area of supplier selection, distribution networks and supply chain design, this study is different from them. To highlight the difference of proposed model with aforementioned papers, Table 1 collected the most relevant works in the area of supplier selection, distribution networks and supply chain design, this study is different from them. To highlight the difference of proposed model with aforementioned papers, Table 1 collected the most relevant works in different criteria including uncertainty approaches, types of network design, objective functions, supplier selection and game theory. In the proposed classification, uncertainty approaches are the fuzzy, stochastic and possibilistic methods. The network design is divided into forward and reverse logistics networks. Finally, the objective functions are the cost and environmental impacts.

One finding from Table 1 is that the present study in comparison with similar papers contributing to the supplier selection and the game theory, has more contributions. They are the simultaneous consideration of a fuzzy environment for both the total cost and environmental pollution criteria. In conclusion, this paper for the first time in the literature proposes a multi-criterion-based FRB model to develop a cooperative green supplier selection problem in a supply chain network.

Proposed framework

The proposed framework to model a supply chain network analyzing the supplier selection is given in Fig. 1. This paper focuses on the transportation cost and carbon emissions cost to establish our GCT model. Then, some criteria based on the total cost, manufacturing process and all reverse logistics activities are considered to evaluate our optimization model. In this regard, the proposed FRB model is implemented to evaluate the criteria and the optimality of our solutions for different companies in our study. Finally, a discussion to
Table 1 Review of relevant studies

| Reference                                | Uncertainty | Network type | Objective function | Supplier selection | Game theory |
|------------------------------------------|-------------|--------------|--------------------|--------------------|-------------|
|                                          |  Fuzzy      |  Stochastic  |  Possibilistic     |  Forward |  Reverse |  Cost |  Environmental impact |                 |             |
| Lozano et al. (2013)                     | √           |              |  √                 |  √      |  √|  √ |  √ |  √ |
| Tavana and Khalili-Damghani (2014)       | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Khalili-Damghani et al., (2014)          | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Selvaraj et al., (2020)                  | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Mu et al. (2012)                         | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Dulebenets et al., (2018)                | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Abioye et al. (2019)                     | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Andersson et al. (2018)                  | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Yu et al., (2012)                        | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Adom et al., (2018)                      | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Collins et al., (2020)                   | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Ryu et al., (2020)                       | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Fathollahi-Fard et al., (2020a)          | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Fathollahi-Fard et al., (2020c)          | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Li et al., (2015)                        | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Lozano et al., (2020a)                   | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Safaeian et al., (2019)                  | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Fallahpour, et al., (2020)               | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| Rafigh et al., (2021)                    | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |
| This study                               | √           |              |  √                 |  √      |  √ |  √ |  √ |  √ |

![Proposed framework of this paper](image-url)

Fig. 1 Proposed framework of this paper
analyze the benefits from our solutions is given. Here, we first establish our optimization model based on the following assumptions:

- All products should be transferred in proportion from each node using vehicles (Mojtahedi et al., 2021).
- This problem is based on the CGT and the transferable utility is often employed in the CGT in our proposed problem (Hafezalkotob, 2015).
- There are a finite number of companies as the suppliers (Safaeian et al., 2019).
- Amount of shipment per week is known and clear for companies (Safaeian et al., 2019).
- There are a number of vehicles and each of them has a specific capacity (Mojtahedi et al., 2021).
- Cost and time of products which are shipped between different locations are known (Fathollahi-Fard et al., 2020a; 2020c).
- Speed of the vehicles is predefined before running the model (Mojtahedi et al., 2021).
- Destinations of the supply chain network should be unique and cannot be changed (Hafezalkotob, 2015).

Before introducing the proposed optimization model, following notations are defined:

**Indices**

$i, j$: Index of locations or destinations of deliveries.

$k$: Index of vehicles.

**Parameters**

$S$: Number of collaborating companies.

$N$: Number of all companies.

$P$: Number of collaborating companies in coalition $P$.

$Q_p^i$: Amount of products which should be shipped weekly between locations $i$ and $j$ by company $P$. $Q_p^i$: Total amount to be shipped by coalition $S$ between locations $i$ and $j$ ($Q_p^i = \sum_{p \in S} Q_p^i$)

$W_k$: Capacity of vehicle type $K$.

$t_{ijk}$: Transportation cost between locations $i$ and $j$ using a vehicle type $k$.

$a_{ik}$: Penalty cost of unmatched trips to location $i$ using vehicles type $k$.

$c_{ijk}$: Capacity of arc $i, j$ of vehicle $k$.

$L_{ijk}$: Amount of loading using vehicle $k$ for arc $(i, j)$ which should be transported.

$d_{ij}$: Distance between $i$ and $j$.

$E_{C_f}$: Energy consumption for fuel of vehicles when it is full.

$EF$: $CO_2$ emission cost per unit produced during the combustion of a certain amount of fuel.

**Decision variables**

$X_{ijk}$: Number of weekly trips between locations $i$ and $j$ using vehicle type $k$ for coalition $S$.

$\Delta_{ik}^+$: Number of unmatched trips to/from location $i$ using vehicle type $k$.

$\Delta_{ik}^-$: Number of unmatched incoming trips to location $i$ using vehicles of type $k$.

$\Delta_{ik}^-$: Negative component of free variables.

$GHG_{TO}$: The total GHG emission cost for the transportation.

The first part of our optimization model focuses on the transportation cost as follows:

$$TC(S) = \text{MIN} \sum_i \sum_j \sum_k t_{ijk}X_{ijk} + \sum_k \sum_i a_{ik}\Delta_{ik}^+$$

s.t.:

$$\sum_k W_{ik}X_{ijk} \geq Q_p^i \forall i, j$$

$$\Delta_{ik} = \sum_j X_{ijk} - \sum_j X_{ikj} \forall i, k$$

$$\Delta_{ik}^+ = \Delta_{ik}^+ - \Delta_{ik}^- \forall i, k$$

$$X_{ijk}\text{integer}, \Delta_{ik}^+, \Delta_{ik}^- \geq 0$$

As given in Eq. (1), the objective function of the above model represents the cost of several number of trips using different types of vehicles. Constraint set (2) explains that different types of vehicles between two locations must be sufficient. Constraint set (3) computes the number of trips which is not according to the plan. Constraint set (5) represents the decision variables which are integer or positive or free.

The second part of the model focuses on costs of $CO_2$ emissions as based on following equation:

$$GHG_{TO} = \left( E_{C_f} + (E_{C_f} - EC_e) \right) \times \frac{L_{ijk}}{c_{ijk}} \times d_{ik} \times EF_{iti}, j, k$$

In the constraint set (6), we assume that the cost of carbon emissions is defined by multiplying the distance and energy conversion factor (EF) which is the rate of energy conversion to calculate the cost of generated carbon emissions for supply chain companies. By another point of view, the green
emissions are considered as the GHG which is computed by multiplying a constant EF value. The fuel consumption is related to the rate of consumption equals to 2.6413 kg $CO_2$ for the combustion of one-liter diesel. Therefore, the unit in the constraint set (6) is kg $CO_2 \times \frac{kg CO_2}{m}$. Finally, the model to support both transportation costs and environmental pollution, is as follows:

\[
TC(S) = \text{MIN} \sum_i \sum_j \sum_k t_{ijk} X_{ijk} + \sum_k a_k \Delta^+_k + \text{GHG}_{TO}
\]

s.t.: Constraints (2) to (5).

In our analyses, two companies are our candidates in the USA and Sweden. We have used the cost factor of Sweden and the USA for converting the carbon emissions. The most important cause of carbon emissions in Sweden is related to the transportation road. It organizes 20% of greenhouses gas. Although passengers in the European Union are responsible for 12% of the overall emission, this rate is higher than Sweden with 19%. It is worth noting that similar policies have also been developed by the governments of Canada and the USA for the promotion of hybrid electric cars. This policy incurred a cost of 109 $/ton $CO_2$ in Sweden which was more successful than the similar policy in the USA market with a cost of 177 $/ton $CO_2$ (Beresteanu and Li, 2011).

**Proposed FRB system**

Data envelopment analysis (DEA) is a mathematical programming approach to evaluate the relative efficiency of decision-making units (DMUs). Ordinary DEA models should employ DMUs Boxes to generate a set of outputs and do not consider intermediaries (Tavana & Khalili-Damghani, 2014). Implementation of DEA concept using fuzzy logic is an introduction to develop a fuzzy rule-based model. The FRB system was applied to many fields such as wastewater assessment (Selvaraj, et al., 2020), parallel computing and ensemble learning (Mu et al., 2020) and SC models (Khalili-Damghani, et al., 2014). As far as we know, the FRB is rarely used in the area of GSCM incorporating a game theory.

To establish the proposed FRB model, this study considers three main factors for the green supplier selection as follows:

i. Manufacturing management with environmental perspective, transportation management, and green transportation are considered. A green manufacturing including different suppliers with environmental perspectives and green procurement, are considered in the first classification (Fathollahi-Fard et al., 2021).

ii. Reverse logistics and eco-design factors including green social responsibility, green design, employee management, green facility management, green packaging, and reverse logistics management, are the set of second classification (Mojtahedi et al., 2021; Fathollahi-Fard et al., 2020a).

iii. Reusing and recycling in manufacturing part including technology for reusing and recycling of waste products (Khalili-Damghani, et al., 2014).

Generally, the transportation cost reverse logistics, and manufacturing are critical factors for the green supplier selection. As it is clear, all inputs/output factors for the FRB mode are given in Table 2 as qualitative variables. All factors are considered in an ambiguous fuzzy environment. The linguistic terms and associated fuzzy numbers are summarized in Tables 3, 4, 5, 6, and 7. It should be noted that the Trapezoidal Fuzzy Numbers (Trimf) are considered in our fuzzy environment.

This approach based on the FRB is using the IF–THEN rule as presented in Fig. 2.

It should be noted that this approach is run by MATLAB R2015b to develop the proposed FRB system. Finally, the properties of proposed FIS are summarized in Table 8.

| Variable                      | Criteria                  |
|-------------------------------|---------------------------|
| Input                         | Transportation cost       |
|                               | Reverse logistic          |
|                               | Manufacturing             |
| Output                        | Project Selection         |

| Linguist term     | Criteria                  |
|-------------------|---------------------------|
| Very Low          | (50, 395,740)             |
| Low               | (740, 1085,1430)          |
| Medium            | (1430 1775,2120)          |
| High              | (2120,2465, 2810)         |
| Very High         | (2810, 3155, 3500)        |

| Linguist term     | Criteria                  |
|-------------------|---------------------------|
| Very Low          | (2.829,3.168,3.507)       |
| Low               | (3.168,3.507,3.846)       |
| Medium            | (3.507,3.846,4.186)       |
| High              | (3.846,4.186,4.525)       |
| Very High         | (4.186,4.525,4.863)       |
Numerical example

In order to illustrate the concept of horizontal cooperation for selecting green supplier selection with the FRB concept, following numerical example is provided.

We have three shipments, namely A, B, C with five destinations and we have three types of vehicle. The flow between five locations for on weekly basis, and the unit of transportation costs between the locations for each type of vehicle are presented. As such, due to page limitation, the values of the parameter $Q_{ij}^p$ meaning the amount that is shipped weekly between locations $i$ and $j$ by company $p$ and values of parameters of $w_i$ (Capacity of vehicles of type $k$) and $t_{ijk}$ (Basic transportation cost between locations $i$ and $j$ using a vehicle type $k$) are reported in Electronic Supplementary Materials F1.

For running the optimization model given in Sect. 3, LINGO software is used. The optimal value is 4363.97. This solution is considered as Scenario 1 as given in Table 9.

Scenario 1:

Table 9 shows that there are several coalitions such as {A}, {B}, {C}, {A, B}, {A, C}, {B, C}, {A, B, C} and each collation has a has different total cost\{$A\} = 4703.875, \{B\} = 4754.094, \{C\} = 4702.75, \{A,B\} = 5136.906, \{A,C\} = 5066.969, \{B,C\} = 5143.875, \{A,B,C\} = 5497.562\$ and the cost saving for an individual company is zero but the cost saving of two to three of Companies increases. It means, save cost in a logistic network by using cooperative game theory. The synergy(s)
proves that the maximum synergy(s) belong to coalition \{A, B, C\}.

Figure 3 shows the core of the game of transportation with three players. The characteristic function of the game must be introduced as a vector \( A = [v(1) v(2) v(3) v(12) v(13) v(23) v(123)] \), for a game of three persons. In this case, \( A = [0, 0, 0, 4308.313, 4320, 4312.969, 8663.157] \) which it is optimal to plot the imputation set first and then superimpose the core. The shaded area corresponds to the core \( C(S) \) which, for all four cases, is nonempty.

In this case, Table 10 shows the allocation obtained, by different CGT methods, namely the Shapley value, the \( \tau \) value for the core centers.

The definition of satisfaction of collation \( S \) is calculated as follow:

\[
F_S(CS, y) = \sum_{p \in S} y_p - CS(S), \forall S \neq \phi, S \subseteq N
\]  

(8)

**Scenario 2:**

In Scenario 2, we solve the model using another example. First, we define location of three companies and five of destinations on the axis coordinates. Second, we have calculated the distance between the company and destinations. Third we used factors \( EC_e \) and \( EC_f \) from Table 11 for obtaining relative contribution of distance and mass to GHG emissions. Finally, they are used in the constraint set (6). In our numerical examples, two companies in USA and Sweden are explained.

It goes without saying that the location of three companies such as A, B, C and five destinations 1, 2, 3, 4 and 5 and reports their coordinates \( A(15,40), B(35,25), C(20,20) \) and \( 1(10,10), 2(0,25), 3(25,25), 4(25,40), 5(35,15) \) are in Electronic Supplementary Materials F2.

Table 11 addresses the weight rating and \( EC_f \) and \( EC_e \). The influence of capacity utilization on GHG emission increase with vehicle loading capacity, as the maximal load compared to vehicle’s empty weight increases.

We have used data that are presented in Tables and Electronic Supplementary Materials F3. Then, Eq. (6) is used. Finally, the result of \( CO_2 \) emission is shown in Electronic Supplementary Materials F4 as reported the amount that

### Table 10 Coalition satisfactions for Shapley value, \( \tau \)-value, Core-center

| Company | Shapley | \( \tau \) Value | Core center |
|---------|---------|-----------------|-------------|
| {A}     | 2888.1  | 2888.2          | 2888.5      |
| {B}     | 2884.6  | 2883.6          | 2881.6      |
| {C}     | 2890.4  | 2891.3          | 2893.1      |
| {AB}    | 1464.387| 1463.487        | 1461.787    |
| {AC}    | 1458.5  | 1459.5          | 1461.6      |
| {BC}    | 1462.031| 1461.931        | 1461.731    |
| {ABC}   | -0.057  | -0.057          | 0.043       |
| MIN FS  | -0.057  | -0.057          | 0.043       |
| MAX FS  | 2890.4  | 2891.3          | 2893.1      |
| SUM FS  | 1863.9944 | 1863.9944   | 1864.0516   |

### Table 11 Relative contribution of distance and mass to GHG emissions

| Vehicle type: Gross | \( EC_e \) (1/100 km) | \( EC_f \) (1/100 km) | Max mass to | importance of distance in [kg co2/km] | importance of tons km in [kg co2/km] |
|--------------------|------------------------|------------------------|-------------|---------------------------------------|---------------------------------------|
| HGV:26 tons        | 18.55                  | 26.45                  | 15          | max. improt (to = 0):100%               | max. improt (to = 15):30%               |
|                    |                        |                        | min. improt (to = 15):70%               | min. improt (to = 0):0%               |
|                    |                        |                        | average:84%                              | average:16%                            |
| HGV:32 tons        | 21.05                  | 31                     | 20          | max. improt (to = 0):100%               | max. improt (to = 0):32%               |
|                    |                        |                        | min. improt (to = 20):68%               | min. improt (to = 0):0%               |
|                    |                        |                        | average:82%                              | average:18%                            |
| HGV:40 tons        | 21.17                  | 31.28                  | 25          | max. improt (to = 0):100%               | max. improt (to = 25):32%               |
|                    |                        |                        | min. improt (to = 25):68%               | min. improt (to = 15)                  |
|                    |                        |                        | average:82%                              | average:16%                            |
is shipped weekly between locations, which is greater than capacity of the vehicle and we have not used them.

Finally, some sensitivity analyses are done to address the research question that the most important assumption is the different capacity of vehicle and how a vehicle’s capacity can affect \(\text{CO}_2\) emission.

With regards to these analyses, when the vehicle is used with high capacity \(\text{CO}_2\) produced which is more than usual, such as a vehicle with 26 and 32 tons. Their results are reported in Electronic Supplementary Materials F4.

The transportation take place between two locations \(i\) and \(j\) that include \{1, 2, 3, 4, 5\} with different collation companies \{A\}, \{B\}, \{C\}, \{AB\}, \{AC\}, \{BC\}, \{ABC\} with different vehicles and various capacities. GHG \(i\) indicate \(\text{CO}_2\) emission transportation between locations \(i\) and \(j\) which has a capacity 26 tons. GHG \(ij\) indicate \(\text{CO}_2\) emission transportation between locations \(i\) and \(j\) with capacity of 32 tons. GHG \(ij\) indicate \(\text{CO}_2\) emission transportation between location \(i\) and \(j\) which has a capacity of 40 tons.

After calculating the cost of each collation, we sum the cost of each company which is shown in Table 12. In this case, we know the cost of \(\text{CO}_2\) emission in two countries, namely Sweden and the USA and these results are reported in Table 12.

Table 13 shows seven coalition such as \{A\}, \{B\}, \{C\}, \{A, B\}, \{A, C\}, \{B, C\}, \{A, B, C\} which optimal \(\text{CO}_2\) cost in Sweden and synergy for each of the possible coalitions, and each one has different total cost \{A\} = 87.76712, \{B\} = 97.66561, \{C\} = 99.36083, \{A, B\} = 103.45205, \{A, C\} = 106.2264, \{B, C\} = 106.1682 and \{A, B, C\} = 126.3547. This indicates that when we increase the numbers coalition \(S\), the total cost of \(\text{CO}_2\) of emission is increased. Although the cost of \(\text{CO}_2\) emission of horizontal cooperation is increased, the cost saving of companies that are merged is increased. It means we can save cost in a logistic network by using the cooperative game theory. The synergy(s) column proves that the maximum synergy(s) belongs to coalition \{A, B, C\}.

Figure 4 shows the core of the game of \(\text{CO}_2\) emission of Sweden in Table 12.

Table 14 shows the optimal \(\text{CO}_2\) cost in the USA and synergy for each of the possible coalition and each one
has different total cost. It is calculated in the same way for Sweden.

Figure 5 shows the core of the game \(CO_2\) emission of the USA with three players. The characteristic function of the game of \(CO_2\) emission in the USA is introduced as a vector \(A = [v(1) v(2) v(3) v(12) v(13) v(23) v(123)]\), for a game of three persons. In this case we have \(A = [0, 0, 0, 133.12456, 131.3722, 147.5404, 336.1082]\) it is optimal to plot the imputation set first and then superimpose the core. The shaded area corresponds to the core \(C (CS)\) which, for all four cases, is nonempty. These results are available in details as given in Tables 15 and 16.

Finally, Tables 17 and 18 present the results for Sweden and the USA, respectively.

Table 17 presents the total cost of each collation with three types of methods for Sweden. Similarly, Table 18 is the results for the USA. The values are close to each other.

To analyze the total cost in Sweden, Fig. 6 shows the comparison between the shapely value, \(\tau\) value and core center. The chart indicates that the lowest cost is related to collation \(\{A, B, C\}\). It means when three players (company) are merged, the total cost (consist of the transportation cost and \(CO_2\) cost) is reduced.

Table 18 presents the total cost of each collation with three types of methods for the USA the values are close to each other. Figure 7 shows the comparison between the shapely value, \(\tau\) value and core center. The chart indicates that the lowest cost is related to collation \(\{A, B, C\}\). It means when three players (Company) are merged, the total cost (consisting of the transportation cost and the \(CO_2\) cost) is reduced.

We compare the cost between two countries with three different methods, namely, Shapley value, \(\tau\) value and core center. These analyses are shown in the Figs. 8, 9, and 10.
The black column is related to the USA country indicating most parts have higher cost than Sweden. Of course, high cost is obvious due to the cost of $CO_2$ emission. However, data indicate that horizontal cooperation in logistic network causes less cost and benefits for each company.

Finally, the result of transportation cost use as input variable in the proposed FRB model. This will help to define complete set of fuzzy IF–THEN rules more efficiently. It is obvious all inputs /output factors except for “transportation cost” in Table 4 qualitative variables. In this example we have assumed factors of Revers Logistic (RL) = 3.254 and Manufacturing (M) = 3.95 and total cost of Sweden’s transportation (C) = 336.1512. This cost is result of summation of transportation cost and $CO_2$ emission with cooperative game theory.

After solving the above model in MATLAB software, represents the proposed in green project selection in software which is divided into the general structure of project selection (a), cost (b), reverse logistics (c) and manufacturing (d) and finally the output (e) as given in Electronic Supplementary Materials F6. Due to page limitation, the part of defined rules in the proposed green project selection are showed in Electronic Supplementary Materials F6.
The software is tuned as 0.5. It is shown in Fig. 11. The surface of FRB approach is shown in Fig. 12.

Conclusion

In this paper, three major factors, namely green procurement, green transportation, and green manufacturing are considered. In order to calculate cost transportation, we use transportation model with cooperative game. The objective of this model is to highlight benefits of the cooperative game and how the cost and $\text{CO}_2$ emission can be reduced during transportation. It is achieved when larger vehicles are used which help to allocate less GHG volume during transportation process. This study contributes to a green supplier selection problem considering the green procurement, green transportation, and green manufacturing. This study contributes to reverse logistics, eco-design, reusing, recycling, and remanufacturing with their high impact on the industries. In addition to the logistics costs and transportation costs, the carbon emissions are considered. With regard to the game theory, this paper uses a cooperative green supplier selection model. To address the first research question (RQ1), our findings confirm that if transportation requirements of two or more companies are combined, it will help manufacturers to have less $\text{CO}_2$ emissions with lower cost. After creating the optimization model to consider the uncertainty, this cooperative game theory model was established in a fuzzy environment to address the second research question (RQ2). In this regard, a fuzzy rule-based (FRB) system was deployed and the set of fuzzy IF–THEN rules, was considered. Then, some sensitivity analyses were done in a numerical example to evaluate the proposed model to address the third research question (RQ3). In order to illustrate the concept of horizontal cooperation, we have presented an example in this paper. The result shows that as the number of coalition $S$ increases, the total cost of $\text{CO}_2$ emission also increases.

The present work faces with a set of limitations which can be considered for future research directions as follows:

Fig. 11  The result of the software

Fig. 12  The surface of FRB approach
• Adding more practical decisions such as inventory and pricing decisions into the proposed framework (Rafigh et al., 2021).
• Considering the concept of internet of thing and advanced technologies for a cooperative GSCM (Moosavi et al., 2021).
• Using a grey prediction model for estimating the uncertain parameters (Islam et al., 2021).
• Applying recent advances in metaheuristics such as the social engineering optimizer (Fathollahi-Fard et al., 2018) and the red deer algorithm (Fathollahi-Fard et al., 2020d).

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Data availability Not applicable.

Declarations

Consent to participate The authors declare that they agree to participate based on the journal’s format.

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