



## SUPPLIER SELECTION AND OPTIMIZATION OF SUPPLY CHAINS

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### ABSTRACT

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Supplier selection is one of the most important components of supply chain management. The main objective of this exercise is to select best suppliers based on different criteria. Those criteria are often closely related with sustainability and are set by the decision-maker. Hence, the objective of this paper is to integrate sustainability and decision-making. The sustainability aspect of the model includes economic, environmental and social dimensions and strategic level of decision-making criteria. The methodology used in this paper is mathematical modeling and the problem is formulated as mixed integer linear programming. The integration of sustainability and supplier selection is presented on an illustrative example of a bio-fuel supply chain. The best multi-objective solution is obtained using the weighting sum method. The study indicates that the integration of several sustainability aspects and supplier selection can be useful for decision making process. The main contribution of this work is the integration of supplier selection with the sustainability of supply chains.

**Contribution/Originality:** The main contribution of this paper is in the field of sustainable supply chain development. The methodology used was mathematical modeling (optimization). The objective was to integrate supplier selection and sustainability of supply chains.

## 1. INTRODUCTION

Supply chains (SCs) are considered one of the main part in today's economy and business organizations (Pasandideh *et al.*, 2015) and their goal is to deliver products from front end (supply) to back end (demand) (Tang and Musa, 2011). Additionally, SCs are characterized by forward (open loop SCs) and reverse movement (closed loop SCs) of material (Easwaran and Üster, 2010; Govindan *et al.*, 2015; Pedram *et al.*, 2017). SCs are integrated networks of raw materials suppliers, manufacturers, warehouses, distribution centers, and consumers (Melo *et al.*, 2009) with various aspects of inter-network (within SCs) competition and relations seen from business managements perspective (Lambert and Cooper, 2000; Mentzer *et al.*, 2001). The common interest of all SCs players is most often reflected in terms of economic gains (Carter and Liane Easton, 2011).

The most common measure of a SC performance is its sustainability (Schaltegger and Burritt, 2014) which is approached at three levels, namely: economic, environmental and social (Beske and Seuring, 2014; Joyce and Paquin, 2016; Rajeev *et al.*, 2017). Although, SCs and sustainability have been defined in many ways over the years, the most often used definition of sustainability describes it as: "development that meets the needs of the present without

compromising the ability of future generations to meet their own needs” (United Nations General Assembly, 1988). While sustainable SC management is defined by Seuring and Müller (2008) as: “the management of material, information and capital flows as well as cooperation among companies along the SC while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements”. From a decision-making standpoint, balancing out all three dimensions of sustainability is a real challenge (Seuring, 2013). Additionally, Pagell and Shevchenko (2014) argue that our current level of understanding the subject at hand is not sufficient to create truly sustainable SCs. They listed several major issues and solutions to them.

Supplier selection is a challenging task in SC management (Liao and Kao, 2011). Hence, supplier selection is important and may have a considerable impact on sustainable development and sustainability of SCs (Banaeian *et al.*, 2018). According to Ayhan (2013) supplier selection, which consists of several different and conflicting objectives, can be defined as an objective of finding the best supplier with best price at the right quality, at the right time and quantity.

The aim of this analysis is to address the issues of supplier selection and sustainable development of SCs as an integrated problem, following the research question: how can SC sustainability be integrated with supplier selection?

In this work, a mathematical programming model is proposed, which integrates economic, environmental, and social performance of a SC with supplier selection. The model is tested on an illustrative example of a bio-fuel SC.

The remainder of the paper is structured as follows: in the next Section we provide the background of the study, i.e., literature review focusing on SC sustainability and supplier selection. Section 3 defines problems and characteristics of the model, while in Section 4, a detailed model is presented. Results are discussed in Section 5, and conclusions and future remarks are given in the last Section.

## 2. LITERATURE REVIEW

There are numerous review papers dealing with the issues studied in this work, some of the most prominent reviews dealing with supplier selection include: De Boer *et al.* (2001); Ho *et al.* (2010) and Govindan *et al.* (2015). Amongst papers dealing with sustainable SCs we may mention: Seuring and Müller (2008); Seuring (2013) and Mujkić *et al.* (2018). However, for this work we have selected and classified papers based on the criteria listed below.

The papers reviewed in this study are classified based on two categories: (I) papers focused on sustainable development as an objective which deals with one or more aspects of sustainability (economic, environmental or social), and (II) papers presenting supplier selection as a decision-making process. Additionally, mathematical modeling was the methodology used in all papers.

### 2.1. Supply Chains and Sustainability

The objective of a SC is to organize the flow of raw materials from extraction to the final product and the delivery to the consumer. However, sustainability has extended it to cover the consideration of product design, manufacturing, by-products, and product life cycle from cradle to grave (Linton *et al.*, 2007). Table 1 presents papers classified based on the mathematical model and explored aspects of sustainability.

You and Grossmann (2008) proposed a MINLP optimization model for a SC network design with three-echelons and stochastic inventory management. In the model, the authors consider only the economic dimension of sustainability, more specifically, minimizing total costs (facilities, distribution centers, and transportation) and inventory. The model was tested on several examples. Alfonso *et al.* (2009) developed a model to optimize biomass facility location as to the costs and CO<sub>2</sub> reduction, i.e. with respect to economic and environmental criteria. Elhedhli and Merrick (2012) studied a SC network design, which takes into account fixed and variable location and production costs, together with CO<sub>2</sub> emissions. Liu and Papageorgiou (2013) proposed a mixed integer linear

programming (MILP) model in which total cost, flow time and lost demand are set as objective functions. Similarly, Mota *et al.* (2015) proposed a multi-objective MILP model to design a SC network structure. The model addressed all the aspects of sustainability with the focus on newly created jobs as the social aspect. The model was tested on a Portugal battery factory. A multi-objective linear programming model was proposed by Banasik *et al.* (2017b) to minimize the flow of materials in an agri-food mushroom closed loop SC. Varsei and Polyakovskiy (2017a) simultaneously considered all dimensions of sustainability and developed a multi-objective model to find the best network configuration, while minimizing costs, greenhouse gas emission and maximizing the social impact.

**Table-1.** Review of previous literature on supplier selection.

Article	Methodology	Sustainability dimension		
		Eco	Env	Soc
You and Grossmann (2008)	MINLP	●		
Alfonso <i>et al.</i> (2009)	LP	●	●	
Elhedhli and Merrick (2012)	LP	●	●	
Liu and Papageorgiou (2013)	MILP	●		
Mota <i>et al.</i> (2015)	MILP	●	●	●
Banasik <i>et al.</i> (2017a)	MILP	●	●	
Varsei and Polyakovskiy (2017b)	MILP	●	●	●
Chávez <i>et al.</i> (2018)	MILP	●	●	●
Alavidooost <i>et al.</i> (2018)	MINLP	●		
How (2019b)	MILP	●	●	●

Source: Author's Research.

A bio-fuel SC with coffee as raw material was proposed by Chávez *et al.* (2018) where net present value (economy), gray water footprint and CO<sub>2</sub> emission (environment), jobs created and food security (society) are considered as objective functions. A three echelon SC model to determine optimal service level and minimize total costs was proposed by Alavidooost *et al.* (2018). How (2019a) presented a MILP model of palm biofuel with simultaneous consideration of economic, environmental and social criteria.

## 2.2. Supplier Selection and Sustainability

Supplier selection is an important decision-making process in SC management and it presents an effective step towards more sustainable development of SCs (Kumar *et al.*, 2014). Sustainability aspects should be included in the supplier selection criteria from economic, environmental and social perspective (Bai and Sarkis, 2010). Integration of sustainability and supplier selection leads to increased complexity of decision-making process. However, integration may produce an overall better performance of a SC (Luthra *et al.*, 2017).

Ng (2008) developed a generic linear model for the selection of the best supplier based on different criteria. The supply chain vs. only buyer's benefit was addressed by Kheljani *et al.* (2009) in terms of several different annual costs. Rezaei and Davoodi (2011) considered a MINLP model with three objective functions (total cost, quality and service level) as decision variables. Sawik (2014) proposed a mathematical model with single and dual sourcing as a decision variable. In the model objective functions are set as the minimization of total costs or maximization of the service level. An integration of sustainable development of a SC and supplier selection was addressed by Azadnia *et al.* (2015). In the model several conflicting objective functions were formulated for total cost minimization and maximization of economic, environmental and social performance. Hashim *et al.* (2017) introduced multi-objective fuzzy model to address several issues including economic, environmental and social aspects. In Table 2 presents some of the works done in the fields of sustainable development of supply chains.

Table-2. Review of previous studies on supply chain sustainability.

Article	Methodology	Sustainability dimension		
		Eco	Env	Soc
Ng (2008)	LP	●		
Kheljani <i>et al.</i> (2009)	MINLP	●		
Rezaei and Davoodi (2011)	MINLP	●		
Sawik (2014)	MILP	●		
Azadnia <i>et al.</i> (2015)	FUZZY	●	●	●
Hashim <i>et al.</i> (2017)	FUZZY	●	●	
Cheraghalipour and Farsad (2018)	MILP	●	●	●
Nourmohamadi <i>et al.</i> (2018)	MILP	●	●	●
Rad and Nahavandi (2018)	MILP	●	●	
Tosarkani and Amin (2018)	MILP	●	●	

Source: Author's Research.

A bi-objective model was proposed by Cheraghalipour and Farsad (2018) the aim of the model is to minimize total costs and maximize total economic, environmental and social scores. Similarly, Nourmohamadi *et al.* (2018) developed a MILP model with the intention to meet four objectives: to deal with total costs, economic, environmental, and social issues. A MILP model was proposed by Rad and Nahavandi (2018) to minimize costs and emission, to maximize consumer satisfaction rate, and to carry out supplier selection based on several different criteria. Tosarkani and Amin (2018) considered a MILP to maximize profit, environmental score and on-time delivery within a closed-loop SCs and minimize defect rates in reverse logistics.

### 3. PROBLEM DEFINITION

The aim of this work is to develop a MILP optimization model for biofuels SC by considering and integrating economic, environmental and social aspects of sustainability with supplier selection as decision-making criteria. The model is formulated as a multi-objective problem with cost minimization (transportation and purchasing costs), minimization of environmental impact (CO<sub>2</sub> emissions) and maximization of social benefits (created jobs). Furthermore, the model considers sustainable supplier selection, considering economic, environmental and social scores. The scores are given to the following echelons: raw material extraction, manufacturer, and retailer. The criteria used here are related to economic, environmental and social performance of the SC. With that in mind, the objective of this work is to minimize the total cost, while maximizing environmental and social aspects of a biofuel SC, and considering sustainability aspects of SCs and supplier selection. Based on that the following is given:

- Flows of raw material, and final products purchased.
- Flows of biofuel produced and capacities of each echelon.
- Transportation and purchasing cost of raw material and biofuels.
- CO<sub>2</sub> emissions related to transportation and production of biofuels.

The problem and the SC defined above is a multi-echelon structure, which includes: raw material, manufacturing, retailers and consumers as shown on Figure 1.

#### 3.1. Supplier Selection Criteria

Most often, supplier selection criteria are based on quantitative performance indicators for quality, delivery, speed and price (Rezaei *et al.*, 2016). However, growing awareness of SC impact on environment and society, is pressing on organizations to reconsider their business models and include other criteria into sustainability and supplier selection process (Luthra *et al.*, 2017). This paper covers all three dimensions of sustainability (economic, environmental and social) (Qorri *et al.*, 2018). Furthermore, the indicators used in this work have been selected and agreed by the authors as indicators the most commonly used in literature (Mata *et al.*, 2013; Kumar Kar and K. Pani, 2014; Zimmer *et al.*, 2016) and a standard framework (Global Reporting Initiative GRI, 2014). The criteria and sub-criteria used in the model are presented in Table 3.

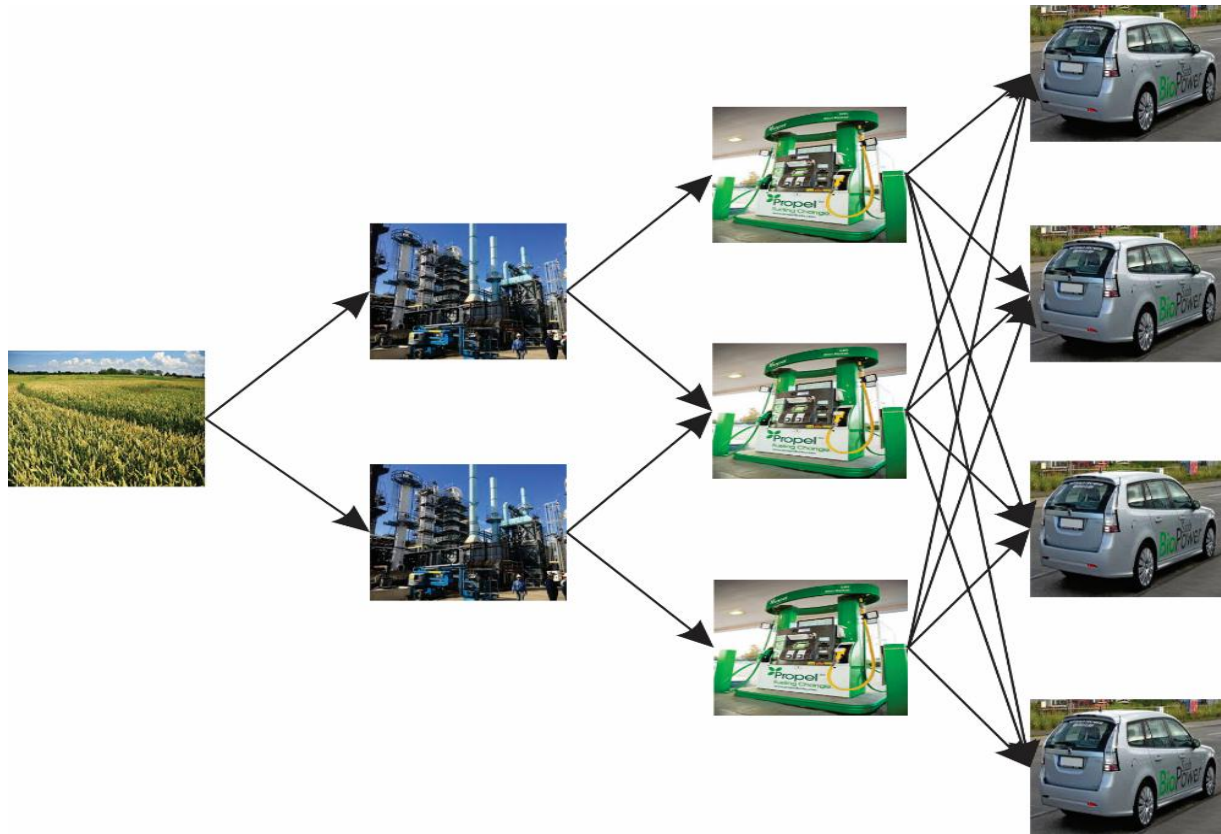


Figure-1. Simplified representation of the supply chain (adopted from Babazadeh *et al.* (2017)).

Table-3. Sustainability criteria and sub-criteria used in the model.

Criteria Sub-criteria	Economic	Environmental	Social
Cost	Transportation cost Purchasing cost	-	-
Environmental impact	-	CO <sub>2</sub> Emission	-
Employment	-	-	Jobs created

Source: Author's Research.

### 3.2. Model Formulation

The indices, parameters and variables used in the model formulation are given and described in Appendix A. While, the models constrains, equations and objective functions are listed below:

Objective functions:

#### 3.2.1. Economic Objective Function

Economic aspects of supply chain are presented in the Equation 1. The cost objective function of the MILP model consists of transportation and purchasing cost:

$$\min Z_1 = \sum_i Tc_{i,j} Q_{i,j} + \sum_j Tc_{j,k} Q_{j,k} + \sum_i Pc_{i,j} Q_{i,j} + \sum_j Pc_{j,k} Q_{j,k} \quad \forall i, j \quad (1)$$

Environmental objective function:

Environmental aspects of supply chain are presented in the Equation 2. The environmental objective function of the model is expressed in terms of CO<sub>2</sub> emission:

$$\min Z_2 = \sum_i D_{ij} Ee + \sum_j D_{jk} Ee + \sum_i Ef_i Q_{ij} + \sum_j Eg_j Q_{jk} \quad \forall i, j \quad (2)$$

Social objective function:

Social aspects of supply chain are presented in the Equation 3. The social objective function of the model is expressed in terms of the number of jobs created:

$$\min Z_3 = \sum_i Jo_i R_i + \sum_j Jo_j R_j \quad \forall i, j \quad (3)$$

Supply constrains:

Total material flow from manufacturer is given in Equation 4. The material flow from manufacturer to retailer is expressed as:

$$\sum_i Ma_i \leq M_i \quad \forall i \quad (4)$$

Total material flow from retailer is given in Equation 5. The material flow from retailer to consumer is expressed as:

$$\sum_j Ra_j \leq R_j \quad \forall j \quad (5)$$

Demand constrains:

Total material demand from retailer is given in Equation 6. The material required by retailer is expressed as:

$$\sum_i Ma_i \leq M_i \quad \forall i \quad (6)$$

Total material demand from consumer is given in Equation 7. The material required by consumer is expressed as:

$$\sum_j Ra_j \leq R_j \quad \forall j \quad (7)$$

### 3.3. Weighted Sum Method

The proposed mathematical model has three conflicting objectives, which must be met using a Pareto optimal set. A solution to the problem is defined as the best possible solution of the conflicting objective functions, which means that the solution cannot be improved by any other method (Mavrotas, 2009). In this work the Pareto optimal solution for economic (total cost minimization) environmental (minimization of CO<sub>2</sub> emission), and social objective functions (maximization of jobs created) are proposed.

The weight sum of all the objective function is given in the Equation 8. Sum of weights is expressed as:

$$\sum_{i=1}^m \omega_m \quad \forall m \quad (8)$$

The multi-objective function is given in Equation 9, and it is expressed as:

$$Mof = \omega_m \frac{Z_{eco} - Z_{eco}^{low}}{Z_{eco}^{up} - Z_{eco}^{low}} + \omega_{m+1} \frac{Z_{env} - Z_{env}^{low}}{Z_{env}^{up} - Z_{env}^{low}} + \omega_{m+2} \frac{Z_{Mof} - Z_{soc}^{low}}{Z_{soc}^{up} - Z_{soc}^{low}} \quad (9)$$

## 4. COMPUTATIONAL RESULTS AND DISCUSSIONS

In this part we discuss the model as illustrated by an example. As mentioned above, the model is formulated as a MILP problem. The linearity of the model comes from the input (production) and output (delivery) capacity of each echelon in the SC network structure and the distance between the two mentioned echelons. The mixed integer part of the model comes from the supplier selection based on different criteria as presented in Table 3. The model is solved in two scenarios and several sub-scenarios. Scenarios are divided based on the weight of each sustainability dimension; results of the multi-objective optimization of the problem are presented in Table 4 and Table 4. Results for multi-objective scenario.



#### 4.1. Data Description of the Problem

This paper presents a multi-echelon SC network design composed of: suppliers, manufacturers, retailers and customers, as shown in Figure 1. We assume that material is transported between the echelons using road transport (trucking) and the cost of transport is expressed in €/km. According to Hooper and Murray (2018) operational cost of trucking in 2017 was 1.691 \$/mile or 0,9198 €/km.

#### 4.2. Multi-Objective Optimization

An illustrative example is presented to analyze the mathematical model. The SC is presented as an open-loop network structure with four types of echelons, namely; raw material production, biofuel production, retailer, and consumer. Each echelon in the network structure has a unique role to play in the SC.

Table-4. Results for multi-objective scenario.

Scenario	Weights			Objective function values		
	Eco	Env	Soc	Total cost	CO <sub>2</sub> emission	Jobs created
1	1.000	0.0000	0.0000	10208200	102595	8678
2	0.6000	0.4000	0.0000	10208200	102595	8678
3	0.6000	0.2000	0.2000	10208200	102595	8678
4	0.6000	0.0000	0.4000	10208200	102595	8678
5	0.3333	0.3333	0.3333	10208200	102595	8678
6	0.2000	0.8000	0.0000	10607200	98403	8421
7	0.2000	0.0000	0.8000	10607200	98403	8421
8	0.2000	0.4000	0.4000	10607200	98403	8421
9	0.2000	0.2000	0.6000	10809700	100658	8175
10	0.2000	0.0000	0.8000	11961200	112182	7295
11	0.0000	1.0000	0.0000	10607200	98403	8421
12	0.0000	0.0000	1.0000	11961200	112182	7295

Source: Author's Research.

Table-5. Optimal network structure scenario of the supply chain.

Scenario	Raw material	Factories	Retailer
1	1,2	1,2,3	1,2,4
6	1,2	1,2,3	1,3,4
12	1,2	1,2,3	1,2,3,4
13	1,2	1,2,3	1,2,3,4

Source: Author's Research.

A more detailed analysis of the results from Table 4 and Table 5. Results for multi-objective scenario is presented below:

The first case (scenario 1) of the multi-objective optimization problem comprises two raw material production plants, two manufacturing factories, and three retailer units. The total cost is € 10,208,200, CO<sub>2</sub> emission is 102,595 and 8,678 jobs created. The second case (scenario 6) of the multi-objective optimization problem includes two raw material production plants, two manufacturing factories, and three retailer units. The total cost is €10,208,200, CO<sub>2</sub> emission is 102,595 and the number of jobs created is 8,678. The third scenario of the multi-objective optimization problem was developed for two raw material production plants, two manufacturing factories, and four retailer units. The total cost is €10,607,200, CO<sub>2</sub> emission is 98,403 and the number of jobs created is 8,421. The fourth scenario of the multi-objective optimization problem includes two raw material production plants, two manufacturing factories, and four retailer units. The total cost for this scenario is €11,961,200, CO<sub>2</sub> emission is 112,182 and the number of jobs created is 7,295.

## 5. CONCLUSIONS FOR FUTURE RESEARCH DIRECTIONS

The importance of sustainability and supplier selection has gained significant attention from academia and practitioners in the recent years. Having said that, the objective of this paper was to show how supplier selection may improve the overall supply chain sustainability. The model used in our study was formulated as a multi-

echelon, multi-supplier and multi-objective MILP model. In the model the weighting sum was used in the decision-making process to set the weight of sustainability criteria and sub-criteria. The model considers all three aspects of sustainability: economic, environmental and social, together with supplier selection. The economic objective function in the model includes the costs of transportation and purchasing, the environmental objective function is to minimize CO<sub>2</sub> emissions, and the social objective function is to maximize the number of jobs created.

Drawbacks identified while conducting this study indicate several possible future research directions that can be recommended to go more in-depth into the issue. First, the model was tested on an illustrative example, while a real-life case would help better demonstrate the combined impact of sustainability and supplier selection. Second, the model takes account of only six sub-criteria, however, with higher number of sub-criteria the overall impact of sustainability and supplier selection could lead to deeper implications. Third, the number of objective functions can be increased to better describe the biofuels SC.

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## Appendix A

### Indices Description

$i$  index for manufacturer,

$j$  index for retailer,

$k$  index for consumer,

### Parameters

$Eco_{ij}$  Economic score of supplier  $i$  (manufacturer),

$Env_{ij}$  Environmental score of supplier  $i$  (manufacturer),

$Soc_{ij}$  Social score of supplier  $i$  (manufacturer),

- $Eco_{jk}$  Economic score of supplier  $\dot{j}$  (retailer),
- $Env_{jk}$  Environmental score of supplier  $\dot{j}$  (retailer),
- $Soc_{jk}$  Social score of supplier  $\dot{j}$  (retailer),
- $W_i^{ECO}$  Weight values for economic criteria from the best worst method for  $i$  manufacturer,
- $W_i^{ENV}$  Weight values for environmental criteria from the best worst method for  $i$  manufacturer,
- $W_i^{SOC}$  Weight values for social criteria from the best worst method for  $i$  manufacturer,
- $W_j^{ECO}$  Weight values for economic criteria from the best worst method for  $\dot{j}$  retailer,
- $W_j^{ENV}$  Weight values for environmental criteria from the best worst method for  $\dot{j}$  retailer,
- $W_j^{SOC}$  Weight values for social criteria from the best worst method for  $\dot{j}$  retailer,
- $Tc_{ij}$  Transportation costs from manufacturer  $i$  to retailer  $\dot{j}$ ,
- $Tc_{jk}$  Transportation costs from retailer  $\dot{j}$  to retailer  $k$ ,
- $Tc_{jk}$  Transportation costs from retailer  $\dot{j}$  to retailer  $k$ ,
- $Ee$  CO<sub>2</sub> emission in kg per km for in case of transportation,
- $R_i$  Factor related to job created by manufacturer  $i$ ,
- $R_j$  Factor related to job created by retailer  $\dot{j}$ ,
- $M_i$  Material available at manufacturer  $i$  for shipped to retailer  $\dot{j}$ ,
- $R_i$  Material available at retailer  $\dot{j}$  for shipped to retailer  $k$

*Variables:*

- $Q_{ij}$  Quantity of items ordered from manufacturer  $i$  to retailer  $\dot{j}$ ,
- $Q_{jk}$  Quantity of items ordered from retailer  $\dot{j}$  to consumer  $k$ ,
- $D_{ij}$  Distance between manufacturer  $i$  and retailer  $\dot{j}$ ,
- $D_{jk}$  Distance between manufacturer  $\dot{j}$  and retailer  $k$ ,
- $Ef_i$  CO<sub>2</sub> emission in kg per kg of martial produced by manufacturer  $i$ ,

$Eg_j$  CO<sub>2</sub> emission in kg per kg of martial stored by retailer  $j$ ,

$Jo_i$  Number of jobs created by manufacturer  $i$ ,

$Jo_j$  Number of jobs created by retailer  $j$ ,

$Ma_i$  Material shipped from manufacturer  $i$  to retailer  $j$ ,

$Ra_j$  Material shipped from retailer  $i$  to consumer  $k$ ,

## Appendix B

The above given model was solved using General Algebraic Modeling System (GAMS) version 24.2.3, and BARON was used as a solver, the problems were solved on an Intel i7 CPU (3.50 GHz) computer with 8 GB of RAM where the results of single-objective optimization are presented. The model is solved for three scenarios, namely: economic, environmental and social aspects of SCs. Additionally, Table 4 presents the results of multi-objective optimization.

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