# Chapter 5
# The Impact of Carbon Tax Policy in a Multi-Objective Green Solid Logistics Modelling Under Sustainable Development

**Soumen Kumar Das, Sankar Kumar Roy, and Gerhard-Wilhelm Weber**

**Abstract** In the last few decades, worldwide atmosphere change has become out to be one of the most significant environmental issues. Carbon emissions and air pollution have motivated a need to design an effective and sustainable logistics network. As a result, environmental policies are included in the transportation system to reconsider and re-structure a greenway distribution network. This chapter addresses a multi-objective optimization problem to design a solid logistics modelling in a green framework. The objectives of the stated problem are as follows: (a) to minimize the total financial costs along with carbon emissions cost, (b) to maximize the customers' satisfaction level simultaneously, and (c) to maximize the sustainable effectiveness conveyances. A multi-objective optimization procedure, namely, global criterion method is introduced to extract a non-dominated solution to the proposed problem. Two numerical examples test the formulated model and solution procedure. A comparative study among the proposed procedure and the other existing relevant procedures is also presented. Concluding remarks are discussed at last.

**Keywords** Solid logistics modelling · Carbon emissions · Carbon tax policy · Sustainable development · Multi-objective optimization

**Abbreviations**

The accompanying abbreviations are utilized in this chapter.

| | |
|---|---|
| DM | Decision-maker, |
| FP | Fuzzy programming, |
| GCM | Global criterion method, |
| SD | Sustainable development, |

S. K. Das · S. K. Roy (✉)
Department of Applied Mathematics with Oceanology and Computer Programming, Vidyasagar University, Midnapore, West Bengal 721102, India

G.-W. Weber
Faculty of Engineering Management, Chair of Marketing and Economic Engineering, Poznan University of Technology, Poznan, Poland
e-mail: gerhard.weber@put.poznan.pl



I. Ali et al. (eds.), *Computational Modelling in Industry 4.0*,
https://doi.org/10.1007/978-981-16-7723-6_5

| | |
|---|---|
| STP | Solid transportation problem, |
| IFP | Intuitionistic fuzzy programming, |
| MOSTP | Multi-objective solid transportation problem, |
| MOGSTP | Multi-objective green solid transportation problem. |

## 1 Introduction and Prior-Related Research

Nowadays, controlling carbon emissions is one of the most attractive and critical issues throughout the world. Figure 1 illustrates the carbon emanations information for various sectors of the world. From Fig. 1, it can be concluded that the carbon emissions have been essentially increased due to logistics network.

Poterba (1991), Chen and Wang (2016) discussed that the increase in carbon outflows is the main reason behind the global warming effect. Thus, governments around the globe have endorsed various policies in which the carbon tax policy (cf. Zhou et al. 2011; Benjaafar et al. 2012; Chen et al. 2013; Konur and Schaefer 2014) is implemented in effective measure to control the global warming effect. As per the carbon charge strategy, the carbon release holders need to pay the carbon charge for every fossil fuel byproduct unit to the policymaker. In the literature, few authors have considered this policy for instance Elhedhli and Merrick (2012), and Turken et al. (2017). This inspired us to formulate green logistics modelling to meet our present needs without polluting the atmosphere. For that reason, the concept of *sustainable development* (SD) (Lélé 1991; Litman and Burwell 2006) has attracted the scientists

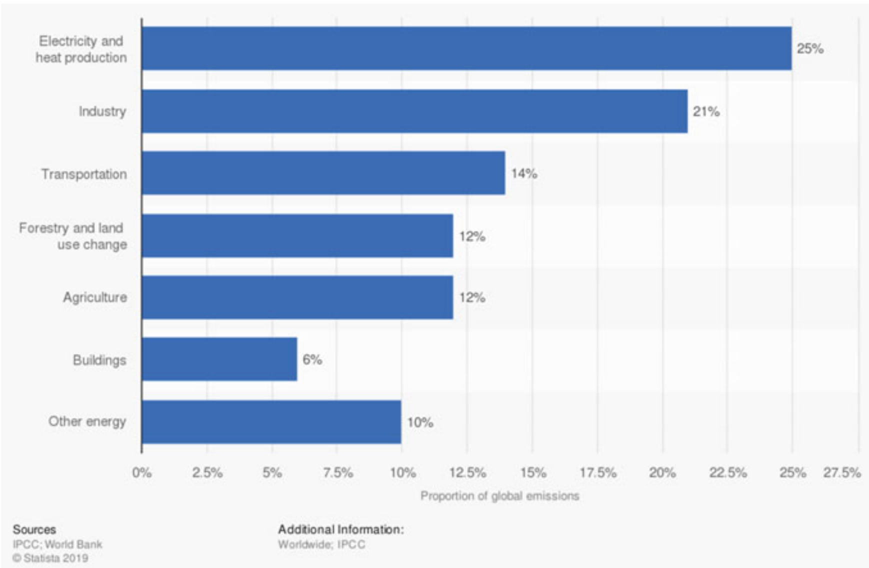



**Fig. 1** Distribution of carbon emissions by industry sectors worldwide in 2019

as a field of research. According to the 'World Commission on Environment and Development', SD is defined as 'the concept of meeting the needs of the present without compromising future generations' ability to meet their needs'. In fact, the financial, social, and environmental aspects are considered simultaneously in SD. Nomani et al. (2017b) proposed a multi-objective model to investigate the SD goals of India. Gupta et al. (2018) presented a sustainable logistics model for the mining sector and then they solved it by an integrated multi-objective solution procedure. Maity et al. (2019b) introduced a sustainable environment in a multi-objective logistics network under the time window.

In last few decades, logistics modelling plays a vital role towards globalization. *Solid transportation problem* (STP) is a part of logistics network design. Substantially, STP, an augmentation of the classical transportation model is mainly described by source, demand, and conveyance set of constraints. The main concept of STP is to disseminate homogeneous products from specific sources to a few destinations via different kind of conveyances (e.g., hydrogen vehicle, diesel vehicle, CNG vehicle, bio-diesel vehicle) with the object that the total cost of the conveyance will be diminished. It was first enlightened by Shell (1955), however, the solution procedure was given by Haley (1962). Afterwards, Jiménez and Verdegay (1998) introduced the idea of fuzziness into an STP. They (Jiménez and Verdegay 1999) introduced a parametric approach to solve a fuzzy STP. It is often difficult to handle the real-world problems by a single objective STP. Due to this fact, several authors introduced multi-objective environment on STP, known as *multi-objective solid transportation problem* (MOSTP) from their different points of view. Tao and Xu (2012) presented the concept rough programming into an MOSTP. Liu et al. (2014) studied an STP in which the parameters were taken as type-2 fuzzy variables. Molla-Alizadeh-Zavardehi et al. (2013) described three metaheuristic algorithms for solving an MOSTP. Nomani et al. (2017a) discussed a new solution procedure to solve a multi-objective logistics modelling. Chen et al. (2017) analyzed an uncertain goal programming for solving a bicriteria STP. Mehlawat et al. (2019) incorporated a *data envelopment analysis* (DEA) concept in an STP under sustainable environment. Roy and Midya (2019) studied an MOSTP with product blending under uncertain environment. Biswas et al. (2019) employed a novel NSGA-II algorithm for solving an MOSTP in crisp and interval environments. Roy et al. (2019) discussed the idea of several items into an STP under a hybrid environment.

An exhaustive comparison on different features among the current research and prior associated studies in logistics network is depicted in Table 1. The comparative study delineates the gaps in previous researches and motivation for this investigation.

To resolve all these issues, in this study, we develop a mathematical model, referred as *multi-objective green solid transportation problem* (MOGSTP). To tackle several realistic and practical attributes of the research gaps, three conflicting objectives, transportation modes, vehicles efficiency, carbon emissions reduction policy, and sustainable development are simultaneously considered in the proposed problem. The summary of this chapter is listed as follows:

**Table 1** A summary of relevant researches on MOSTP

| Literature | TC | TT | CE | CM | VE | Sustainability |
|---|---|---|---|---|---|---|
| Elhedhli and Merrick (2012) | ✓ | | ✓ | | | |
| Paksoy et al. (2012) | ✓ | | ✓ | ✓ | | |
| Tao and Xu (2012) | ✓ | ✓ | | ✓ | | |
| Chen et al. (2013) | ✓ | | ✓ | | | |
| Molla-Alizadeh-Zavardehi et al. (2013) | ✓ | | | ✓ | | |
| Konur and Schaefer (2014) | ✓ | | ✓ | | | |
| Chen and Wang (2016) | ✓ | | ✓ | ✓ | | |
| Nomani et al. (2017a) | ✓ | ✓ | | | | |
| Chen et al. (2017) | ✓ | ✓ | | ✓ | | |
| Gupta et al. (2018) | ✓ | | ✓ | ✓ | ✓ | |
| Roy and Midya (2019) | ✓ | ✓ | | ✓ | | |
| Biswas et al. (2019) | ✓ | ✓ | | ✓ | | |
| Roy et al. (2019) | ✓ | ✓ | | ✓ | | |
| Das et al. (2020a) | ✓ | | | ✓ | | |
| Maity et al. (2019b) | ✓ | ✓ | | | | ✓ |
| Mehlawat et al. (2019) | ✓ | | | ✓ | ✓ | ✓ |
| Das and Roy (2019) | ✓ | ✓ | ✓ | | | |
| Tirkolaee et al. (2020) | ✓ | | ✓ | | | ✓ |
| Proposed model | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

TC: Transportation cost; TT: Transportation time; CE: Carbon emissions; CM: Conveyance modes; VE: Vehicles efficiency

- This is the first study to investigate a transportation model to impact the carbon emissions reduction policy under sustainable environment.
- The model gives the decisions regarding the product flow from sources to destinations via sustainable transportation modes.
- The total conveyances cost with maintaining, fixed-charge cost and carbon emissions cost, delivery time, including loading and unloading time, and vehicle efficiency are also studied.
- A solution procedure on multi-objective optimization is described to receive an optimal solution of MOGSTP.
- A comparative study among the proposed procedure and the other existing relevant procedures is investigated to obtain the best Pareto-optimal solution.
- The impact of carbon tax policy in MOGSTP under sustainable environment is also discussed.

This chapter is sorted out as follows: Sect. 2 addresses the problem identification and mathematical model for MOGSTP. The methodology to solve the above model is discussed in Sect. 3. Then, Sect. 4 illustrates the efficiency of the stated problem and procedure with two real-world examples. Section 5 provides the outcomes of the application examples with the impact of carbon tax policy and a comparison with other relevant solution procedures. Finally, concluding remarks are given with future directions of this study in Sect. 6.

# 2 Mathematical Formulation

Here, initially, we define the proposed problem and its assumptions to formulate the mathematical model. Thereafter, we discuss index sets, decision variables, and parameters. At last, the three objective functions and constraints are described.

## *2.1 Model Background*

The proposed study deals with a multi-objective problem to formulate a sustainable solid logistics network considering carbon emissions. The important objectives are: (O1) to lessen the total shipping cost and time, and to maximize sustainable vehicles efficiency under an emission control policy, and (O2) to seek the optimal amount of transported goods simultaneously. In addition, apart from that, the following factors are described in the model: (I) weights of the vehicles dependent on economical, environmental, and social features; (II) fixed-charge costs such as setup costs underway frameworks, toll charges on an expressway and so on; (III) servicing costs of the conveyances; (IV) loading and unloading time for the transported products, which give more accuracy of the logistic time; (V) follow the carbon tax policy for reducing carbon emissions. This study's main focus is to design a green transportation model by considering outrageous climate occasions for reducing carbon emissions under a sustainable environment. The considered green logistics network as depicted in Fig. 2, is comprised of sources ($S_1$, $S_2$, and $S_3$), destinations ($D_1$, $D_2$, $D_3$ and $D_4$) and conveyances ($T_1$, $T_2$, $T_3$ and $T_4$). Moreover, the dotted lines are designated as the product flow from sources to destinations through conveyances under a sustainable environment.

## *2.2 Nomenclature*

The nomenclatures are listed below to construct our model:

***Indices***

$i$ Index of sources ($i = 1, 2, \ldots, m$);
$j$ Index of destinations ($j = 1, 2, \ldots, n$);
$k$ Index of transportation modes ($k = 1, 2, \ldots, p$).

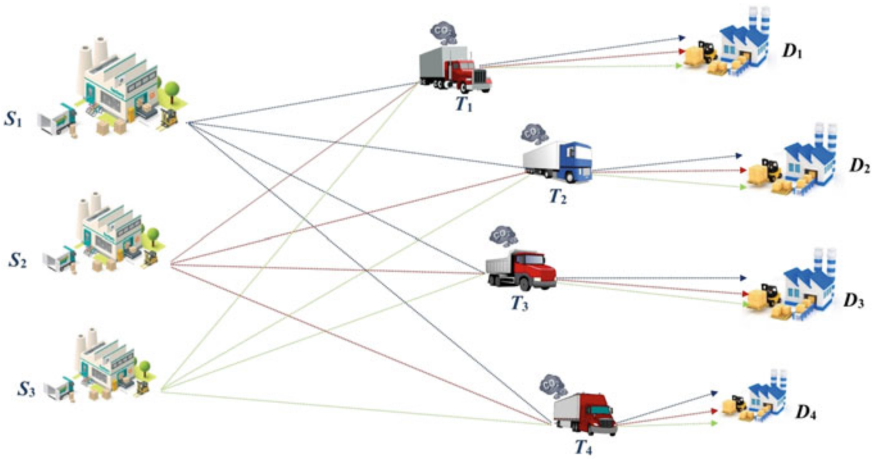



**Fig. 2** Pictorial representation of a green solid logistics network

***Sets***

$X$ $\{(x_{ijk})$: subject to the constraints $\forall i, j, k\}$: the feasible space;
$F$ $\{(x^B_{ijk})$: $\forall i, j, k\}$: the optimal feasible set.

***Decision variable***

$x_{ijk}$ Quantity to be sent from $i$th source to $j$th destination by $k$th vehicles.

***Parameters***

$a_i$ Availability of $i$th source;
$b_j$ Demand at $j$th destination;
$c_k$ Capacity of $k$th transportation mode;
$e_{ijk}$ Unit cost for transporting unit item per unit distance from the $i$th source to the $j$th destination by $k$th vehicle;
$t_{ijk}$ Transport time for $k$th vehicle per unit distance from $i$th source to $j$th destination;
$l_i$ Loading time of unit item at $i$th source;
$l'_j$ Unloading time of unit quantity at $j$th destination;
$M_k$ Servicing cost of $k$th conveyance;
$f_{ijk}$ Fixed-charge to distribute products from $i$th–$j$th route by $k$th transportation mode;
$h_k$ Unit $CO_2$ mitigation by $k$th vehicle;
$P_c$ Carbon tax revenue for each unit of mitigation;
$\alpha_k$ Effectiveness of $k$th conveyance in economical aspects;
$\beta_k$ Effectiveness of $k$th conveyance in environmental evaluation;
$\gamma_k$ Effectiveness of $k$th conveyance in social features;
$w_1$ Weight for economical aspects;
$w_2$ Weight for environmental evaluation;

$w_3$ Weight for social features.

## 2.3 Assumption

There are the following assumptions:

- The dispersed product is the homogeneous kind. The idea of transportation modes is heterogeneous. Transportation cost is straightforwardly relative to the unit of delivered products.
- The time is likely to be proportional to the distance that is not dependent on the unit distributed item. $CO_2$ mitigation is reliant on the distance gone by the movements, fuel consumption, and transported goods.

## 2.4 Mathematical Model

This section provides a mathematical formulation in the light of solid logistics modelling, carbon tax policy, and sustainable environment. The mathematical model of MOGSTP is addressed as follows:

**Model 1**

$$\text{minimize } Z_{1(x)} = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}[e_{ijk}x_{ijk} + M_k d_{ij} y_{ijk} + f_{ijk} y_{ijk}] + P_c \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p} h_k d_{ij} x_{ijk} \quad (1)$$

$$\text{minimize } Z_{2(x)} = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}[t_{ijk} y_{ijk} + \left(l_i + l'_j\right) x_{ijk}] \quad (2)$$

$$\text{maximize } Z_{3(x)} = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}(w_1\alpha_k + w_2\beta_k + w_3\gamma_k) x_{ijk} \quad (3)$$

$$\text{subject to } \sum_{j=1}^{n}\sum_{k=1}^{p} x_{ijk} \le a_i, \quad i = 1, 2, \ldots, m, \quad (4)$$

$$\sum_{i=1}^{m}\sum_{k=1}^{p} x_{ijk} \ge b_j, \quad j = 1, 2, \ldots, n, \quad (5)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ijk} \le c_k, \quad k = 1, 2, \ldots, p, \quad (6)$$

$$y_{ijk} = \begin{cases} 1, \text{ if } x_{ijk} > 0, \\ 0, \text{ otherwise.} \end{cases} \tag{7}$$

$$\sum_{i=1}^{m} a_i \geq \sum_{j=1}^{n} b_j \text{ and } \sum_{k=1}^{p} c_k \geq \sum_{j=1}^{n} b_j, \tag{8}$$

$$x_{ijk} \geq 0, \quad i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, p. \tag{9}$$

The objective function (1) intends to minimize the total shipping cost along with $CO_2$ mitigation cost. Terms 1–4 of (1) address the all out transportation cost, servicing cost, fixed-charge cost, and $CO_2$ mitigation cost separately. The objective function (2) is identified with clients' fulfilment, which expectations to diminish the total shipping time, loading and unloading time from $i$th source to $j$th destination via $k$th conveyance. The objective function (3) is connected with economical, environmental, and social aspects, which indicates choosing conveyances depending on their sustainable effectiveness. Limitation (4) implements that each source's by and the large disseminated amount should be less or equivalent to its ability. Imperative (5) forces that the in generally delivered units of every objective satisfy the interest. Imperative (6) shows that every transportation mode's generally speaking shipped streams can't outperform its capacity. Constraint (7) represents the relationship between continuous and binary variables. Requirements (8) allude to the practical basis of the issue. Eventually, requirement (9) is the non-antagonism conditions.

**Definition 1** An ideal solution of the proposed model is the one that optimizes each of the objective independently, i.e., $Z_q(x^*) = \min_{(x)\in F} Z_q(x)$, $q = 1, 2$ and $Z_3(x^*) = \max_{(x)\in F} Z_3(x)$.

**Definition 2** A solution $x^A \in F$ of Model 1 is called an anti-ideal if it satisfies the condition $Z_q(x^A) = \max_{(x)\in F} Z_q(x)$, $q = 1, 2$ and $Z_3(x^A) = \min_{(x)\in F} Z_3(x)$.

**Definition 3** A solution $x^P \in F$ is a Pareto-optimal solution of Model 1 if there does not exist any other solution $x \in F$ such that $Z_q(x) \leq Z_q(x^P)$ for $1 \leq q \leq 2$ and $Z_3(x) \geq Z_3(x^P)$ with at least one inequality holding as strict inequality.

## 3 Solution Procedure

In a multi-objective optimization problem, the *decision-maker* (DM) has to minimize/maximize the non-commensurable nature of objective functions all at once. Due to this fact, no single optimum outcome exists that simultaneously optimizes all the objective functions. For that reason, the idea of a Pareto frontis introduced instead of an ideal outcome. Here, we introduce a multi-objective solution procedure, explicitly, a *global criterion method* (GCM) (Shih and Chang 1995) to solve Model 1. An algorithm flowchart is depicted in Fig. 3.

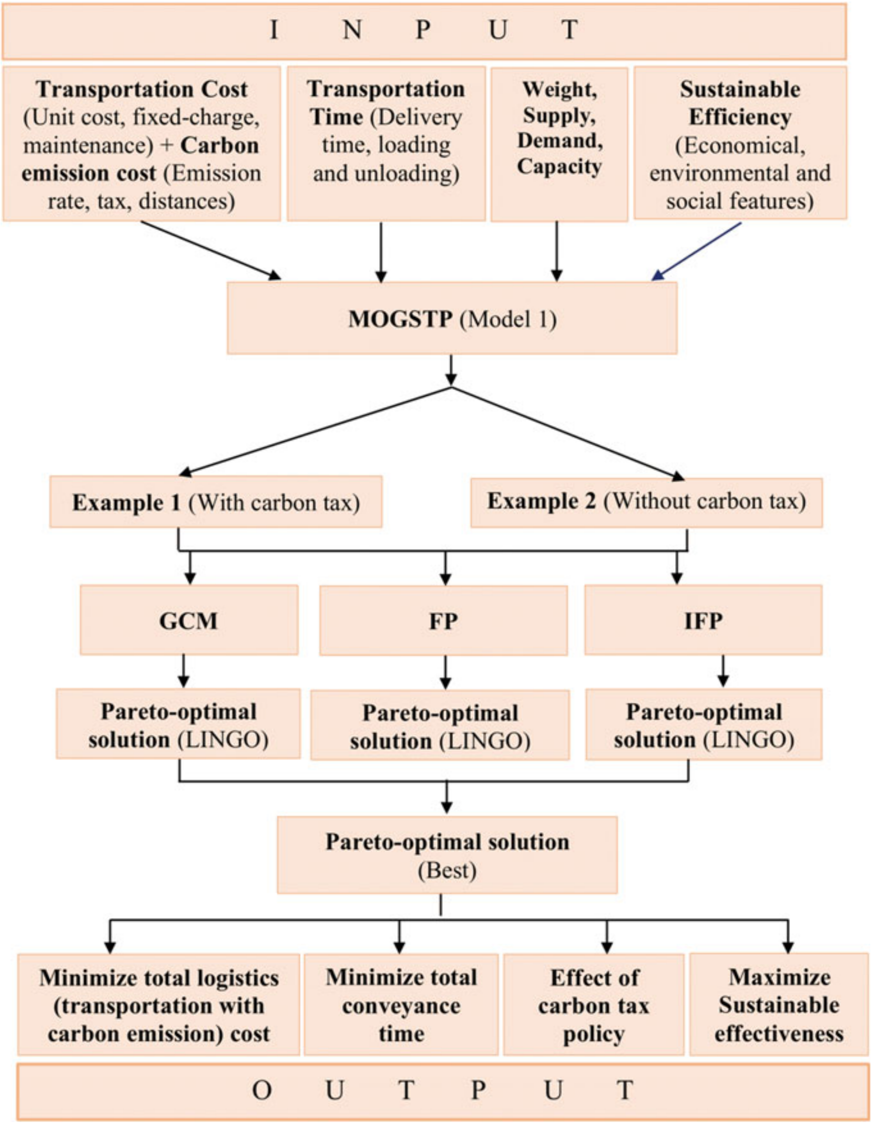



**Fig. 3** Algorithm flowchart of the proposed problem

## *3.1 GCM*

GCM uses the possibility of the briefest path from the ideal front to discover a Pareto front; the stated methodology does not need any earlier data (objectives and loads) on target capacities from the DM. Indeed, GCM yields a rudimentary numerical construction that makes it more obvious and utilize. Further, the proposed procedure furnishes a Pareto ideal outcome with less computational time and memory concerning different methodology. The following steps can derive the Pareto-optimal solution of Model 1:

**Step 1**: Initially, three single green solid transportation problems are solved independently by considering one at a time.

**Step 2**: Then, the ideal $(Z_1^{\min}, Z_2^{\min}, Z_3^{\max})$ and anti-ideal $(Z_1^{\max}, Z_2^{\max}, Z_3^{\min})$ solutions are calculated employing the results of Step 1.

**Step 3**: The simplified formulation of Model 1 can be addressed as stated below:

**Model 2**

$$\text{minimize} \left[ \sum_{q=1}^{2} \left( \frac{Z_q(x) - Z_q^{\min}}{Z_q^{\max} - Z_q^{\min}} \right)^2 + \left( \frac{Z_3(x) - Z_3^{\max}}{Z_3^{\max} - Z_3^{\min}} \right)^2 \right]^{\frac{1}{2}}$$

subject to the constraints (4) to (9).

**Proposition 1** *Assuming $x^P$ is an optimal outcome of Model 1, then it will be a Pareto front $x^P$ of Model 2.*

**Proof** This proposition can be proved by contradiction. Let us assume that $x^P$ is an optimal outcome of Model 1 that is not a Pareto-optimal outcome of Model 2. Subsequently, there exists a solution $x'$ such that $(x')$ dominates $x^P$. This implies:

$$\left[ \sum_{q=1}^{2} \left( \frac{Z_q(x') - Z_q^{\min}}{Z_q^{\max} - Z_q^{\min}} \right)^2 + \left( \frac{Z_3(x') - Z_3^{\max}}{Z_3^{\max} - Z_3^{\min}} \right)^2 \right]^{\frac{1}{2}}$$
$$< \left[ \sum_{q=1}^{2} \left( \frac{Z_q(x^P) - Z_q^{\min}}{Z_q^{\max} - Z_q^{\min}} \right)^2 + \left( \frac{Z_3(x^P) - Z_3^{\max}}{Z_3^{\max} - Z_3^{\min}} \right)^2 \right]^{\frac{1}{2}},$$

which directly contradicts to the fact that $x^P$ is an optimal solution of Model 2. That completes the proof.

## 4 Numerical Experiment

In this section, two application examples are illustrated to validate the formulated problem and methodology numerically.

***Example 1*** A company has four $(m = 4)$ source plants, labelled as $S_1$, $S_2$, $S_3$ and $S_4$, and three $(n = 3)$ distribution centres like $D_1$, $D_2$ and $D_3$, respectively.

Goods are distributed by two ($p = 2$) transportation modes from source plants to distribution centres. Due to environmental concerns and carbon tax policy, the company chooses two sustainable conveyances: hydrogen fuel-based vehicle ($k_1$) and bio-diesel based vehicle ($k_2$). The company's goal is to reduce the total logistics cost and carbon emissions cost, conveyance time, and increase the effectiveness of sustainable vehicles. The distances between sources and destinations are given in Table 2 with their corresponding supplies and demands. The unit logistics cost (INR), delivery time (minutes), and fixed-charge cost (INR) parameters are displayed in Table 3.

The other inputs are as follows:

Capacities of conveyances (KG) $c_1 = 1060$, $c_2 = 1210$; Loading time (minutes) $l_1 = 90$, $l_2 = 120$, $l_3 = 60$, $l_4 = 80$; Carbon emissions tax (INR/KG) $P_c = 0.4$; Unloading time (minutes) $l'_1 = 60$, $l'_2 = 40$, $l'_3 = 30$; Carbon emissions rate (KG/L) $h_1 = 0.3$, $h_2 = 0.5$; Weights of the sustainability aspects $w_1 = 0.3$, $w_2 = 0.5$, $w_3 = 0.2$; Maintenance cost (INR) $M_1 = 0.3$, $M_2 = 0.5$; Effectiveness of conveyances $\alpha_1 = 0.9$, $\alpha_2 = 0.75$, $\beta_1 = 0.85$, $\beta_2 = 0.7$, $\gamma_1 = 0.6$, $\gamma_2 = 0.85$.

**Table 2** Distances ($d_{ij}$) (KM) of sources-destinations with supply and demand (KG)

| | $D_1$ | $D_2$ | $D_3$ | $a_i$ |
|---|---|---|---|---|
| $S_1$ | 45 | 60 | 80 | 670 |
| $S_2$ | 55 | 40 | 100 | 710 |
| $S_3$ | 70 | 90 | 50 | 520 |
| $S_4$ | 100 | 50 | 60 | 370 |
| $b_j$ | 835 | 740 | 695 | |

**Table 3** Transportation cost for unit quantity, conveyance time, and fixed-charge cost ($e_{ijk}, t_{ijk}, f_{ijk}$)

| Source–destination | Conveyance ($k = 1$) | Conveyance ($k = 2$) |
|---|---|---|
| 1−1 | (16, 30, 220) | (14, 45, 350) |
| 1−2 | (22, 45, 145) | (15, 60, 190) |
| 1−3 | (26, 60, 300) | (20, 80, 250) |
| 2−1 | (16, 41.5, 280) | (14, 55, 390) |
| 2−2 | (16, 30, 245) | (11, 40, 500) |
| 2−3 | (12, 75, 360) | (11, 100, 500) |
| 3−1 | (15, 52.5, 400) | (10, 70, 435) |
| 3−2 | (14, 67.5, 450) | (12, 90, 410) |
| 3−3 | (10, 37.5, 425) | (90, 50, 420) |
| 4−1 | (18, 75, 400) | (13, 100, 600) |
| 4−2 | (17, 37.5, 430) | (15, 50, 495) |
| 4−3 | (13, 45, 540) | (12, 60, 470) |

***Example 2*** We consider the fossil fuel byproducts charge $P_c = 0$, and the others continue as before as in Example 1.

## 5 Experimental Result and Exploration

The optimal solutions of the proposed problem are extracted from the GCM. The GCM is carried out employing LINGO 18.0.56 software on an Intel Core i5 processor with 8 GB RAM under Mac OS environment. The 'most preferred' Pareto fronts of both the applications are listed in Tables 4 and 5. The analytical outcomes reveal that the economic, clients' fulfilment, and sustainable objectives are optimized. When the carbon emissions cost is added along with the total logistics cost, then firms' profit will be reduced. Because of this reality, the organization will consistently be worried about fossil fuel byproducts because of the dispersion of merchandise. The company will always select the sustainable conveyances which emit less $CO_2$. In this regard, the third objective function plays a vital role in choosing conveyances which increases the sustainable efficiency score.

Along these lines, the expressed detailing can handle financial advancement without inconvenience to ecological and natural assets. Thereafter, the carbon tax policy helps the company choose 'most preferred' choices for enhancing their economic and sustainable development and upholds the policymaker for lessening fossil fuel byproducts. The impact of carbon tax policy is illustrated in Fig. 4.

**Table 4** The Pareto ideal outcome of Example 1

| Methodology | Pareto-front out come | CPU time (s) | Memory (K) |
|---|---|---|---|
| GCM | $\mathbf{Z_1 = 52257.52}$, $\mathbf{Z_2 = 307230.0}$, $\mathbf{Z_3 = 1765.35}$, $x_{111} = 558.94$, $x_{112} = 67.115$, $x_{122} = 43.942$, $x_{212} = 208.942$, $x_{221} = 501.05$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.18 | 72 |
| FP | $\lambda = 0.808$, $Z_1 = 52523.96$, $Z_2 = 307230.0$, $Z_3 = 1765.35$, $x_{111} = 568.30$, $x_{122} = 101.69$, $x_{211} = 48.386$, $x_{212} = 218.30$, $x_{221} = 443.30$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.27 | 73 |
| IFP | $\lambda = 0.712$, $\theta = 0.287$, $Z_1 = 52523.96$, $Z_2 = 307230.0$, $Z_3 = 1765.35$, $x_{111} = 568.30$, $x_{122} = 101.69$, $x_{211} = 48.386$, $x_{212} = 218.30$, $x_{221} = 443.30$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.23 | 74 |

Bold-front refers the 'most preferred' Pareto front

**Table 5** The Pareto-ideal outcome of Example 2

| Methodology | Pareto-front out come | CPU time (s) | Memory (K) |
|---|---|---|---|
| GCM | $\mathbf{Z_1 = 34154.44}$, $\mathbf{Z_2 = 307230.0}$, $\mathbf{Z_3 = 1765.35}$, $x_{111} = 523.94$, $x_{112} = 137.13$, $x_{122} = 8.937$, $x_{212} = 173.94$, $x_{221} = 536.06$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.18 | 72 |
| FP | $\lambda = 0.865$, $Z_1 = 34156.79$, $Z_2 = 307230.0$, $Z_3 = 1765.35$, $x_{111} = 561.28$, $x_{112} = 62.428$, $x_{122} = 46.285$, $x_{212} = 211.28$, $x_{221} = 498.71$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.23 | 73 |
| IFP | $\lambda = 0.865$, $\theta = 0.135$, $Z_1 = 34156.79$, $Z_2 = 307230.0$, $Z_3 = 1765.35$, $x_{111} = 561.28$, $x_{112} = 62.428$, $x_{122} = 46.285$, $x_{212} = 211.28$, $x_{221} = 498.71$, $x_{332} = 520.0$, $x_{422} = 195.0$, $x_{432} = 175.0$ and remaining all $x_{ijk} = 0$ | 0.27 | 74 |

Bold-front refers the 'most preferred' Pareto front


**Fig. 4** Effect of carbon tax policy in MOGSTP

## 5.1 Comparative Study

In this subsection, the aforementioned examples are also resolved with existing relevant two solution procedures, namely: (i) *Fuzzy programming* (FP) and (ii) *Intuitionistic fuzzy programming* (IFP). The obtained outcomes are compared so that the DM has a choice to get the best Pareto-optimal solutions. Table 6 shows that the obtained

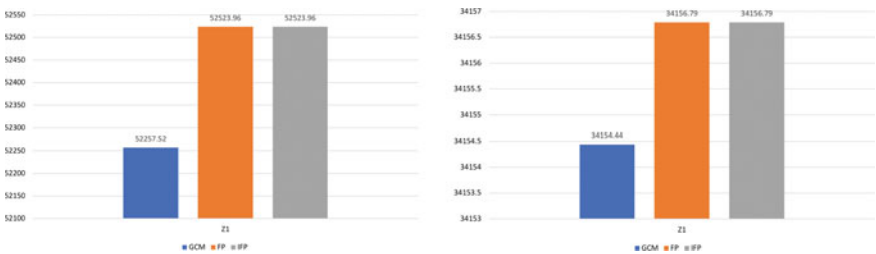
**Table 6** Outcomes comparison

| Example | GCM | FP | IFP |
|---|---|---|---|
| Example 1 | $Z_1 =$ 52257.52 | $Z_1 =$ 52523.96 | $Z_1 =$ 52523.96 |
| | $Z_2 =$ 307230.0 | $Z_2 =$ 307230.0 | $Z_2 =$ 307230.0 |
| | $Z_3 = 1765.35$ | $Z_3 = 1765.35$ | $Z_3 = 1765.35$ |
| | CPU time = 0.18 s | CPU time = 0.23 s | CPU time = 0.27 s |
| | Memory = 72 K | Memory = 73 K | Memory = 74 K |
| Example 2 | $Z_1 =$ 34154.44 | $Z_1 =$ 34156.79 | $Z_1 =$ 34156.79 |
| | $Z_2 =$ 307230.0 | $Z_2 =$ 307230.0 | $Z_2 =$ 307230.0 |
| | $Z_3 = 1765.35$ | $Z_3 = 1765.35$ | $Z_3 = 1765.35$ |
| | CPU time = 0.18 s | CPU time = 0.23 s | CPU time = 0.27 s |
| | Memory = 72 K | Memory = 73 K | Memory = 74 K |

outcomes by the proposed GCM are better compared with the FP and IFP in terms of sustained accuracy and lower computational complexity, displayed in Figs. 5 and 6.

***Fuzzy programming* (FP)**

After employing FP (Zimmermann 1978; Inuiguchi et al. 1990; Li and Lai 2000), the simplified fuzzy model of Model 1 can be stated as below:




(a) Optimum value of $Z_1$ by three procedures for Example 1.

(b) Optimum value of $Z_1$ by three procedures for Example 2.

**Fig. 5** Comparison optimum value of $Z_1$ by three procedures


(a) CPU time for the three methods. (b) Computational memory by the three methods.

**Fig. 6** Comparison lower computational complexity of three approaches

**Model 3**

$$\begin{aligned}&\text{maximize } \lambda\\&\text{subject to } Z_q(x,)+\lambda\left(U_q-L_q\right)\le U_q, q=1,2,3,\\&\text{the constraints (4) to (9)},\\&\lambda\ge 0.\end{aligned}$$

Here, $\lambda$ is the degree of fulfilment of anoutcome.

***Intuitionistic fuzzy programming* (IFP)**

After employing IFP (Angelov 1997; Roy et al. 2018a; Roy and Midya 2019), the intuitionistic optimization model for Model 1 can be expressed as follows:

**Model 4**

$$\begin{aligned}&\text{maximize } \theta-\mu\\&\text{subject to } Z_q(x,)+\theta\left(U_q-L_q\right)\le U_q, q=1,2,3,\\&Z_q(x,)-\mu\left(U_q-L_q\right)\le L_q, q=1,2,3,\\&\text{the constraints (4) to (9)},\\&\theta\ge\mu, \theta+\mu\le 1, \theta,\mu\in[0,1].\end{aligned}$$

Here, $\theta$ and $\mu$ indicate the grade of fulfilment and disappointment of anoutcome.

## 6 Concluding Remark and Outlook

In this chapter, a green solid logistics modelling has been addressed by thinking about the affordable, clients' fulfilment, and ecological goals under sustainable development. To help the choices, the stated model has been detailed with the aforementioned three non-commensurable objectives under a fossil fuel byproducts decrease strategy.

In addition, the unknown quantities of distributed products by various conveyances have been found simultaneously. Several factors like unit logistics cost, fixed-charge cost, carbon emissions cost, maintenance cost, three types of sustainable parameters, loading, and unloading time have been taken into account in this study. GCM has been utilized for optimizing the above objectives in a successful way. Afterwards, two applications have been presented to delineate the proposed problem and GCM. Further, the outcomes have been derived from GCM that is compared with the obtained solutions by FP and IFP. Among the three solution procedures, better Pareto-optimal outcomes have been received from the proposed GCM in terms of sustained accuracy and lower computational complexity. Ultimately, choices in regards to decreasing carbon emanations because of transportation frameworks have been examined, as well. It has been concluded that our formulation can proceed with the economic progress without detriment to ecological and regular assets.

There are a few interesting topics for future research works of this study by considering different kinds of environments such as grey systems (Roy et al. 2017a), robust environment (Goli et al. 2019; Khalilpourazari et al. 2019), stochastic (Mahapatra et al. 2013), neutrosophic set (Das and Roy 2019), dual-hesitant fuzzy (Maity et al. 2019a), interval valued (Roy and Maity 2017), multi-choice type (Roy et al. 2017b), location problem (Das et al. 2020a, b, c, 2021), rough sets (Roy et al. 2018b), type-2 fuzzy set (Roy and Bhaumik 2018; Roy and Maiti 2020), and biofuel supply chain (Paksoy et al. 2013). Further, the several nature inspired optimization algorithms and stochastic methods can be employed to solve the proposed model.

## References

Angelov PP (1997) Optimization in an intuitionistic fuzzy environment. Fuzzy Sets Syst 86(3):299–306

Benjaafar S, Li Y, Daskin M (2012) Carbon footprint and the management of supply chains: Insights from simple models. IEEE Trans Autom Sci Eng 10(1):99–116

Biswas A, Shaikh AA, Niaki STA (2019) Multi-objective non-linear fixed charge transportation problem with multiple modes of transportation in crisp and interval environments. Appl Soft Comput 80:628–649

Chen L, Peng J, Zhang B (2017) Uncertain goal programming models for bicriteria solid transportation problem. Appl Soft Comput 51:49–59

Chen X, Benjaafar S, Elomri A (2013) The carbon-constrained EOQ. Oper Res Lett 41(2):172–179

Chen X, Wang X (2016) Effects of carbon emission reduction policies on transportation mode selections with stochastic demand. Transp Res Part E: Logist Transp Rev 90:196–205

Das SK, Roy SK (2019) Effect of variable carbon emission in a multi-objective transportation-p-facility location problem under neutrosophic environment. Comput Ind Eng 132:311–324

Das SK, Roy SK, Weber G-W (2020a) Heuristic approaches for solid transportation-p-facility location problem. CEJOR 28:939–961

Das SK, Roy SK, Weber GW (2020b) An exact and a heuristic approach for the transportation–facility location problem. Comput Manag Sci 17:389–407

Das SK, Roy SK, Weber G-W (2020c) Application of type-2 fuzzy logic to a multi-objective green solid transportation-location problem with dwell time under carbon tax, cap and offset policy: fuzzy vs. non-fuzzy techniques. IEEE Trans Fuzzy Syst 28(11):2711–2725

Das SK, Pervin M, Roy SK, Weber G-W (2021) Multi-objective solid transportation-location problem with variable carbon emission in inventory management: a hybrid approach. Ann Oper Res. https://doi.org/10.1007/s10479-020-03809-z

Elhedhli S, Merrick R (2012) Green supply chain network design to reduce carbon emissions. Transp Res Part D: Transp Environ 17(5):370–379

Goli A, Tirkolaee EB, Malmir B, Bian G-B, Sangaiah AK (2019) A multi-objective invasive weed optimization algorithm for robust aggregate production planning under uncertain seasonal demand. Computing 101(6):499–529

Gupta P, Mehlawat MK, Aggarwal U, Charles V (2018) An integrated ahp-dea multi-objective optimization model for sustainable transportation in mining industry. Resour Policy. https://doi.org/10.1016/j.resourpol.2018.04.007

Haley K (1962) New methods in mathematical programming—the solid transportation problem. Oper Res 10(4):448–463

Inuiguchi M, Ichihashi H, Tanaka H (1990) Fuzzy programming: a survey of recent developments. In: Stochastic versus fuzzy approaches to multiobjective mathematical programming under uncertainty. Springer, pp 45–68

Jiménez F, Verdegay JL (1998) Uncertain solid transportation problems. Fuzzy Sets Syst 100(1–3):45–57

Jiménez F, Verdegay JL (1999) Solving fuzzy solid transportation problems by an evolutionary algorithm based parametric approach. Eur J Oper Res 117(3):485–510

Khalilpourazari S, Mirzazadeh A, Weber G-W, Pasandideh SHR (2019) A robust fuzzy approach for constrained multi-product economic production quantity with imperfect items and rework process. Optimization 69(1):63–90

Konur D, Schaefer B (2014) Integrated inventory control and transportation decisions under carbon emissions regulations: LTL vs. Tl carriers. Transp Res Part E: Logist Transp Rev 68:14–38

Lélé SM (1991) Sustainable development: a critical review. World Dev 19(6):607–621

Li L, Lai KK (2000) A fuzzy approach to the multiobjective transportation problem. Comput Oper Res 27(1):43–57

Litman T, Burwell D (2006) Issues in sustainable transportation. Int J Glob Environ Issues 6(4):331–347

Liu P, Yang L, Wang L, Li S (2014) A solid transportation problem with type-2 fuzzy variables. Appl Soft Comput 24:543–558

Mahapatra DR, Roy SK, Biswal MP (2013) Multi-choice stochastic transportation problem involving extreme value distribution. Appl Math Model 37(4):2230–2240

Maity G, Mardanya D, Roy SK, Weber G-W (2019a) A new approach for solving dual-hesitant fuzzy transportation problem with restrictions. Sādhanā 44(4):75. https://doi.org/10.1007/s12046-018-1045-1

Maity G, Roy SK, Verdegay JL (2019b) Time variant multi-objective interval-valued transportation problem in sustainable development. Sustainability 11(21):6161. https://doi.org/10.3390/su11216161

Mehlawat MK, Kannan D, Gupta P, Aggarwal U (2019) Sustainable transportation planning for a three-stage fixed charge multi-objective transportation problem. Ann Oper Res 1–37. https://doi.org/10.1007/s10479-019-03451-4

Molla-Alizadeh-Zavardehi S, Nezhad SS, Tavakkoli-Moghaddam R, Yazdani M (2013) Solving a fuzzy fixed charge solid transportation problem by metaheuristics. Math Comput Model 57(5–6):1543–1558

Nomani MA, Ali I, Ahmed A (2017a) A new approach for solving multi-objective transportation problems. Int J Manag Sci Eng Manag 12(3):165–173

Nomani MA, Ali I, Fügenschuh A, Ahmed A (2017b) A fuzzy goal programming approach to analyse sustainable development goals of india. Appl Econ Lett 24(7):443–447

Paksoy T, Özceylan E, Weber G-W (2013) Profit oriented supply chain network optimization. CEJOR 21(2):455–478

Paksoy T, Pehlivan NY, Özceylan E (2012) Fuzzy multi-objective optimization of a green supply chain network with risk management that includes environmental hazards. Hum Ecol Risk Assess Int J 18(5):1120–1151

Poterba JM (1991) Tax policy to combat global warming: on designing a carbon tax. Technical report, National Bureau of Economic Research

Roy SK, Bhaumik A (2018) Intelligent water management: a triangular type-2 intuitionistic fuzzy matrix games approach. Water Resour Manag 32(3):949–968

Roy SK, Ebrahimnejad A, Verdegay JL, Das S (2018a) New approach for solving intuitionistic fuzzy multi-objective transportation problem. Sādhanā 43(1):3. https://doi.org/10.1007/s12046-017-0777-7

Roy SK, Midya S, Vincent FY (2018b) Multi-objective fixed-charge transportation problem with random rough variables. Int J Uncertain Fuzz Knowl Based Syst 26(6):971–996

Roy SK, Maiti SK (2020) Reduction methods of type-2 fuzzy variables and their applications to stackelberg game. Appl Intell 50:1398–1415. https://doi.org/10.1007/s10489-019-01578-2

Roy SK, Maity G (2017) Minimizing cost and time through single objective function in multi-choice interval valued transportation problem. J Intell Fuzzy Syst 32(3):1697–1709

Roy SK, Maity G, Weber G-W (2017a) Multi-objective two-stage grey transportation problem using utility function with goals. Cent Eur J Oper Res 25(2):417–439

Roy SK, Maity G, Weber GW, Gök SZA (2017b) Conic scalarization approach to solve multi-choice multi-objective transportation problem with interval goal. Ann Oper Res 253(1):599–620

Roy SK, Midya S (2019) Multi-objective fixed-charge solid transportation problem with product blending under intuitionistic fuzzy environment. Appl Intell 49(10):3524–3538

Roy SK, Midya S, Webe G-W (2019) Multi-objective multi-item fixed-charge solid transportation problem under twofold uncertainty. Neural Comput Appl 31(12):8593–8613

Shell E (1955) Distribution of a product by several properties, directorate of management analysis. In: Proceedings of the second symposium in linear programming, vol 2, pp 615–642

Shih C, Chang C (1995) Pareto optimization of alternative global criterion method for fuzzy structural design. Comput Struct 54(3):455–460

Tao Z, Xu J (2012) A class of rough multiple objective programming and its application to solid transportation problem. Inf Sci 188:215–235

Tirkolaee EB, Mardani A, Dashtian Z, Soltani M, Weber G-W (2020) A novel hybrid method using fuzzy decision making and multi-objective programming for sustainable-reliable supplier selection in two-echelon supply chain design. J Clean Prod 250:119517

Turken N, Carrillo J, Verter V (2017) Facility location and capacity acquisition under carbon tax and emissions limits: to centralize or to decentralize? Int J Prod Econ 187:126–141

Zhou S, Shi M, Li N, Yuan Y (2011) Impacts of carbon tax policy on $CO_2$ mitigation and economic growth in china. Adv Clim Chang Res 2(3):124–133

Zimmermann H-J (1978) Fuzzy programming and linear programming with several objective functions. Fuzzy Sets Syst 1(1):45–55