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ORIGINAL ARTICLE

Sustainable supplier evaluation and selection with a novel two-stage DEA model in the presence of uncontrollable inputs and undesirable outputs: a plastic case study

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Abstract
Today in the global market, sustainable supply chain management has turned into a significant issue for managers and researchers. Selection and evaluation related to the rewarding and satisfying supplier are one of the main points in each supply chain. Data envelopment analysis (DEA) is a popular method to measure the performance and efficiency of suppliers and organizations. In this study, a novel two-stage DEA network model is proposed in the presence of uncontrollable inputs and undesirable outputs with considering the set of intermediate elements between two stages to evaluate and select the best sustainable supplier. The provided model is applied in a plastic case study by ten decision-making units (DMUs) as suppliers or alternatives to denote validity and applicability of the suggested model.

Keywords Supply chain management · Sustainable supplier selection · Two-stage data envelopment analysis · Uncontrollable inputs · Undesirable outputs · Multiple criteria decision-making

1 Introduction

Today, the supply chain has a significant role in the business world and this issue becomes the step success between markets. Therefore, researchers try to explore this crucial issue [10, 11, 52].

Other dimensions are significant for globalization like environmental and social issues in the process of crucial appearance of supply chain management. Finally, this extensive attention results to the sustainability approach [67, 77]. In fact, natural resources are becoming less and less while there is great consideration of wealth parity and corporate social responsibility. These situations make sustainability for business priority [46]. Furthermore, activists in this tendency attempt to reduce destroying economic and social effects of their trade and simultaneously, they expand the benefits in their supply chains. Actually, one of the main factors in sustainable development is sustainable supply chain management [27, 36, 64].

Selection of the best supplier is one of the most significant parts of sustainable supply chain management [60]. The difficult issue is finding a convenient supplier in the supply chain management category because it involves terms and governing strategies that they have complicated characters [88]. Originally, all the decisions are under evaluations and selections' affection in supply management sector ([66, 83, 90] [8, 26, 29, 30, 91]). Likewise, social criteria, these days, play a key role in field of sustainable supply chain management which managers are focused on it to improve the quality of their evaluations and decisions [61].

In general, these days, economic benefits, social pressures, government legislation, environmental concerns, and electronic commerce are leading organizations to practice sustainable supply chain, and the complexity and expertize-demanding nature of supply chain are leading companies to select rewarding suppliers. But it is only the beginning of the supplier selection story [45]. That is to say, once a company decides to select suppliers, the big questions rise and that is which supplier is the most proper one. The selection of one

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supplier from a large number and a wide variety of suppliers y various degrees of capabilities and potentials is a multi-faceted and complex task that requires ample time and a multiple criteria decision-making (MCDM) solution approach [48].

In the study, we propose a two-stage data envelopment analysis (DEA) model in the presence of uncontrollable inputs include reliability cost and undesirable outputs involve hazardous substances with considering the set of intermediate elements include number of sustainable products as desirable output and controllable input of the first and second stage respectively between two stages to evaluate and select the most appropriate sustainable suppliers. DEA has been a more popular performance analysis model with the public and private sectors as a decision-making model. DEA has been developed by Charnes, Cooper, and Rhodes [13]. DEA is a non-parametric method of estimation, whereby the estimation of the frontier does not require choosing a parametric functional form. DEA could be beneficial for every industry or organization in which a logically homogeneous set of decision-making units (DMUs) use a similar set of inputs in order to produce a certain range of outputs [5]. Of course, both inputs and outputs might be in different combinations. It should be noted that in the present study, supplier is deemed as a DMU.

In this study, in order to evaluate and select the sustainable supplier and also determine the efficiency, a two-stage DEA model is developed. The research continues with literature review as to Section 2. Section 3 represents the proposed two-stage DEA model. In Section 4, the case study and results are represented. Eventually, conclusion and future research scopes are provided in Section 5.

2 Literature review

In this section, first, the other methods for sustainable supplier selection are reviewed in Section 2.1. Section 2.2 provides previous researchers of DEA in terms of sustainable supplier selection. Finally, Section 2.3 represents sustainable criteria to select the sustainable supplier.

2.1 Sustainable supplier selection methods

In the previous studies, researchers have used various approach to mathematical programming while they are trying to select the most suitable DMU provider. Summary of such applied techniques could be found in Table 1. However, other DEA models are complicated, almost all the decision-making processes involved in DMU providers, and they are based on the procedures that assign weights to different performance measures. Although, there is a basic problem with the systems that assign optional weights to factors, and its subjectivity. Moreover, the decision-maker is always faced with a perplexing and its complicated task of assigning precise numbers to preferences. On the other hand, there are too many performances criteria involved while assessing the weighting information, it is a very difficult and frightening task.

One of the multiple criteria decision-making methods to select sustainable supplier is the Decision-Making Trial and Evaluation Laboratory (DEMATEL). For instance, Tsai and Chou [86] propose a hybrid method regarding DEMATEL and the atrial natriuretic peptide (ANP) that ANP achieved the criteria weights in order to select the sustainable supplier. Luthra et al. [56] use gray DEMATEL to measure the connections of sustainable suppliers and rank them. Govindan et al. [33] propose a fuzzy technique to order preference by similarity to ideal solution (TOPSIS) in order to stable supplier selection regarding triple bottom line (economic, environmental, and social). Luthra et al. [57] develop and provide a hybrid and they integrated model based on analytical hierarchy process (AHP) and VIKOR as a multiple criteria decision-making method to select the best sustainable supplier between 22 suppliers. Table 1 illustrates summary of methods which are used to sustainable supplier choose.

2.2 DEA for sustainable supplier selection

Jauhar et al. [44] proposed a new model of DEA to practice differential evolution for the select suitable sustainable supplier. Raut et al. [72] provided a model based on DEA and artificial neural networks to calculate the maximally efficient. Moreover, they asserted their model is more accurate, effective, and systematic to select the sustainable supplier. Izadikhah et al. [41] suggested a basic DEA model reformulates with interval volume discount offers, fuzzy data, and ordinal data. Hatami-Marbini et al. [38] proposed a fuzzy DEA model for sustainable supplier selection and evaluation by flexible cross-efficiency evaluation. Table 2 denotes some previous studies of sustainable supplier selection with DEA method.

2.3 Sustainable supplier selection criteria

Researchers and managers usually consider many criteria to select and rank suitable supplier while they are using in sustainable supplier selection that they are parted in three dimensions include economic, environmental, and also social which they organized sustainability. For instance, cost, quality, delivery, service, and lead time are the popular criteria in economic dimension. On the other hand, eco-design production, environment protection certification, green packaging, green design, etc. the criteria have belonged to environmental dimension. Furthermore, they can be named voice of the customer, education, health, safety, and so on in social dimension [64]. Table 3 represents some of the criteria for sustainable supplier selection in three parted dimension.

Table 1 The methods used in sustainable supplier selection

Methods	Authors (references)
DEMATEL	Tsai and Chou [86]; Fu et al. [28]; Fallahian-Najafabadi et al. [22]; Mavi et al. [62]; Su et al. [81]; Luthra et al. [56]; Song et al. [80]
TOPSIS	Awasthi et al. [3]; Shen et al. [78]; Govindan et al. [33]; Orji and Wei [69]; Fallahpour et al. [23]; Onu et al. [68];
VIKOR	Awasthi and Kannan [4]; Luthra et al. [57]
AHP	Chu et al. [17]; Lee et al. [53]; Pego-Guerra et al. [70]; Chiouy et al. [16]; Büyüközkan and Çifçi [10]; Dai and Blackhurst [20]; Khatri and Srivastava [50]; Kaur et al. [49]; Ahmadi et al. [1]
ANP	Hsu and Hu [40]
conceptual models	Henri and Journeault [39]; Yang et al. [94]; Caniëls et al. [12]; Genovese et al. [37]; Blome et al. [7]
Mathematical and other methods	Tsai and Hung [36, 87]; Verdecho et al. [89]; Amindoust et al. [2]; Reuter et al. [73]; Kannan et al. [47] Sarkis and Dhavale [74]; Yazdani et al. [95]; Zarbakhshnia et al. [97]

In this research, a two-stage DEA model in the presence of uncontrollable inputs and undesirable outputs with considering the set of intermediate elements between two stages is developed to evaluate and select sustainable. The contributions of this study are as follows:

- In our paper, for the first time, undesirable outputs and uncontrollable inputs are applied in a two-stage DEA model together.
- In this model, the set of intermediate elements between two stages is considered as output and input of first and second stage respectively.
- An extensive literature of DEA, other methods and also criteria of sustainable supplier selection are represented.

In this paper, a two-stage DEA model used for sustainable supplier selection.

3 Proposed model

Two-stage DEA models are commonly used to calculate the efficiency of the activities which are organized in two separate and distinct stages but in a package as DMU. The first stage of each two-stage network uses several inputs and generates several outputs. The outputs of the first stage are the inputs of the second stage which are called the intermediate elements [76].

Compared to the traditional methods of DEA, the supply chain could be considered a black box, where the inputs and outputs are the matters of inquiry, and what enters the box is usually disregarded. On the contrary to the black-box technology, there are production systems which use a connecting structure. A classic example of this is a production system where the product of one division or sub-process creates an intermediate output which is used as input in another division or sub-process [92]. Furthermore, according to Favero and

Table 2 DEA methods utilized for sustainable supplier selection

Authors (references)	Methods	Definitions
Azadi et al. [6]	F-DEA	An integrated DEA enhanced Russell measure model in fuzzy context
Mahdiloo et al. [58]	Multiple objective-DEA	A multiple objective linear programming DEA model
Shi et al. [79]	Systematic DEA	the C^2R model of the DEA method and the super-efficiency DEA model
Mahdiloo et al. [59]	Two-stage DEA	A two-stage multiple criteria DEA
Tavana et al. [84]	DDEA	A hybrid goal programming and dynamic DEA
Yousefi et al. [96]	DDEA	A robust dynamic data envelopment analysis
Mirhedayatian et al.[65]	Network DEA	Evaluating green supply chain management
Wen and Chi [93]; Kuo and Lin [51]	Hybrid DEA	Green supplier selection
Zhou et al. [98]	Type-2 fuzzy multi-objective DEA	A type-2 fuzzy multi-objective DEA to compute both efficiency and effectiveness
Boudaghi and Saen [9]	DEA–DA	A model of DEA–discriminant analysis

Table 3 Criteria of sustainable supplier selection

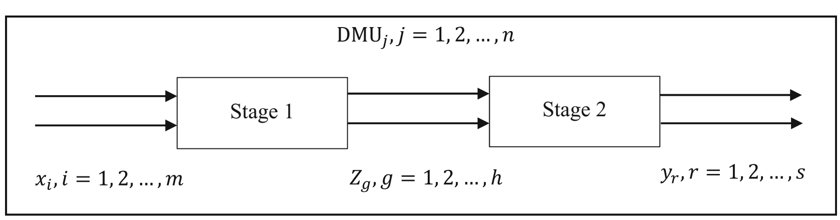
Dimensions	Criteria	Authors (references)								
		Efendigil et al. [21]	Govindan [32]	Sasikumar and Haq [75]	Govindan et al. [35]	Govindan et al. [34]	Da Silveira Guimarães and Salomon [19]	Prakash and Barua [71]	Tavana et al. [85]	Mavi et al. [64]
Economic	Quality		✓	✓	✓			✓	✓	✓
	Cost	✓	✓	✓	✓		✓	✓	✓	✓
	Lead time	✓	✓						✓	✓
	Delivery and services	✓	✓	✓	✓			✓		✓
	Transportation				✓			✓	✓	✓
Environment	Recycle			✓	✓	✓	✓	✓	✓	✓
	green packaging			✓	✓			✓	✓	✓
	green design			✓	✓			✓	✓	✓
	Green technology capability			✓			✓	✓		
	Environment protection certification		✓						✓	
	Eco-design production					✓				✓
Social	Health and safety					✓				✓
	Voice of customer	✓			✓					✓
	health and safety				✓		✓			✓

Papi [25], three approaches could be applied to the input and output specification—mainly production approach, intermediation approach, and the asset approach. Different conditions demand the application of different methods; hence, prior to making a decision on the choice of methods, it is essential to attentively analyze the characteristics of the measurement object. As illustrated in Fig. 1, different designs have been deemed as the DMUs. By considering the middle products, the two-stage design is well capable of measuring the total efficiency of the DMU as well as the relationship between its stages [15]. In other words, classical DEA models, like concurrent engineering approaches [55], use a "black-box" method in calculating the efficiency of the processes and do not relate the roots of the inefficiency of the activities to their different stages. Nonetheless, this method is restricted in its computation of the efficiencies of processes which involved the two stages (or sub-activities) that the outputs of the first stage are the inputs of another stage [15]. With using the traditional black-box method to the computation of the efficiency of a two-stage process, it is not always possible to follow the roots of the inefficiencies. Nevertheless, with using a two-stage DEA model to compute the total efficiency as the integration of two separate efficiency ratios. Simply put, the efficiency ratio of the first stage and efficiency ratio of the second stage, it is possible to recognize the total efficiency of the activities and also the efficiency status of their sub-activities. This is, obviously, more informative than simply calculating total efficiency as the ratio of the final outputs of the whole system to its inputs [59].

Likewise, with opening the black box and using the two-stage DEA models, optimization of the decision-making units (DMUs) and processes can be obtained by considering different scenarios. It can be receiving by (1) optimizing the efficiencies of the first and second stage of the two-stage activity simultaneously, or (2) optimizing the efficiency of the first stage as the more significant and the guide stage first then optimizing the less significant and the follower the second stage, or (3) optimizing the efficiency of the second stage first then the first stage. These alternative scenarios are impossible with the classical DEA models owing to the fact that each process and activity is not represented by the integration of its sub-activities [42, 63].

According to Fig. 1 considering n number of DMUs, each $DMU_j (j = 1, 2, \ldots, n)$ includes M inputs $x_i (i = 1, 2, \ldots, m)$ and H outputs $Z_g (g = 1, 2, \ldots, H)$ for the first stage. The H as outputs of the first stage are the inputs of the second stage as the set of intermediate elements. In other words, outputs of the first stage are equal to inputs of the second stage which

Fig. 1 A typical structure of two-stage DEA process [15]



generates outputs of the second stage $y_r(r = 1, 2, \ldots, s)$ as final outputs. These notations come from [31]. To make CCR input-oriented DEA model for this network, we have:

$$\begin{aligned}&E_0 = Max\textstyle\sum_{r=1}^{s} u_r Y_{r0}\\ &\text{s.t}\\ &\textstyle\sum_{i=1}^{m} v_i X_{i0} = 1\\ &\textstyle\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \le 0 \quad ;(j = 1, \ldots, n)\\ &\textstyle\sum_{g=1}^{h} w_g Z_{gj} - \sum_{i=1}^{m} v_i X_{ij} \le 0 \quad ;(j = 1, \ldots, n)\\ &\textstyle\sum_{r=1}^{s} u_r Y_{rj} - \sum_{g=1}^{h} w_g Z_{gj} \le 0 \quad ;(j = 1, \ldots, n)\\ &u_r, v_i, w_g \ge \varepsilon \quad ,(r = 1, 2, \ldots, s), (i = 1, 2, \ldots, m), (g = 1, 2, \ldots, H)\end{aligned} \tag{1}$$

In the model (1), E_0 is the total relative efficiency of DMU and the first and second constraints are the system constraints and also third and fourth are the division constraints. Also, the total relative efficiency of DMU in two-stage models is computed by Eq. (2) or (3).

$$E_0 = E_O^{(1)} \times E_O^{(2)} \tag{2}$$

Or

$$E_0 = \frac{1}{2}\left(E_O^{(1)} + E_0^{(2)}\right) \tag{3}$$

where $E_O^{(1)}$ is the relative efficiency of the first stage and $E_0^{(2)}$ is the relative efficiency of stage 2; moreover, $E_0, E_O^{(1)}$, and $E_0^{(2)}$ are computed by Eqs. (4), (5), and (6), respectively.

$$E_0 = \frac{\sum_{r=1}^{s} u_r^* Y_{r0}}{\sum_{i=1}^{m} v_i^* X_{i0}} \tag{4}$$

$$E_O^{(1)} = \frac{\sum_{g=1}^{h} w_g^* Z_{g0}}{\sum_{i=1}^{m} v_i^* X_{i0}} \tag{5}$$

$$E_O^{(2)} = \frac{\sum_{r=1}^{s} u_r^* Y_{r0}}{\sum_{g=1}^{h} w_g^* Z_{g0}} \tag{6}$$

The suggested two-stage DEA model with uncontrollable inputs and undesirable outputs is elaborated. Figure 2 demonstrates the structure of two-stage DMU in the presence of uncontrollable inputs and undesirable outputs.

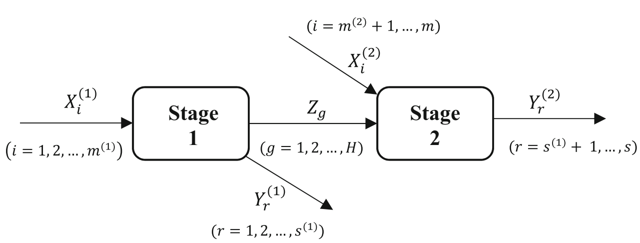


Fig. 2 Schematic of the structure of two-stage DMU with uncontrollable inputs and undesirable outputs

Figure 2 illustrates the structure of a two-stage network which is designed with output in the first stage and input in the second stage and also in the presence of the set of intermediate elements between two stages as the output of the first stage and the input of the second stage. In order to make mathematical DEA model for the mentioned network, first, we should elaborate $E_O^{(1)}$ and $E_O^{(2)}$ as two separated model (7) and (8) which are as follows:

$$\begin{aligned}&E_O^{(1)} = \max \frac{\sum_{r=1}^{s^{(1)}} u_r Y_{r0}^{(1)} + \sum_{g=1}^{h} w_g Z_{g0}}{\sum_{i=1}^{m^{(1)}} v_i X_{i0}^{(1)}}\\ &\text{s.t}\\ &\textstyle\sum_{g=1}^{h} w_g Z_{gi} + \sum_{r=1}^{s^{(1)}} u_r Y_{rj}^{(1)} - \sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} \le 0 \quad ;(j = 1, \ldots, n)\\ &u_r, v_i, w_g \ge \varepsilon \quad ;\forall r, i, g\end{aligned} \tag{7}$$

And

$$\begin{aligned}&E_O^{(2)} = max \frac{\sum_{r=s^{(1)}+1}^{s} u_r Y_{r0}^{(2)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{i0}^{(2)} + \sum_{g=1}^{h} w_g Z_{gi}}\\ &\text{s.t}\\ &\textstyle\sum_{r=s^{(1)}+1}^{s} u_r Y_{rj}^{(2)} - \left(\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} + \sum_{g=1}^{h} w_g Z_{gi}\right) \le 0 \quad ;(j = 1, \ldots, n)\\ &u_r, v_i, w_g \ge \varepsilon \quad ;\forall r, i, g\end{aligned} \tag{8}$$

where $X_{i0}^{(1)}$ is the input of the first stage, $Y_{r0}^{(1)}$ is the output of the first stage which is not entered to the second stage, $X_{i0}^{(2)}$ is the input of the second stage, and $Y_{r0}^{(2)}$ is the final output of the second stage. Finally, in order to calculate the total relative efficiency, we use the mean of $E_O^{(1)}$ and $E_O^{(2)}$, as the model (9) is

$$\begin{aligned}&E_0 = max \frac{1}{2}\left(\frac{\sum_{r=1}^{s^{(1)}} u_r Y_{r0}^{(1)} + \sum_{g=1}^{h} w_g Z_{g0}}{\sum_{i=1}^{m^{(1)}} v_i X_{i0}^{(1)}} + \frac{\sum_{r=s^{(1)}+1}^{s} u_r Y_{r0}^{(2)}}{\sum_{i=m^{(1)}+1}^{m} v_i X_{i0}^{(2)} + \sum_{g=1}^{h} w_g Z_{gi}}\right)\\ &\text{s.t}\\ &\textstyle\sum_{r=1}^{s^{(1)}} u_r Y_{rj}^{(1)} + \sum_{g=1}^{h} w_g Z_{gi} - \sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} \le 0 \quad ;(j = 1, \ldots, n)\\ &\textstyle\sum_{r=s^{(1)}+1}^{s} u_r Y_{rj}^{(2)} - \left(\sum_{i=m^{(1)}+1}^{m} v_i X_{ij}^{(2)} + \sum_{g=1}^{h} w_g Z_{gi}\right) \le 0 \quad ;(j = 1, \ldots, n)\\ &u_r, v_i, w_g \ge \varepsilon \quad ;\forall r, i, g\end{aligned} \tag{9}$$

3.1 Undesirable outputs

DEA calculates the relative efficiency of DMUs with multiple performance criteria that are classified into outputs and inputs. Once the efficient frontier is specified, inefficient DMUs can modify their performance to obtain the efficient frontier by either elevating their current output levels or reducing their current input levels [65]. DEA generally suppose that producing more outputs comparative to fewer inputs is a factor of efficiency. Nevertheless, in the presence of undesirable outputs, DMUs with more valuable (desirable) outputs and fewer bad (undesirable) outputs comparative to fewer inputs should be identified as efficient [18]. For instance, if inefficiency exists in manufacturing processes that final goods are produced along with the production of waste and pollutants, then the respective outputs of waste and pollutants are undesirable (bad) and should be decreased to modify performance [24].

Desirable outputs are shown by g index $Y_{r0}^{(2)g}$; however, undesirable outputs are shown by b index $Y_{r0}^{(2)b}$. According to Eqs. (10) and (11), undesirable outputs are turned into desirable outputs so that it can help to the computation of model be easier. This equation was provided by Jahanshahloo et al. [43] as follows:

$$k_r = \max_j Y_{rj} + 1 \quad ;(j = 1, \ldots, n) \tag{10}$$

Then, we have

$$Y_{r0}^{(2)g} \rightarrow -Y_{r0}^{(2)b} + k_r = Y_{r0}^{(2)g'} \quad ; Y_{r0}^{g'} > 1 \tag{11}$$

$Y_{r0}^{(2)g'}$ is a desirable output of the second stage that was an undesirable output of the second stage which is changed by Eq. (10). So, with the application of Eq. (10) to the linear model (7), we change the undesirable output to desirable outputs as follows:

$$\begin{aligned} & E_O^{(1)} = max\sum_{r=1}^{s^{(1)}} u_r Y_{r0}^{(1)} + \sum_{g=1}^{h} w_g Z_{g0} \\ & \text{s.t} \\ & \sum_{i=1}^{m^{(1)}} v_i X_{i0}^{(1)} = 1 \\ & \sum_{g=1}^{h} w_g Z_{gi} + \sum_{r=1}^{s^{(1)}} u_r Y_{rj}^{(1)} - \sum_{i=1}^{m^{(1)}} v_i X_{ij}^{(1)} \le 0 \quad ;(j = 1, \ldots, n) \\ & u_r, v_i, w_g \ge 0 \quad ;\forall r, i, g \end{aligned} \tag{12}$$

Then the model (12) is turned into a dual model based on Lagrange method [54]. Hence, we have model (13):

$$\begin{aligned} & \min \theta_0 - \varepsilon \left(\sum_i s_i^- + \sum_r s_r^+ \right) \\ & \text{s.t} \\ & \sum_j \lambda_j X_{ij} \le \theta_0 X_{i0} \quad ;(i = 1, 2, \ldots, m) \\ & \sum_j \lambda_j Z_{gi}^{g} \ge Z_{g0}^{g} \quad ;(g = 1, 2, \ldots, H) \\ & \sum_j \lambda_j Z_{gi}^{g'} \ge Z_{g0}^{g'} \quad ;(g = 1, 2, \ldots, H) \\ & \sum_j \lambda_j Y_{rj} \ge Y_{r0} \quad ;(r = 1, 2, \ldots, s) \\ & \sum_j \lambda_j Y_{rj}^{g'} \ge Y_{rj}^{g'} \quad ;(r = 1, 2, \ldots, s) u_r, v_i, w_g \ge 0 \quad ;\forall r, i, g \end{aligned} \tag{13}$$

3.2 Uncontrollable inputs

About applying uncontrollable inputs, we consider an interval as a set of number to play a role of uncontrollable inputs in such a way that in this interval, there are a high limit and a low limit that the inputs are selected from the numbers between these two limit as uncontrollable inputs (see Fig. 3).

So, in order to apply the intervals to the model, we have two intervals as $X_{i0} = \left(X_{i0}^l, X_{i0}^h\right)$, and $X_{ij} = \left(X_{ij}^l, X_{ij}^h\right)$ which are applied to model (13) to design the model (14) in the presence of undesirable outputs and uncontrollable inputs as follows:

$$\begin{aligned} & \min \theta_0 - \varepsilon \left(\sum_i s_i^- + \sum_r s_r^+ \right) \\ & \text{s.t} \\ & \sum_j \lambda_j \left(X_{ij}^l, X_{ij}^h \right) \le \theta_0 \left(X_{i0}^l, X_{i0}^h \right) \quad ;(i = 1, 2, \ldots, m) \\ & \sum_j \lambda_j Z_{gi}^{g} \ge Z_{g0}^{g} \quad ;(g = 1, 2, \ldots, H) \\ & \sum_j \lambda_j Z_{gi}^{g'} \ge Z_{g0}^{g'} \quad ;(g = 1, 2, \ldots, H) \\ & \sum_j \lambda_j Y_{rj} \ge Y_{r0} \quad ;(r = 1, 2, \ldots, s) \\ & \sum_j \lambda_j Y_{rj}^{g'} \ge Y_{rj}^{g'} \quad ;(r = 1, 2, \ldots, s) u_r, v_i, w_g \ge 0 \quad ;\forall r, i, g \end{aligned} \tag{14}$$

Since the model (14) cannot solve with intervals, Eq. (14) is used to turn the intervals to algebra in order to achieve the ability to solve regarding Sunaga [82].

$$X \in (a, b) \rightarrow X = a + (b - a)\beta \quad ; 0 \le \beta \le 1 \tag{15}$$

Therefore,

$$X_{ij} = X_{ij}^l + \left(X_{ij}^h - X_{ij}^l \right) \beta_{ij} \quad ; 0 \le \beta_{ij} \le 1 \tag{16}$$

$$X_{i0} = X_{i0}^l + \left(X_{i0}^h - X_{i0}^l \right) \beta_{i0} \quad ; 0 \le \beta_{i0} \le 1 \tag{17}$$

Fig. 3 Entrance uncontrollable inputs to DMU$_j$ with an interval

Eventually, the above Eqs. (15), (16), and (17) are applied to model (14), then we have the final model (18) as follows:

$$\begin{aligned}
&\min \theta_0 - \varepsilon\left(i\sum_i s_i^- + \sum_r s_t^+\right) \\
&\text{s.t} \\
&\sum_j \lambda_j\left(X_{ij}^l + \left(X_{ij}^h - X_{ij}^l\right)\beta_{ij}\right) \le \theta_0\left(X_{i0}^l + \left(X_{i0}^h - X_{i0}^l\right)\beta_{i0}\right) \quad ;(i = 1,2,\ldots,m) \\
&\sum_j \lambda_j Z_{gi}^g \ge Z_{g0}^g \quad ;(g = 1,2,\ldots,H) \\
&\sum_j \lambda_j Z_{gi}^{g'} \ge Z_{g0}^{g'} \quad ;(g = 1,2,\ldots,H) \\
&\sum_j \lambda_j Y_{rj} \ge Y_{r0} \quad ;(r = 1,2,\ldots,s) \\
&\sum_j \lambda_j Y_{rj}^{g'} \ge Y_{rj}^{g'} \quad ;(r = 1,2,\ldots,s) \\
&u_r, v_i, w_g \ge 0 \quad ;\forall r,i,g
\end{aligned} \tag{18}$$

3.3 Chen and Zhu's approach for two-stage DEA

In this section, one of the most popular and successful two-stage DEA model in literature is applied to the case study of this paper for the purpose of comparison its results with results which achieved from our proposed model to validate the results and advantage of the suggested model. This model was provided by Chen and Zhu [14]. The Chen and Zhu's model is as follows:

$$\begin{aligned}
&\min w_1\alpha - w_2\beta \\
&\text{s.t} \\
&\textstyle\sum_{j=1}^n \lambda_j x_{ij} \le a x_{i0} && ;i = 1,\ldots,m \\
&\textstyle\sum_{j=1}^n \lambda_j Z_{dj} \ge Z_{d0} && ;d = 1,\ldots,D \\
&\textstyle\sum_{j=1}^n \lambda_j = 1 && ;j = 1,\ldots,n \\
&\lambda_j \ge 0, \quad a \le 1 \\
&\textstyle\sum_{j=1}^n \mu_j Z_{dj} \le Z_{d0} && ;d = 1,\ldots,D \\
&\textstyle\sum_{j=1}^n \mu_j y_{rj} \ge \beta y_{r0} && ;r = 1,\ldots,S \\
&\textstyle\sum_{j=1}^n \mu_j = 1 && ;j = 1,\ldots,n \\
&\mu_j, \beta \ge 0
\end{aligned} \tag{19}$$

Suppose w_1 and w_2 are the relative importance, α and β are the efficiency values, and also λ_j and μ_j are weights of each stage for DMU_j. Additionally, suppose Z_{d0} is the optimal value for the set of intermediate elements dth (d = 1, …, D) which is gained from the model (19).

Table 4 The used criteria for sustainable supply chain

Nomenclatures	Criteria
Eco	Eco-design cost
Lc	Logistics cost
Ntm	Number of tune raw material
Rc	Reliability cost
Hs	Hazardous substances
Nsp	Number of sustainable products
Fc	Fuel cost
Clh	The cost of labor health
CO2	CO2 emission
Ndp	Number of delivered products
Nop	Number of occupation opportunities

In order to compare this model with proposed, the main property of the proposed model is the presence of undesirable outputs and uncontrollable inputs. However, according to Chen and Zhu [14], to evaluate the efficiency of each stage, the purpose is by the fewer inputs, obtaining the more outputs. So, if the outputs of the first stage decreased, the inputs of the second stage decreased as well, because the outputs of the first stage are the inputs of the second stage indeed. Therefore, the set of intermediate elements should be decreased from one side and increased on the other. Similarly, this model looks for the best possible values of μ_j and β to generate the best possible efficiency point for the DMU_0. Notwithstanding, it will be appreciated that this complete independence of the DMU_0 in selecting its own weights for the inputs, intermediate measures, and outputs can sometimes lead to an unrealistically high-efficiency point of the DMU due to the fact that each DMU can specify extreme small weights or extreme large weights to some of its criteria to obtain the highest possible efficiency point according to the constraints defined by the linear program. In order to dominate these concerns, in the first stage of the proposed model, only inputs are reduced and in the second stage, only outputs are speeded up. Consequently, in constraints of the model, the first and second stages are considered as input-oriented and output-oriented

Fig. 4 The structure of sustainable supply chain

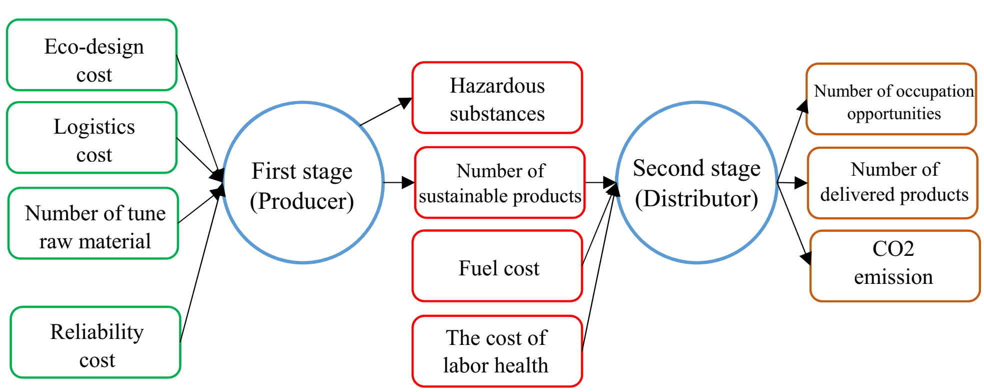


Table 5 The data related to this case study and ten suppliers

Supplier (DMU)	Eco	Lc	Ntm	Rc	Hs	Nsp	Fc	Clh	CO2	Ndp	Nop
Axon Polymer	390	94	103	58	71	236	396	138	177	432	3
Corbi Polymer	398	96	127	66	44	281	453	143	169	423	2
Iran Masterbatch,	290	109	112	74	45	246	240	113	165	410	2
Karan Co.	318	79	103	77	33	287	443	134	179	596	3
Noavaran Baspar	288	94	133	88	55	276	527	151	169	477	2
Parsan Polymer	338	105	144	89	64	296	351	178	165	505	3
Plasto Iran	326	199	157	94	40	319	529	124	180	491	3
Razin Polymer	329	89	129	96	44	329	395	193	184	533	2
Polyma	350	76	114	106	72	297	310	155	166	410	3
Persian Plastic	295	93	99	69	42	218	405	144	173	440	3

respectively and optimal value for the set of intermediate elements will receive.

4 Case study and results

One very good case for the application of the proposed framework is the field of plastic packing strap industry. Nowadays, this industry is a hot industry that needs rewarding and satisfying suppliers in order to supply polypropylene (raw plastic), so supplier has to be selected relying on DEA. In order to further investigate and verify the robustness of the proposed approach, it will be fully analyzed. This study would bear practical implications for home appliances manufacturers in evaluating and selecting the proper sustainable supplier, and as well it aids them in achieving efficiency in supply chain procedures. The case study of this research is Shahriar Plast Company which is founded in 2006 in Iran-Karaj-Safadasht.

In this section, the structure of sustainable supply chain of suppliers for a plastic packing strap company is represented. The sustainable supply chain is structured by two-stage as supplier and distributor. The inputs of first stage or producer are Eco-design cost, logistics cost, number of tune raw material, and reliability cost. All the inputs of the producer are controllable except reliability cost. The outputs of first stage are hazardous substances and number of sustainable products that hazardous substances is undesirable output which does not enter to second stage (distributor) while number of sustainable products is a desirable output and enter to the second stage as a controllable input directly, also number of sustainable products called as the set of intermediate elements. Moreover, there are two other controllable inputs for the second stage as fuel cost and the cost of labor health10000 Rials that enter the second stage directly and independently. Eventually, three factors are exited from the second stage as outputs that the number of occupation opportunities and the number of delivered products is desirable outputs and CO_2 emission is the undesirable output. Figure 4 shows the structure of the elaborated two-stage sustainable supply chain.

In order to evaluate and select supplier for the defined company, ten suppliers in raw plastics field are defined. Each sustainable supply chain is considered as a DMU. Table 4 represents the used criteria for the sustainable supply chain. Furthermore, the data related to case study are provided

Table 6 The results of objective functions and ranking

Supplier (DMU)	$E_O^{(1)}$: efficiency score of stage 1	$E_O^{(2)}$: efficiency score of stage 2	E_0: total efficiency	Rank
Axon Polymer	1	0.746631	0.873316	1
Corbi Polymer	0.684329	0.885799	0.785064	4
Iran Masterbatch	0.717621	1	0.858811	2
Karan Co.	0.565662	0.821237	0.69345	7
Noavaran Baspar	0.674307	1	0.837154	3
Parsan Polymer	0.942492	0.564571	0.753532	5
Plasto Iran	1	0.329685	0.664843	9
Razin Polymer	1	0.486219	0.74311	6
Polyma		0.968372	0.484186	10
Persian Plastic	0.338834	1	0.669417	8
Average	0.769249	0.780251	0.736288	–

Table 7 The results of objective function and ranking with Chen and Zhu [14] approach

Supplier (DMU)	$E_O^{(1)}$: efficiency score of stage 1	$E_O^{(2)}$: efficiency score of stage 2	E_0: total efficiency	Rank
Axon Polymer	1	1	1	1
Corbi Polymer	0.936789	0.992859	0.93010	5
Iran Masterbatch	1	1	1	1
Karan Co.	1	1	1	1
Noavaran Baspar	1	0.96571	0.96571	3
Parsan Polymer	0.99207	0.967281	0.95962	4
Plasto Iran	1	1	1	1
Razin Polymer	1	0.97394	0.97394	2
Polyma	1	1	1	1
Persian Plastic	0.981281	0.99251	0.97394	2
Average	0.99101	0.99092	0.98033	–

in Table 5 for producer and distributor stages, uncontrollable inputs, undesirable outputs, and also the set of intermediate elements by ten defined suppliers.

As mentioned earlier, the DMU is efficient which its efficiency should be one; otherwise, the DMU is inefficient. Table 6 denotes the results of objective functions are achieved by Lingo software. The results represent that sustainable supply chain of Karan Co. and Polyma companies are efficient because their efficiency is equal to one and the other companies are inefficient.

There is another approach to design two-stage DEA model that is proposed by Chen and Zhu [14] (model (19)). This approach is one of the most popular methods to evaluate the performance of supply chains with envelopment format. For the reason, there are uncontrollable inputs, in the solution process, the effect of objective function variable (α) is eliminated. In addition, undesirable outputs with Eqs. (10) and (11) are applied to model (19) in order to turn the model with the capability of measurement uncontrollable inputs and undesirable outputs. Additionally, the weights of stages are equivalent to each other and equal to 0.5 for each stage. Table 7 represents the results of the solution with Model (19).

Based on the results of the model (18), 3 suppliers out of 10 suppliers gained a stage 1 efficiency score of 1, and the average of the efficiency scores among all DMUs is 0.769249. Regarding the efficiency results of stage 2, 3 suppliers scored an efficiency score of 1, and the average of the stage 2 efficiency is 0.780251. It will be represented that for most DMUs, the efficiency scores of stage 1 and stage 2 are equal, while these results are so difference concerning the model (19), 7 suppliers out of 10 suppliers received efficiency score 1 in stage and this number is 5 suppliers in stage 2, similarly the average of stages efficiency are 0.99101 and 0.99092 for the first and second stage respectively (see Fig. 5). This difference comes from several reasons, first of all, the applying method for uncontrollable inputs are different for two methods and since in proposed model (model (18)) we use the interval method, it can not only be so exact than model (19) but also is more close to the real world situation. The second reason is related to intermediate elements effects and how the efficiency of stages are added to each other, model (19) use Eq. (2) in order to add efficiency of stages, so they multiplied the efficiency of stages, whereas in model (18), Eq. (3) is applied. Thus, Tables 6 and 7 illustrate the difference of two methods, also if the number of the stage is increased, we will not be able to use Eq. (2). Consequently, Eq. (3) (mean method) is far more effective than the other one. As a consequence, the intermediate elements play a role as relevance elements, it means, if the output of the first stage is decreased as inputs of the second stage and the intermediate elements, the inputs of the second stage are reduced too. Therefore, the efficiency of the first stage is declined and the total efficiency is cut down

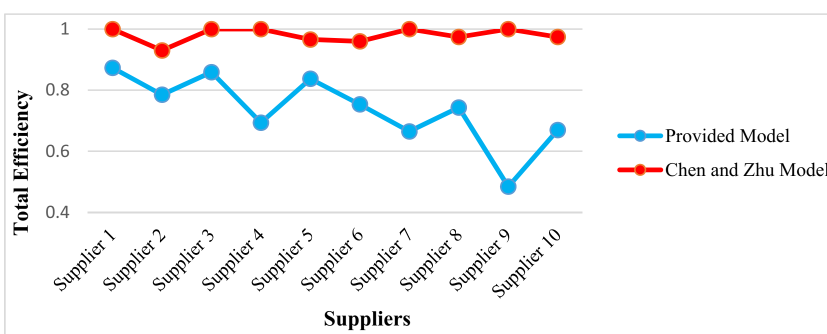


Fig. 5 Efficiency comparison of the two model

too, by way of elaboration, the intermediate elements are concerning both of the stages and being inefficiency in one of the stage can effect on the efficiency of other stage and also total efficiency. Hence, a two-stage DMU is efficient when both of the stages are efficient, the key point for this matter is the intermediate elements as relevance elements.

Furthermore, it is so hard to select the best supplier between five efficient suppliers which obtained by model (19), it means, need another decision-making approach to select the best supplier between five efficient suppliers and rank them. In the contrary, selecting the best supplier by the provided model is far easy, for the reason, this model is near to real world and calculates the exact efficiency (see Fig. 5), so, all the computed efficiency are different to each other and rank easily.

With survey at the results gained from data for sustainable supply chain illustrates, the estimate of suggested model is much correct and exact than model (19) because the set of intermediate elements and also their effects to objective function are considered in the suggested model. As well, the results report that in model (19) five DMU are efficient while in the suggested model, there are not any completely efficient DMU since the model is more near to real world and also with using Eq. (2) for the purpose of computation total efficiency of DMU, the effect of the intermediate elements are missed approximately in model (19). In other words, the value of targeting in suggested more exact than model (19), because this model includes the set of intermediate elements while model (19), compute the efficiency of each model separately and then multiply to each other, whereas in model 18 with using Eq. (3), the mean of efficiency scores is reported.

5 Conclusion and future research scopes

The sustainable supply chain management is defined as managing of raw materials, part, products and all processes from suppliers to producers and finally customers and consumers and also guarantees for environment protection and social responsibility in the all of circle life of goods. Nowadays, companies more than past focus on environment and social issues because governments legislate some rules in order to protect the environment and cover the social responsibility, therefore, companies utilize the sustainable supply chain management with green and sustainable purchase, improve the quality of products, Eco-design, the cost of labor health and supplier stock management, etc. Hence, selecting the sustainable supplier with evaluation sustainable supply chain of suppliers has turned into a significant point and tool. In order to organize a structure for measurement of performance and efficiency, the DEA method is a popular method.

In the paper, a two-stage DEA model in the presence of uncontrollable inputs and undesirable outputs with considering the set of intermediate elements between two stages is provided to evaluate and select the most suitable sustainable suppliers. In the two-stage DEA network, some factors called the set of intermediate elements between two stages. So, with considering these elements managers and experts can calculate the correct and exact efficiency of organizations (DMU). The two-stage DEA network in the presence of uncontrollable inputs and undesirable outputs can be near to real situation in the world. The suggested two-stage DEA model is in envelopment format. The main advantage of this model is that desired constraints could be added to the model in order to face with non-linearization. Also, the model including uncontrollable inputs, undesirable outputs and the set of intermediate elements between two stages simultaneously. One more point to put forward is that some data (criteria) without entre to the first stage, enter to the second stage directly. This advantage could help the model to be near to real situation.

For the future researchers, the authors suggested the provided model can utilize to other industries or supplier selection applications. Future researchers can apply fuzzy logic to face with uncertainty in the real world and also apply negative data in the suggested model.

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