Towards sustainability in sourcing: A hybrid MCDM approach

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ABSTRACT

Recently, a growing interest in achieving sustainability development goals in business has increased in a way that challenging decision makers in seeking sustainable sourcing considering economic, environmental and social aspects. A hybrid fuzzy TOPSIS-fuzzy multi objectives optimization model was developed to solve supplier selection and order allocation problem in a three-echelon supply chain considering sustainability aspects. The objectives include minimization of expected costs, environmental impact and travel time and maximization of social impact. Fuzzy TOPSIS was employed to evaluate suppliers' performance vis-a-vis traditional, green and social criteria. The obtained performance score was then integrated into the fuzzy multi-objective model. Then, a set of Pareto solutions was derived by using the LP-metrics method. The developed fuzzy TOPSIS-fuzzy multi-objective model was validated on a three-echelon meat supply chain. This study has considered several sustainability oriented-criteria in sourcing. The research outcome revealed significant managerial and practical implications of the sourcing optimization model.

Keywords: Sustainable sourcing; Purchasing; Food supply chain; Fuzzy TOPSIS; MCDM.

1. INTRODUCTION

Supplier selection and order allocation is a main key factor in implementing a robust supply chain management (Mohammed et al., 2018 & 2018a). This is based on the fact that firms depend more on suppliers to obtain a cost-effective product quality. Furthermore, purchasing activity is one of the main tasks for enterprises since its costs represents more than 50% of all enterprises' internal costs (Yazdani et al., 2016 & Mohamemd et al., 2019). It is regarded as a multifaceted, multi-criteria decision-making activity since different and conflicting criteria should be considered and assessed to assign consistent suppliers

Sustainable supply chain management is a new pattern that has been emerging recently in industries and enterprises (Fallahpour et al., 2017; and Mohammed et al., 2018b). It makes a significant influence on supply chain performance in the economic, environmental and social aspects. Sustainable supply chain management could be the organization of the streams of assets, data, human resources and merchandises between and among all echelons of the supply chain to gain the optimal compromise among economic, green and social aspects. This new pattern increases the challenges for a decision maker in selecting the sustainable suppliers in which takin into account traditional (e.g. economic), green and social aspects. Where, decision makers are being increasingly motivated to improve their supply chain activities in coping efficiently with the objectives of sustainable development. Where the sustainable growth threatens the current supply chain partners to either cope with the new regulations or leave the field for new players.

Despite that several research studies have employed mathematical programming approaches in solving supplier selection problem, integrating multi-criteria decision making (MCDM) algorithms with fuzzy multi-objective optimization model for two-stage supplier selection and order allocation problem with respect to traditional, green and social aspects, particularly in food industry is, to the best of our knowledge, an original research. Where the emphasis on sustainability concerns in supplier selection and order allocation problem is still at an early stage. This research presents a development of a hybrid approach for solving supplier selection and order allocation problem in a meat supply chain considering traditional, green and social aspects in addition to the travel time which is a main key factor for food quality. A numerical case study was used to examine the efficacy of the developed integrated approach. The developed integrated fuzzy TOPSIS-fuzzy multi-objective approach is expected to provide supply chain managers particularly in food sector with the insights of the sustainable criteria that need to be measured in evaluating and selecting suppliers according to their sustainability performance. Also, supply chain managers can utilize the developed approach to evaluate and select the superior suppliers based on several sustainable criteria.

2. LITERATURE REVIEW

Historically, traditional criteria e.g. price, quality, and delivery reliability are usually used mainly by the purchasing team at companies to evaluate suppliers (Mohammed et al., 2019 & 2019a). Govindan et al. (2016) and Gaziulusoy (2015) discussed that firms cannot lack behind responsibilities of sustainability in industry because of the increasing awareness of sustainability, rigorous government regulations, and growing public capacity. With the aim of improving business performance and gaining a higher competitive advantage, decision makers should perform supplier selection activity considering sustainability aspect in industrial supply chains. The latter is based on the fact of suppliers may act a crucial role in establishing a sustainable supply chain concept and in attaining traditional economic, green and social initiatives. In this study, the important sustainable criteria for evaluating suppliers' performance in the supply chain under study have been attained through literature resources, and they were approved by decision makers' opinions. The criteria were categorized into three dimensions: traditional, green and social.

MCDM techniques lead decision makers to thoroughly obtain compromised solutions among conflicting criteria when evaluating and selecting suppliers. Araújo et al. (2017) conducted a review study on MCDM applied for evaluating and selecting suppliers. This section reviews previous studies on supplier evaluation and selection incorporating traditional criteria such costs, delivery time, commitment, product quality, etc. For instance, Bottani and Rizzi (2005) used fuzzy AHP (analytical hierarchic process) to solve a supplier selection problem in an e-procurement environment.

Green supply chain management was defined as the process of purchasing, producing, marketing, and performing various packaging and logistic activities while considering the ecological balance (Nujoom et al., 2018 & 2019; and Mohammed et al., 2019b). Sustainability extended the green pattern in combining economic, environmental and social responsibilities. In the section, we reviewed researches that used mathematical approaches in evaluating suppliers considering economic and environmental criteria (green) and economic, environmental and social criteria (sustainable).

A comprehensive literature review on mathematical approaches employed for green supplier selection was presented by Nielsen et al. (2014) and Govindan et al. (2015). Recently, several research works have been published in considering sustainability aspect into supplier selection decisions in supply chain management. Govindan and Sivakumar (2016) proposed an integrated MCDM and multi-objective optimization approach as an aid to reveal the superior green supplier.

Nowadays, an efficient supplier selection in food section has become an essential manner (Matos and Hall, 2007). This indicates the need for effectively considering the three pillars of sustainability within food supply chain management. Banaeian et al. (2017) presented a comparison among TOPSIS, VIKOR and GRA methods aiming to rank suppliers in agri-food industry considering economic and environmental criteria.

Markedly, several research has conducted relative to traditional and green focused supplier selection activity, but there is still partial literature on supplier selection considering the triple bottom line of sustainability (traditional, green and social) (Mahdiloo et al., 2015; Grimm et al., 2016), in particular for a two-stage supplier chain where some evaluation criteria for the two stages are different.

3. RESEARCH METHODOLOGY

This work aims at solving a two-stage sustainable supplier selection and order allocation problem for a meat supply chain consists of sets of farms, abattoirs and retailers through a development of an integrated fuzzy TOPSIS-fuzzy multi-objective approach. Fig.1 shows three sets of sustainable criteria used for evaluating the suppliers. Fuzzy TOPSIS was applied for assessing and ranking suppliers based on the criteria shown in Fig. 2. A fuzzy multi-objective was developed for allocating the optimal quantity of livestock and meat packets to be purchased from each livestock and meat packets suppliers, respectively.

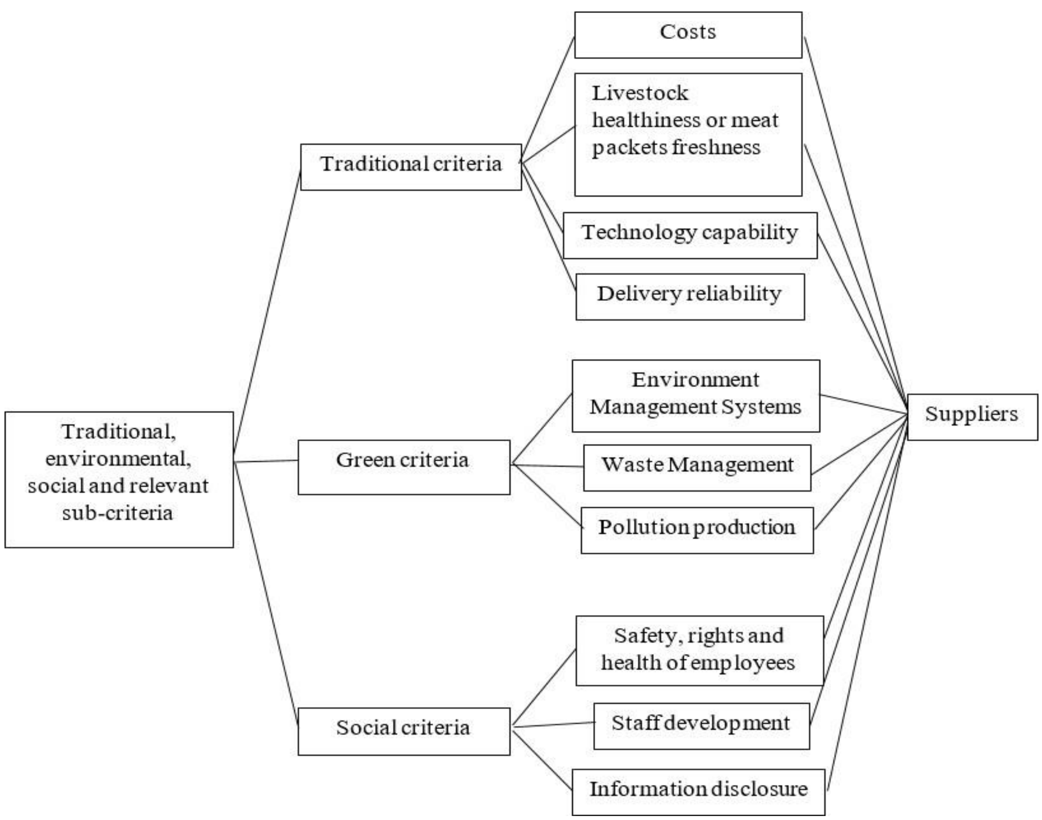

Figure 1. Sustainable supplier selection criteria.

MCDM is highlighted as one of the most efficient methods employed in solving supplier selection decision-making problems (Chai et al., 2013; Govindan et al., 2015). In this work, Fuzzy

TOPSIS was used for ranking suppliers towards their performance in traditional, green and social criteria. Decision makers at the purchasing team (e.g., a purchasing manager, senior buyers and junior buyers) need to evaluate each potential supplier based on its performance vis-à-vis criteria (see Fig. 2). Fuzzy TOPSIS was implemented based on the following steps presented by Mohammed (2019).

3.1 The hybrid fuzzy multi-objective model

A multi-objective optimization model was developed to solve the order allocation problem for the supply chain under investigation in allocating the quantities of products (e.g. livestock and meat packets) to be ordered from each selected supplier (e.g. farms and abattoirs). The objectives are minimization of the expected Costs (F1), environmental impacts (F2) and travel Time (F4) and maximization of social Impacts (F3).

Sets

I set of livestock suppliers (farms) (1… i… I)
J set of meat packets suppliers (abattoirs) (1… j… J)
K set of retailers (1… k… K)

Parameters

C_i^p purchasing cost per unit of livestock ordered from supplier i
C_j^p purchasing cost per unit of meat packets ordered from supplier j
C_{ij}^t unit transportation cost per mile from supplier i to abattoir j
C_{jk}^t unit transportation cost per mile from supplier j to retailer k
C_i^a administration cost per order of supplier i
C_j^a administration cost per order of supplier j
d_{ik} transportation distance of livestock from supplier i to abattoir k
d_{jk} transportation distance of meat packets from supplier j to retailer k
TC transportation capacity per lorry
V velocity of lorry
S supply capacity of supplier i
S supply capacity of supplier j
Dj quantity of livestock to be ordered by abattoir j
Dk quantity of livestock to be ordered by retailer k
CO_{2ij} CO_2 emission in gram per mile for each lorry travelling from farm i to abattoir j
CO_{2jk} CO_2 emission in gram per mile for each lorry travelling from abattoir j to retailer k

Decision Variables

q_{ij} quantity of livestock to be ordered from livestock supplier (farm) i to meat packets supplier (abattoir) j
q_{jk} quantity of meat packets to be ordered from meat packets supplier (abattoir) j to retailer k

u_i = 1: if livestock supplier (farm) i is selected
0: otherwise

v_j = 1: if meat packets supplier (abattoir) j is selected
0: otherwise

The first objective function aims at minimizing the sum of purchasing cost, administration cost (e.g. ordering and documentation) and transportation cost. Minimization of expected cost F1 can be expressed as follows:

$$Min\ F1 = \sum_{i\in I}\sum_{j\in J} C_i^p q_{ij} + \sum_{j\in J}\sum_{k\in K} C_j^p q_{jk} + \sum_{i\in I} C_i^a u_i + \sum_{j\in J} C_j^a v_j + \sum_{i\in I}\sum_{j\in J} C_{ij}^t \left\lceil \frac{q_{ij}}{TC} \right\rceil d_{ij} + \sum_{j\in J}\sum_{k\in K} C_{jk}^t \left\lceil \frac{q_{jk}}{TC} \right\rceil d_{jk} \quad (1)$$

The second objective function aims at minimizing the F2 in terms of CO2 emissions throughout the transportation process from farms to abattoirs and from abattoirs to retailers. Minimization of environmental impact F2 can be expressed as follows:

$$Min\ F2 = \sum_{i\in I}\sum_{j\in J} CO_{2ij} \left\lceil \frac{q_{ij}}{TC} \right\rceil d_{ij} + \sum_{j\in J}\sum_{k\in K} CO_{2jk} \left\lceil \frac{q_{ij}}{TC} \right\rceil d_{jk} \quad (2)$$

The third objective function aims at maximizing the social impact of suppliers (e.g. farms and abattoirs). To this aim, Suppliers' weights in social criteria (and s s w w i j) obtained by Fuzzy TOPSIS are employed as a coefficient for all livestock ordered from farm i to abattoir j and for all meat packets ordered from abattoir j to retailer k. Maximization of social impact F3 can be expressed as follows:

$$Max\ F3 = \sum_{i\in I}\sum_{j\in J} w_i^s q_{ij} + \sum_{j\in J}\sum_{k\in K} w_j^s q_{jk} \quad (3)$$

Realizing the significant importance of travel time in food industry as a key factor for food quality, this objective function aims at minimizes the travel time of all livestock from farms to abattoirs and of all meat packets from abattoirs to retailers. Minimization of travel time F4 can be expressed as follows:

$$Min\ F4 = \sum_{i\in I}\sum_{j\in J} \frac{d_{ij}}{V} q_{ij} + \sum_{j\in J}\sum_{k\in K} \frac{d_{jk}}{V} q_{jk} \quad (4)$$

s.t.

Eqs. 5 & 6 ensure that all quantity of livestock ordered from supplier i and of meat packets ordered from supplier j should not exceed the capacity of both farms and abattoirs. These constraints for both suppliers i and j can be expressed as follows:

$$\sum_{i \in I} q_{ij} \leq S_i u_i \qquad \forall j \in J \tag{5}$$

$$\sum_{j \in J} q_{jk} \leq S_j v_j \qquad \forall k \in K \tag{6}$$

Eqs. 7-9 ensure that the demands of abattoir j and retailer k are fulfilled from supplier i and supplier j, respectively. These constraints can be expressed as follows:

$$\sum_{i \in I} q_{ij} \geq D_j \qquad \forall j \in J \tag{7}$$

$$\sum_{j \in J} q_{jk} \geq D_k \qquad \forall k \in K \tag{8}$$

$$D_k \geq \sum_{k \in K} q_{jk} \qquad \forall j \in J \tag{9}$$

Eqs. 10 & 11 ensure that (1) the quantity of all products throughout the meat supply chain are non-negative; and (2) the decision variables ui and vj are binary. These constraints can be expressed as follows:

$$q_{ij}, q_{jk} \geq 0 \quad \forall i, j, k \tag{10}$$

$$u_i, v_j \in \{1, 0\}, \quad \forall i, j \tag{11}$$

3.1.1 Coping with uncertainty

In this work transportation and purchase costs, demands, CO2 emissions and capacity levels were treated as uncertain input parameters. To cope with these uncertainties, the multiobjective optimization model formulated in section 3.1 was re-formulated. The corresponding crisp model can be expressed as follows (Jiménez López et al., 2007):

$$Min\ F1=\sum_{i\in I}\sum_{j\in J}\left(\frac{C_i^{p\,pes}+2C_i^{p\,mos}+C_i^{p\,opt}}{4}\right)q_{ij}+\sum_{j\in J}\sum_{k\in K}\left(\frac{C_j^{p\,pes}+2C_j^{p\,mos}+C_j^{p\,opt}}{4}\right)q_{jk} \tag{12}$$

$$+\sum_{i\in I}C_i^a u_i+\sum_{j\in J}C_j^a v_j+\sum_{i\in I}\sum_{j\in J}\left(\frac{C_{ij}^{t\,pes}+2C_{ij}^{t\,mos}+C_{ij}^{t\,opt}}{4}\right)\left[\frac{q_{ij}}{TC}\right]d_{ij}$$

$$+\sum_{j\in J}\sum_{k\in K}\left(\frac{C_{jk}^{t\,pes}+2C_{jk}^{t\,mos}+C_{jk}^{t\,opt}}{4}\right)\left[\frac{q_{jk}}{TC}\right]d_{jk}$$

$$Min\ F2=\sum_{i\in I}\sum_{j\in J}\left(\frac{CO_{2ij}^{\ pes}+2CO_{2ij}^{\ mos}+CO_{2ij}^{\ opt}}{4}\right)\left[\frac{q_{ij}}{TC}\right]d_{ij}+ \tag{13}$$

$$\sum_{j\in J}\sum_{k\in K}\left(\frac{CO_{2jk}^{\ pes}+2CO_{2jk}^{\ mos}+CO_{2jk}^{\ opt}}{4}\right)\left[\frac{q_{ij}}{TC}\right]d_{jk}$$

$$Max\ F3=\sum_{i\in I}\sum_{j\in J}w_i^s q_{ij}+\sum_{j\in J}\sum_{k\in K}w_j^s q_{jk} \tag{14}$$

$$Min\ F4=\sum_{i\in I}\sum_{j\in J}\frac{d_{ij}}{V}q_{ij}+\sum_{j\in J}\sum_{k\in K}\frac{d_{jk}}{V}q_{jk} \tag{15}$$

s.t.

$$\sum_{i\in I}q_{ij}\le S_i\left[\frac{\alpha}{2}.\frac{S_{i1}+S_{i2}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{S_{i3}+S_{i4}}{2}\right]u_i \qquad \forall j\in J \tag{16}$$

$$\sum_{j\in J}q_{jk}\le\left[\frac{\alpha}{2}.\frac{S_{j1}+S_{j2}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{S_{j3}+S_{j4}}{2}\right]\mathrm{v}_j \qquad \forall\ \mathrm{k}\in K \tag{17}$$

$$\sum_{i\in I}q_{ij}\ge\left[\frac{\alpha}{2}.\frac{D_{j1}+D_{j2}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{D_{j3}+D_{j4}}{2}\right] \qquad \forall j\in J \tag{18}$$

$$\sum_{j\in J}q_{jk}\ge\left[\frac{\alpha}{2}.\frac{D_{k1}+D_{k2}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{D_{k3}+D_{k4}}{2}\right] \qquad \forall k\in K \tag{19}$$

$$\left[\frac{\alpha}{2}.\frac{D_{k1}+D_{k2}}{2}+\left(1-\frac{\alpha}{2}\right)\frac{D_{k3}+D_{k4}}{2}\right]\ge\sum_{k\in K}q_{jk} \qquad \forall j\in J \tag{20}$$

$$q_{ij},q_{jk}\ \ \ge 0\ \ \forall i,j,k \tag{21}$$

$$u_i,v_j\in\{1,0\},\ \ \forall i,j \tag{22}$$

3.1.2 Revealing Pareto solutions: LP-metrics

In this work, the LP-metrics approach was used to obtain a set of Pareto solutions derived from the developed fuzzy optimization model. Based on this approach, the aggregation formula is expressed as follows (Al-e-hashem et al., 2011):

$$Min\ \mathrm{F}=\left[w_1\frac{F1-F1^*}{F1^*}+w_2\frac{F2-F2^*}{F2^*}+w_3\frac{F3-F3^*}{F3^*}+w_4\frac{F4-F4^*}{F4^*}\right] \tag{23}$$

Subject to Eqs. 16-22. the ideal objectives values (F1*, F2*, F3* and F4*) were obtained via the individual optimization for the four objective functions.

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4. APPLICATION

The case under study considers a supplier selection and order allocation problem in a meat supply chain in selecting the sustainable suppliers of livestock and meat packets. Table 1 shows the input parameters utilized for applying the case under study that includes 3 livestock suppliers, 3 meat packets suppliers and 5 retailers. Transportation distances among livestock and meat packets suppliers and retailers were estimated using Google Map. The optimization model was solved via LINGO[11] software running on a personal computer with a Corei5 2.5GHz processor and with 4GB RAM.

Table 1. Related data

I = 3 (livestock suppliers)	C^t_i = 1-1.5 (GBP/mile)	d_{jk} = 110, 174 (mile)
J = 3 (meat packets suppliers)	C^t_{jk} = 1-1.5 (GBP/mile)	TC = 80 (unit/vehicle)
K = 5 (retailers)	C^a_i = 3-4.5 (GBP/unit)	V = 90-110 (mile/hour)
C^p_i = 130 – 150 (GBP/unit)	C^a_j = 3-4.5 (GBP/unit)	S_i = 1500, 1800 (unit)
C^p_j = 155-175 (GBP/unit)	d_{ij} = 43, 210 (mile)	S_j = 1600, 2000 (unit)
D_j = 1250, 1450 (unit)	D_k = 1100, 1300 (unit)	CO_{2ij} = 271, 294 (gram/mile) CO_{2jk} = 271, 294 (gram/mile)

In this section, the relative weight of sustainable criteria (see Fig. 1) was obtained by AHP, followed by the implementation of Fuzzy TOPSIS to evaluate and rank suppliers. The evaluation of criteria and suppliers were performed by two decision makers from an abattoir (D_{a1} and D_{a2}) for evaluating three livestock suppliers (S_{l1}, S_{l2}, S_{l3}) and two decision makers from two retailers (D_{r1} and D_{r2}) for evaluating three meat packets suppliers (S_{m1}, S_{m2}, S_{m3}).

Table 2 shows the obtained weights of criteria and sub-criteria obtained by AHP based on $D_{a1 \text{ and } 2}$ and $D_{r1 \text{ and } 2}$. As reported in Table 2, regarding traditional criteria, product cost has revealed the highest weight of 0.431 compared to the lowest weight for the delivery reliability with a weight of 0.081 form $D_{a1 \text{ and } 2}$ perspectives. While, traditional criterion of livestock healthiness or meat packets freshness has revealed the highest weight of 0.411 compared to the lowest weight for the delivery reliability with a weight of 0.033 form $D_{r1 \text{ and } 2}$ perspectives.

Next, fuzzy TOPSIS was applied to evaluate and rank suppliers. Table 3 shows the obtained results of livestock and meat packets suppliers, respectively. According to the obtained values, the ranking of the three livestock suppliers is given as S_{l3}> S_{l1}> S_{l2} and is given as S_{m2}> S_{m3}> S_{m1} of the three meat packets suppliers. Subsequently, the results, revealed that livestock supplier three and meat packets supplier two are the best sustainable supplier.

Table 2. Weight of sustainability criteria

	$D_{a1\ and\ 2}$			$D_{r1\ and\ 2}$	
Criteria	**Sub-criteria**	**Weight**	**Criteria**	**Sub-criteria**	**Weight**
Traditional	t1	0.431	Traditional	t1	0.345
	t2	0.352		t2	0.411
	t3	0.136		t3	0.211
	t4	0.081		t4	0.033
Green	g1	0.261	Green	g1	0.396
	g2	0.279		g2	0.337
	g3	0.459		g3	0.267
Social	s1	0.543	Social	s1	0.274
	s2	0.097		s2	0.385
	s3	0.360		s3	0.342

Table 3. Rank of the two-level suppliers

	D_i^+	D_i^-	**CC**	**Rank**
S_{l1}	28.169	2.875	0.926	2
S_{l2}	28.086	2.795	0.905	3
S_{l3}	28.179	2.884	0.928	1
S_{m1}	28.081	2.786	0.903	3
S_{m2}	28.260	2.963	0.949	1
S_{m3}	28.093	2.799	0.906	2

Afterward, the developed hybrid model (see section 3.1.1) was optimized in terms of revealing a set of Pareto solutions by using LP-metrics (see section 3.1.2) to solve the order allocation plan. The minimum and maximum values for the four objectives were determined using the individual optimization. The results are ({Min, Max}) = ({334,438, 489,520}, {450814.39, 739901.27}, {1360.5, 1730}, {43.1, 203.7}). Subsequently, the ideal solutions ($F1^*, F2^*, F3^*$ and $F4^*$) are: $F1^*$ = 334,438, $F2^*$ = 450814.39, $F3^*$ = 1730 and $F4^*$ = 43.1). Next, 10 different combinations of weights were allocated for the four objectives. The fuzzy multi-objective model was optimized by using the LP-metrics approach. Table 4 shows the obtained Pareto solutions. It should be mentioned that ten α-level (0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and1) with an incremental step 0.1 was assigned for each solution. Each of the obtained Pareto solution leads to a different order allocation with respect to the trade-off among the four objectives. Thus, decision makers need to select one solution to allocate their orders from each supplier. Such a decision could be determined either by the experts of decision makers or by using decision-making approaches. In this work, solution number 5 was selected as the final solution based on decision maker's opinion. Based on solution number 5, Table 5 shows the optimal quantity of livestock and meat packets that should be ordered from livestock and meat packets suppliers, respectively. For instance, abattoirs 1, 2 and 3 should order 205, 111 and 203 livestock from livestock supplier 1, respectively.

Table 4. Pareto solutions

Solution	μ_{F1}	μ_{F2}	μ_{F3}	μ_{F4}	Min F1	Min F2	Max F3	Min F4
1	0.97	0.93	0.066	0.93	336,777	455652	1362	44
2	0.83	0.87	0.16	0.80	345,760	479871	1371	60
3	0.77	0.71	0.26	0.74	361,881	509998	1422	79
4	0.62	0.66	0.33	0.65	361,881	541771	1498	94
5	0.75	0.49	0.55	0.55	339,773	570228	1510	122
6	0.59	0.40	0.56	0.47	411,009	622220	1523	128
7	0.39	0.31	0.67	0.34	431,088	635871	1581	151
8	0.28	0.28	0.77	0.25	438,000	685881	1622	161
9	0.15	0.15	0.86	0.16	455,127	698666	1676	184
10	0.066	0.07	0.96	0.09	469,998	735771	1700	201

Table 5. Suggested order allocation

Supplier	Abattoir 1	Abattoir 2	Abattoir 3	Retailer 1	Retailer 2	Retailer 3	Retailer 4	Retailer 5
S_{l1}	205	111	203	-	-	-	-	-
S_{l2}	275	170	80	-	-	-	-	-
S_{l3}	188	211	-	-	-	-	-	-
S_{m1}	-	-	-	128	147	134	141	131
S_{m2}	-	-	-	115	42	-	110	-
S_{m3}	-	-	-	-	106	130	144	150

Firms that follow similar circumstances (e.g., a two-stage supply chain) could use the developed model for assessing the sustainability performance of their suppliers, and accordingly set the order allocation plan. In addition, the evaluation process can be used by suppliers themselves to improve their service through the evaluation of their status with respect to the defined traditional, green and social criteria.

5. CONCLUSIONS

This research presents a development of an integrated approach to solve a sustainable two-stage supplier selection and order allocation problem for a meat supply chain considering traditional, green and social criteria. The developed approach can be concluded in six steps: sub-criteria for traditional, green and social criteria were identified in the first step. In the second step, fuzzy TOPSIS was used for ranking the suppliers based on the identified sub-criteria. Its robustness was verified with sensitivity analysis in varying the weight of sustainable criteria in six different scenarios. In the third step, a multi-objective optimization model was developed for obtaining the optimal solutions of order allocation in quantity. The objectives are minimizing the expected costs of transportation, purchasing and administration, the environmental impact (particularly, CO_2 emissions) and the travel time of products and maximizing the social impacts. In the fourth step, the multi-objective model was redeveloped into a fuzzy multi-objective model to handle the uncertainty in some of the input data (e.g. transportation and purchase costs, demands, CO_2 emissions and capacities). In the fifth step, LP-metrics approach was applied to reveal a number of Pareto solutions based on the developed fuzzy multi-objective optimization model and the final solution was determined by using the global criterion approach in the sixth step. Although, we applied this study on a meat supply chain, the obtained sustainable supplier selection and order allocation plan shows that the developed fuzzy TOPSIS-fuzzy multi-objective approach can be used as a reference for similar supply chains in evaluating the sustainable performance of the potential suppliers and ordering the optimal quantity of product from each supplier with respect to obtaining a trade-off among conflicting objectives.

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