**International Journal of Research in Management**
www.managementpaper.net
Online ISSN: 2664-8806, Print ISSN: 2664-8792
Received: 08-06-2022, Accepted: 24-06-2022, Published: 10-07-2022
Volume 4, Issue 2, 2022, Page No. 1-11

# How to diminish the industrial pollution for the future? A new approach based on the combined methodology of robustness analysis and data envelopment analysis

**Azadeh Omid[1], Adel Azar[2], Mahmoud Dehghan Nayeri[2]**
[1] Student of Industrial Management, Management and Economics Faculty, Tarbiat Modares University, Tehran, Iran
[2] Department of Industrial Management, Management and Economics Faculty, Tarbiat Modares University, Tehran, Iran

**Abstract**
Pollution produced by industrial activities is one of the main sources of environmental contamination that may transform into a disaster in future years. Numerous actions can be employed to eliminate this problem, while just the most efficient actions should be applied based on the limitation of resources; but the unpredictable and unstructured nature of the future makes the procedure of decision making difficult. In this regard, a valuable soft operational research technique is Robustness Analysis (RA) which benefits from flexibility and simplicity, but, in the contrary, is ineffective where conflicting parameters affect the desirability of decisions. For solving this defeat, a comprehensive approach is needed to compare decisions in a situation where multiple parameters are available. In doing so, this paper suggests the combination of RA and Data Envelopment Analysis (DEA) which empowers RA by adding the benefits of multifaceted analysis. The results prove the advantages of the proposed methodology for decision making in an unpredictable future.

**Keywords:** industrial pollution, robustness analysis, soft or, data envelopment analysis, future uncertainty

## Introduction

In the past decades, industrial development without environmental planning had led to the rapid environmental deterioration in a manner that this issue became critical for most industrial cities. Industrialization is an inseparable part of the big cities that host lots of small and medium enterprises, including Tehran, where this research is conducted in. A high rate of dying because of the pollution-related diseases and hazardous air quality is a confirmation sign for the fact that Tehran is rated as one of the world's most polluted cities [1]. This research concentrates on making future decisions in order to eliminate the environmental pollution produced from industrial activities in the polluted cities, where are nowadays in a hazardous situation from the environmental point of view.

Lots of decisions can be employed for reducing industrial pollutions; while, the effort of this investigation is to identify the most effective ones due to the limitation in budget and resources. The uncertain and unpredictable nature of the future makes the decision-making procedure difficult. In addition, the existence of different participants with different priorities in the environmental protection issue adds more difficulty to the decision-making problem. therefore, the environmental decision problems for the future are often characterized by multiple conflicting objectives and deep uncertainties [2]. During the decision-making procedure, all participants' priorities should be considered in order to result in a comprehensive consequence. Otherwise, although some decisions may seem very efficient in reducing environmental pollution, they will never reach the implementation stage because of the organizational resistance. This will happen since organizational desires such as the cost of equipment and personnel needed for implementation is not considered during the decision making. To avoid this from happening, decision-makers should consider all participants' priorities in addition to the uncertainties.

Robustness Analysis (RA) introduced by Rosenhead and Mingers [3] is a problem structuring method that facilitates decision making in an uncertain future by the means of future scenarios. But in the standard format, it lacks a comprehensive comparison ability among the decisions in the situation where the problem is multifaceted and multiple parameters influence the desirability of decisions simultaneously. For solving this problem, this paper suggests the combination of RA and Data Envelopment Analysis (DEA) which is one of the most efficient methods employed to evaluate the relative efficiency of Decision Making Units (DMUs) in the presence of multiple inputs and outputs by means of mathematical programming. The advantages of DEA over the other multi-criteria decision making methods such as AHP is that, first of all, DEA is able to deal with both quantitative and qualitative data simultaneously without a need for transforming data; besides, DEA is more efficient in the situation where lots of alternatives and criteria exist and finally, DEA is unbiased and independent from decision-makers' opinions. Consequently, for the first time, this research proposes a combined

methodology of RA and DEA for the issue of finding efficient actions for diminishing the environmental pollution of the industries in uncertain future years.
The rest of the paper is organized as follows: the next section will be narrowed to a relevant literature review. In Section 3, the methodological framework of the combined model introduced in this paper, is explained in full detail. In addition, the context of the environmental pollution reduction problem structuring and its relation to the choice of methodology is developed. Then, the results of the proposed methodology and the upcoming discussions can be found in Section 4. Finally, in Section 5, we will draw out some conclusions from the study and introduce new fields of research.

**Literature Review**

Rapid industrialization over the recent years caused serious environmental pollution in the capital cities; as an instance, Tehran citizens are exposed to annual $PM_{2.5}$ approximately two to four times higher than the WHO guideline level [4]. Environmental issues will become more critical in future years based on the fact that expanding the industrial production scale can increase industrial pollution emissions [5]. As far as industrial cities host lots of production industries and industrial agglomeration increases the pollution agglomeration [6], an extensive collaboration between organizations, people and the environment is needed to reduce the pollution of the production sectors in future years. Since decision making for future has been combined with deep uncertainties, organizations tend to identify more strategies and evaluate the most efficient ones for implementation, which is precisely what robust decision support approaches aim to provide [7]. Some real-world problems are categorized as messy [8] or wicked [9] problems that are happening in the situations where there is complexity, uncertainty about the future, doubt about others' actions and differences in priorities and interests within the groups. Wicked problems are multifaceted issues that have no single solution, and are observed through conflicting views by different stakeholders [10]. In this kind of problem, the factors to be taken into account, the relations between them or the objectives of the problem cannot be objectively determined or at least consensually agreed. In order to overcome this kind of problem, there is a need for literature that assist planners and decision-makers with making long-term plans under deep uncertainty (e.g. Herman, Reed [11], Kwakkel, Haasnoot [12] and Thissen, Kwakkel [13]). Accordingly, some methodologies known as Problem Structuring Methods (PSMs) have been developed [14] which furnished the framework for the decision process. There are lots of PSMs including Strategic options development and analysis (SODA) [15, 16], soft systems methodology (SSM) [17], Strategic choice approach (SCA) [18], robustness analysis [14] and drama theory [19]. An introduction to each of these methods in addition to an overview can be found in Rosenheim & Mingers (2001). later, Smith and Shaw [20] developed a framework by means of a literature review to identify similarities between PSMs, in a manner that their framework poses some questions to determine whether if an approach could be a PSM or not. In addition, Namen *et al*. (2010) published an article about the use of Robustness Analysis for planning actions and compare this approach with other soft Operations Research (OR) methodologies [21].
Problem structuring methods belong to the soft OR which in opposite to the hard one, shed light on the human, social and political factors that affect strategy formulation and policy-making. Generally, there are two distinct categories in OR literature including hard and soft approaches. It is generally accepted that each method of OR can be ordered along a spectrum from hard to soft. Robustness Analysis (RA) is a member of the PSM family, particularly suited to situations with high uncertainty and the possibility of taking decisions sequentially. This decision-aiding methodology facilitates decision making in flexible planning for an unpredictable future [14]. The main reason for using robustness analysis in this study besides its simplicity is to identify representative possible future states which are known as the scenarios. Scenarios describe futures that 'could be' rather than futures that 'will be' [22]. The organizing principle of the robustness approach is to maintain the possibility of achieving a respectable performance of the system across a wide range of different future scenarios [23]. As shown in Lempert and Groves [24], in contrary to the past, where static planning was efficient, adaptive planning has obvious attractiveness based on the deep uncertainties and stresses about the future conditions in the present decade.
The main advantage of Robustness Analysis (RA) is that by keeping options on the table [14], this methodology proposes an appropriate manner for decision-makers to logically compare all the options in the probabilistic future scenarios. In another word, RA does not recommend a complete 'solution', but counts on taking only those decisions which have to be taken now, leaving all further actions for future choice. In contrast, the main disadvantage of RA is related to its comparison stage where the decisions are compared based on their desirability or otherwise debility. The main shortcoming of this comparison process is that assigning just a single value as the desirability/debility of each decision and then using this value in the comparison stage, is not a comprehensive approach. Since in some cases, the desirability of each action should be considered by multi parameters where each of these parameters' values shows desirability from one point of view which is different from the others. As an instance, in the situation of decision making about environmental pollution, some decisions may seem very desirable from an environmental point of view while simultaneously may seem catastrophic from an organizational point of view. As mentioned in Mosadeghi, Warnken [25], Multi-criteria decision-making techniques have become widely used in strategic environmental decision making. Marttunen, Lienert [26] reviewed literature combining PSMs and Multi-Criteria Decision Analysis (MCDA) methods and represented that combining PSMs with MCDA produces a richer view of the decision situation and supports different phases of the decision-making process more effectively. In the same paper, it is expressed that the combination of RA and MCDA are very rare or non-existent [26]. In another study, Witt *et al*. (2020) state that

integration of multi-criteria analysis allows for better Problem structuring by focusing on relevant alternatives, external uncertainties, and evaluation criteria [27].

Data Envelopment Analysis (DEA) is designed to help decision-makers to measure the efficiency of a set of units in the presence of multiple values considered as inputs or outputs [28]. The main advantage of DEA is its ability in measuring the relative efficiency of a set of units where the presence of multiple inputs and outputs makes comparisons difficult. It is firstly introduced by Charnes, Cooper, and Rhodes is an approach for identifying best practices of peer decision-making units (DMUs) in the presence of multiple inputs and outputs [29]. DEA is a non-parametric technique that measures the efficiency of a set of DMUs by means of linear programming; therefore, it is classified as a hard OR. Two basic DEA models are named as the CCR and the BCC models which measure the performance under the assumption of a constant and variable return to scale respectively [28]. A recent survey of DEA literature can be found in research by Emrouznejad and Yang [30]. Although DEA has been utilized to evaluate efficiency in a wide variety of applications, this paper proposes a novel application of DEA for decision making for the future. Briefly, this paper suggests the combination of hard and soft OR in order to exploit the advantages of both in dealing with the complicated problem of environmental pollution.

## Material and Methods

This section narrows on the method for finding a sequence of actions for diminishing the environmental pollution in the following future years by considering all decision-makers' viewpoints. The work reported herein is carried out in the city of Tehran where is suffering from catastrophic environmental conditions. In this regard, Robustness Analysis (RA) emerged as an appropriate methodology due to the strength of the uncertainty about the future which would otherwise get in the way of making clear commitments to action [14]. The methodological framework of the robustness analysis is that in the first step, a sequence of decisions based on the viewpoints of the decision-makers involved in the issue is proposed. In deciding sequentially, a set of relevant decisions which can be taken up to certain planning can be considered as a path of action or in a summarized form, an action. The second step is to propose probable future scenarios. Then, the third step focuses on comparing the actions and assess the desirability of each path of decisions in future scenarios. Finally, the robustness of the actions is evaluated and the robust actions in the most future scenarios will be considered.

In the standard robustness approach available in the literature, the desirability is assessed by the decision-makers with a single value. As an instance, a set of qualified values such as ‘desirable, acceptable, undesirable and catastrophic’ are used for comparing the desirability of actions through the future scenarios [31]. This approach is inapplicable in the situation where desirability is assessed from different viewpoints, especially while some may be in conflict. Moreover, in a situation where some factors are assessed by quantitative data, a more comprehensive approach is needed for comparing the actions. To be more clarified, in the problem such as decision making for diminishing the environmental pollution in the future, different participants’ perspectives will result in the consideration of different factors during the desirability assessment. As an example, the cost of the equipment and personnel needed for each decision will be considered by the quantitative data and are desirable to be as minimum as possible, while the desirability of the decision from the environmental, organizational or consumers’ perspective should be considered by qualitative data and are desirable to be as maximum as possible. In addition, the desirability of these different perspectives may be in conflict with each other, so it cannot be assessed by just a single value.

Based on the disability of the robustness analysis in comparison stage in the situation that multiple factors need to be considered concurrently, this investigation proposes a development to the robustness analysis and combines it with Data Envelopment Analysis (DEA) for measuring the efficiency of each action in the future scenarios by considering all points of view simultaneously. The advantage of DEA is to deal with both quantitative and qualitative data at once; besides, it is able to compare a set of units while multiple inputs and outputs are available. In addition, by means of DEA, it is possible to assess the parameters which are desirable to be minimized as the inputs and the parameters which are desirable to be maximized as the outputs. Therefore it is well-suited for empowering the proposed methodology.

As mentioned, the paper aims to deal with the issue of diminishing the environmental pollution of Tehran in the following ten years. Hence, in the following, an explanation of the methodology developed to this aim is proposed. In this regard, firstly a detailed description for each of the robustness analysis stages can be found in addition to the upcoming explanation related to the case study. Then, the combination of the DEA and robustness analysis for attaining a comprehensive approach is proposed in detail.

### A Sequence of Actions for Diminishing Environmental Pollution

Some tips for reducing industrial pollution are introduced by the environmental consultant agencies active in the environmental protection area around the world. Here a set of actions available for diminishing the environmental pollution in an industrial city is provided based on an extensive research. In robustness analysis, the first step is to build a Sequential Decision Chart (SDC) which displays the set of relevant decisions that can be taken up sequentially. These actions are classified sequentially while the vertical dimension represents the possible alternative choices at each particular decision point. As the chart below, four categories of decisions are available for diminishing the environmental pollution of the area including fundamental decisions, production-related decisions, distribution-related decisions and the decisions related to the services. In addition, each of these categories is divided into more divisions which totally is available in Figure 1.

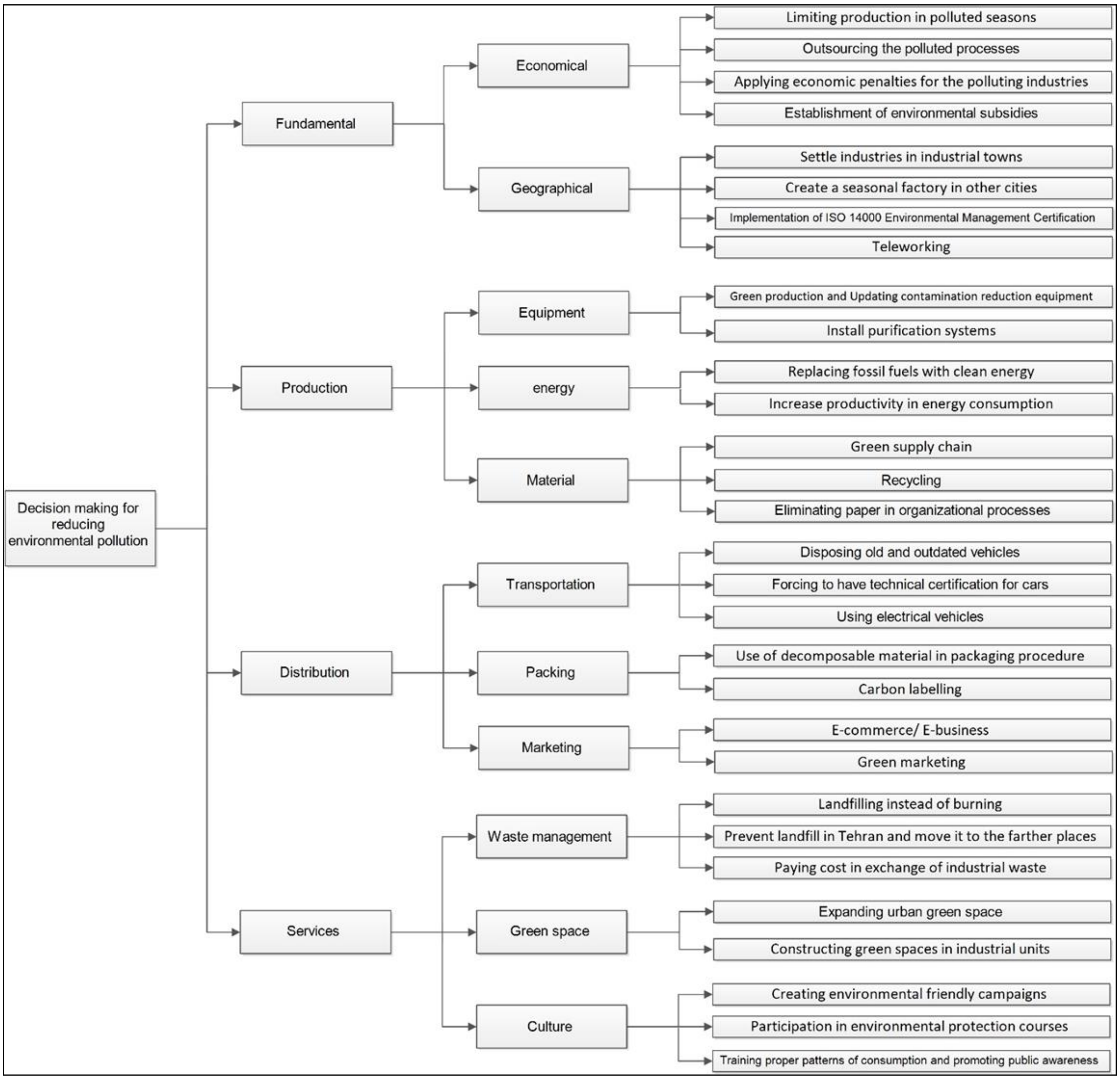


**Fig 1:** Sequential decision chart (SDC) for diminishing the environmental pollution

**Identifying Multiple Plausible Future Scenarios**

According to the RA steps, it's time to focus on future conditions and introduce probable happening in the following ten-year time horizon. Based on the economic, technology and society's conditions in an extremely uncertain and unpredicted future, identification of "best-guess" future conditions might no longer be appropriate; Instead, multiple plausible futures need to be considered [32] as future scenarios. Mahmoud, Liu [33] defined scenarios as the possible future situations which characterize alternative plausible conditions under various assumptions. Considering future scenarios is so useful particularly in the cases where the probability of the uncertainties occurrences are usually unknown such as in the investigation done by Kotireddy, Hoes [34] where a non-probabilistic robustness assessment methodology, based on scenario analysis, is developed to identify robust designs.

In the complex economic and environmental conditions, it is hard to consider alternative futures exactly. Although lots of parameters influence the future scenarios, two of them including "economic conditions of the society" and "amount of society's cooperation in environmental issue" are chosen as the most effective parameters influencing the future scenarios. These two parameters are chosen as the answer of "which parameters will influence future situations mostly in the area of environmental issue?" which was asked from some environmental specialists of Iran's Environmental Protection Agency. In a spectrum of changes, the economic conditions will fluctuate between prosperity in optimistic viewpoint and downturn in pessimistic viewpoint. Otherwise, the society will position themselves in the cooperative position against the environmental issues or in contrary, non-cooperative position which depends on the amount of community awareness spread in the society against the environmental issues. Therefore, the actual future will likely hold a combination of these parameters' fluctuation as Figure 2. In Table 2, four future scenarios are explained completely.

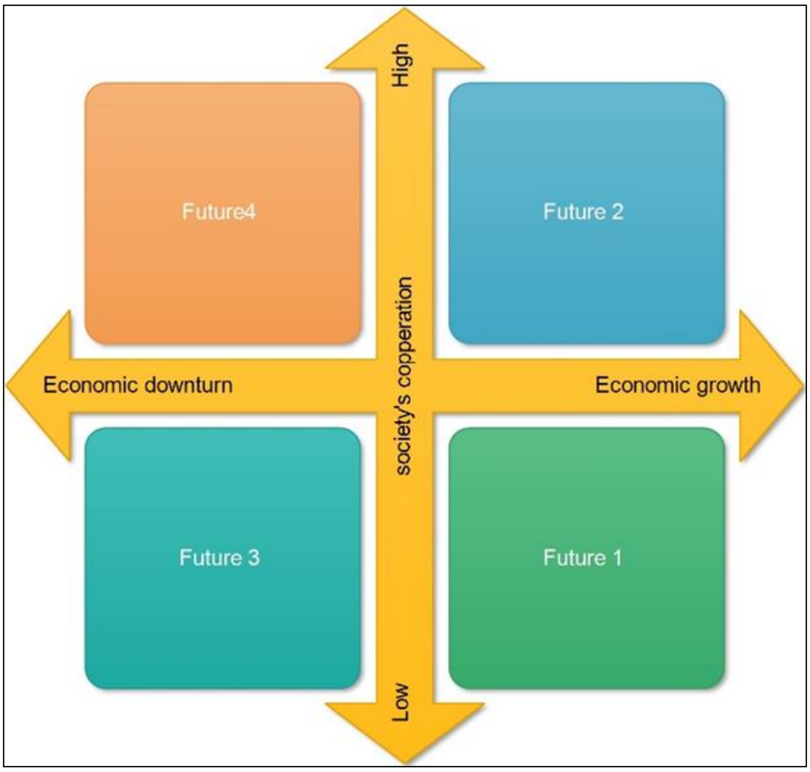


**Fig 2:** Parameters influencing future scenarios

**Table 1:** Scenarios for Future

| Future 1 (F1) | Future 2 (F2) |
|---|---|
| This scenario represents the conditions of economic growth period. In this scenario, industries are improving vastly, the production rate is increasing and products are exported widely overseas. In this situation, by increasing the amount of factories production, the amount of pollution from factories exits will increase, which will result in strong climate signals that compel managers to re-evaluate its position on environmental protection. As climate change brings damage to the ecosystem and human infrastructure, it will force companies to produce greenly and use fossil fuels efficiently. In such a situation, green science and modern technologies can help companies to develop their energy consumption efficiency. In summarized, in this scenario, a movement toward an environmental paradigm mobilized by organizations and can be named as a top to a bottom scenario. | In this scenario, consumption patterns turned toward conservation. In contrast to the F1, in this scenario, a movement toward a new societal paradigm occurs from the bottom-up, mobilized by individuals. In this situation, the population is impressed by climate signals, global warming, and poor air quality and it compels the population to put resolving climate change ahead of the other priorities. Therefore, the people and consumers reassess their pathway toward society. In this regard, society's culture drives toward green consumption and people tend to consume green products even in exchange for more money. On the other hand, the pattern of consumption is changed and citizens are widely collaborating in recycling. In addition, carbon labeling on the products is advocated by the consumers and will bring a competitive advantage for the products. In this scenario, the public attitude of society about the issue of the environment is changed based on extensive culture making in society and especially among the children in schools. |
| **Future 3 (F3)** | **Future 4 (F4)** |
| In this scenario, the issue of the environment has the least priority based on the economic downturn and non-cooperative society. Ruined economic conditions compel production companies to reduce their production costs and employ economy saving methods. Besides, customers' purchasing power decrease and consumers tend to buy cheaper products. Consequently, environmental protection becomes the last concern not only for the production companies but also for the consumers. | In this scenario, the society decides to interfere and by the help of government, force the companies to produce greenly by the instrument of penalties, incentives or relief in taxes paid by the factories. Climate signals which are becoming stronger by the time, reveal ecosystem vulnerability and encourage the society to fulfill a basic action such as industrial capital transference to the unpolluted areas. |

**Comparing the Actions and Assess the Efficient Ones**

In this stage, the sequence of actions for diminishing environmental pollution will be compared in order to find the best solution in each of the future scenarios for solving the pollution problem of the capital city. Consequently, each action has different setup costs; the same as the issue that needs a different number of staff and the other facilities such as law-making. Furthermore, the actions for diminishing environmental pollutions will affect production rate and production volume in a different manner and will bring the different extent of organizational resistance among employees, so have different amounts of desirability from managers and staff or totally the organizational point of view. In addition, each action will have a different influence on customer loyalty; besides, each decision plays a different role in diminishing environmental pollution while some are more effective than the others. But it should be considered that considering just one perspective such as the environmental viewpoint during the desirability assessment, is inappropriate since of the fact that companies owners will not cooperate in the decisions which seem worthlessly from their viewpoints as the same as the employees of the companies and the people in the society.

As can be clearly seen, a single desirability mark is unable to conclude all these different terms timely, inevitably each feature needs to be mounted separately. Therefore, an accurate methodology is needed to compare the actions based on different featuring amounts. As far as some features such as cost of equipment and employing staff tend to be minimized and some others such as different perspective desirability tend to be maximized contra wisely, this investigation suggests the use of DEA as a comparing tool. In this regard, the action which needs to be compared is considered as the DMUs and the variables that should be minimized are considered as the inputs of the DMUs as well as the variables which should be maximized as the outputs of the DMUs.

In this regard, the parameters such as the cost of equipment needed for each decision and the cost of the staffs and personnel in each decision are considered as the inputs and the parameters such as the desirability of each decision from environmental points of view, organizational points of view and society and consumers' points of view are considered as the outputs in the efficiency assessment by means of data envelopment analysis. Moreover, during the desirability assessment, the collaboration of the analysts is needed in order to score the decision sequence based on their desirability. As mentioned, some other factors such as the cost of the equipment in each sequence of decisions and the cost of the staff involved in each decision should be considered in addition to the different perspective desirability.

In conventional DEA, data is supposed to be non-negative continuous values. However, there are situations when data are bounded, discrete, ordinal or on a Likert scale. In some types of problems, quantitative data are not available; especially in cases where an estimation for the desirability of some factors in the future is the issue. In this regard, a qualitative data envelopment analysis is needed in order to assess efficiency. The standard data envelopment analysis cannot be used in the presence of qualitative data, because conventional DEA model is capable only of treating the information as if it has cardinal meaning. In other words, something which receives a score of 4 is evaluated to be twice important as something that receive the score of 2. But in the case of qualitative data, no one seriously believes that an "extremely important" classification for a parameter should be interpreted literally as meaning that this project rates three times better than one which is only classified as "important" [35].

In the literature, two main approaches for the qualitative data envelopment analysis are introduced by Cook *et al*. (1993, 1996) and Cooper *et al*. (1999). Firstly, in 1993, Cook *et al*. presented a procedure for incorporating an ordinal factor into the DEA structure [36]. Then, Cook *et al*. in 1996 developed the data envelopment analysis in the presence of both quantitative and qualitative factors [37]. The approach of Cook *et al* (1993, 1996) attribute values to the multipliers and then let the DEA optimization derive the values for the rank positions. While in the reverse approach, the IDEA approach of Cooper *et al* (1999) first attribute values to the imprecise data and second, optimize to arrive at optimal multipliers [38]. In 2011 Cook stated that these seemingly quite different approaches would appear to arrive at the same final point [35]. Hence this paper uses the variable return to scale quantitative DEA approach introduced by Cook *et al*. in 1996 which is provided in model (1).

In the situation where all factors are quantitative, the conventional radial projection model for measuring DMU efficiency is expressed by the ratio of weighted outputs to weighted inputs which is transformed to a linear form by means of Charnes and Cooper transformation [39]. The same is true in the situation where both quantitative and qualitative factors are available.

The efficiency of DMU "o" follows from the solution of model (1) by considering the situation in which a set of N DMUs, k=1, N are to be evaluated in terms of $R_1$ numerical outputs, $R_2$ ordinal outputs, $I_1$ numerical inputs, and $I_2$ ordinal inputs.

$$e_o = \max(\mu_o + \sum_{r\epsilon R_1} \mu_r^1 y_{ro}^1 + \sum_{r\epsilon R_2} \sum_{l=1}^{L} w_{rl}^1 \bar{\gamma}_{ro}(l)) \tag{1}$$

$$s.t. \sum_{i\in I_1} v_i^1 x_{io}^1 + \sum_{i\in I_2} \sum_{l=1}^{L} w_{rl}^2 \bar{\delta}_{io}(l) = 1$$

$$\mu_o + \sum_{r\epsilon R_1} \mu_r^1 y_{rk}^1 + \sum_{r\epsilon R_2} \sum_{l=1}^{L} w_{rl}^1 \bar{\gamma}_{rk}(l) - \sum_{i\in I_1} v_i^1 x_{ik}^1 - \sum_{i\in I_2} \sum_{l=1}^{L} w_{il}^2 \bar{\delta}_{ik}(l) \le 0$$

$$\mu_r^1, v_i^1, w_{rl}^1, w_{il}^2 \ge \varepsilon$$

In model (1), $e_o$ is the efficiency of DMU$_o$ which consumes $x^1_{io}$ numerical inputs and $\bar{\delta}_{io}$ ordinal inputs in order to produces $y^1_{ro}$ numerical outputs and $\bar{\gamma}_{ro}$ ordinal outputs. The term $\mu_o$ is presented in model (1) based on the assumption of variable return to scale. The multipliers $\mu^1_r, v^1_i, w^1_{rl}, w^2_{il}$ relates to the quantitative outputs, quantitative inputs, qualitative outputs and qualitative inputs weights assessed as a result of model (1), respectively and $\varepsilon$ is a non-negative infinitesimal lower bound. The slight difference between model (1) and the conventional VRS model of Banker, Charnes [40] is the presence both numerical and ordinal inputs and outputs, while in the conventional VRS model of Banker, Charnes [40], just the numerical ones were presented. The terms $\bar{\gamma}_{rk}(l)$ and $\bar{\delta}_{ik}(l)$ which are the notations of ordinal outputs and inputs respectively, are defined as follows:

$$\bar{\gamma}_{rk}(l) = \sum_{n=1}^{l} \gamma_{rk}(n) = \gamma_{rk}(1) + \gamma_{rk}(2) + \cdots + \gamma_{rk}(l)$$

$$\bar{\delta}_{ik}(l) = \sum_{n=l}^{L} \delta_{ik}(n) = \delta_{ik}(L) + \delta_{ik}(L-1) + \cdots + \delta_{ik}(l)$$

While:

$$\gamma_{rk}(n) = \begin{cases} 1 & if\ DMU\ k\ is\ ranked\ in\ nth\ position\ on\ output\ r \\ 0, & otherwise \end{cases}$$

$$\delta_{ik}(n) = \begin{cases} 1 & if\ DMU\ k\ is\ ranked\ in\ nth\ position\ on\ input\ i \\ 0, & otherwise \end{cases}$$

**Table 2:** Dataset of Futures inputs and outputs

| DMUs | Future 1 | | | | | Future 2 | | | | | Future 3 | | | | | Future 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Inputs | | Outputs | | | Inputs | | Outputs | | | Inputs | | Outputs | | | Inputs | | Outputs | | |
| | $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | $Y_3$ | $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | $Y_3$ | $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | $Y_3$ | $X_1$ | $X_2$ | $Y_1$ | $Y_2$ | $Y_3$ |
| | Cost of equipment | Cost of personnel | Desirability from environmental sight | Desirability from organizational sight | Desirability from consumers sight | Cost of equipment | Cost of personnel | Desirability from environmental sight | Desirability from organizational sight | Desirability from consumers sight | Cost of equipment | Cost of personnel | Desirability from environmental sight | Desirability from organizational sight | Desirability from consumers sight | Cost of equipment | Cost of personnel | Desirability from environmental sight | Desirability from organizational sight | Desirability from consumers sight |
| DMU1 | 15 | 43 | 2 | 5 | 5 | 12 | 28 | 4 | 5 | 5 | 42 | 34 | 5 | 5 | 3 | 6 | 9 | 2 | 3 | 2 |
| DMU2 | 12 | 8 | 2 | 1 | 2 | 24 | 19 | 5 | 5 | 4 | 46 | 21 | 5 | 5 | 4 | 41 | 43 | 4 | 4 | 1 |
| DMU3 | 41 | 13 | 5 | 5 | 3 | 32 | 21 | 4 | 5 | 3 | 23 | 18 | 5 | 5 | 5 | 11 | 21 | 4 | 1 | 3 |
| DMU4 | 12 | 24 | 5 | 4 | 3 | 12 | 19 | 3 | 3 | 3 | 18 | 19 | 2 | 3 | 3 | 5 | 15 | 2 | 3 | 1 |
| DMU5 | 50 | 46 | 2 | 4 | 3 | 34 | 28 | 3 | 4 | 2 | 41 | 24 | 5 | 5 | 3 | 48 | 19 | 1 | 1 | 1 |
| DMU6 | 47 | 47 | 5 | 3 | 2 | 47 | 12 | 5 | 3 | 1 | 43 | 45 | 5 | 5 | 5 | 39 | 15 | 5 | 3 | 2 |
| DMU7 | 31 | 24 | 1 | 1 | 1 | 19 | 21 | 3 | 3 | 3 | 45 | 45 | 1 | 5 | 3 | 31 | 14 | 2 | 3 | 3 |
| DMU8 | 23 | 46 | 2 | 3 | 2 | 41 | 27 | 3 | 3 | 1 | 43 | 22 | 5 | 2 | 2 | 42 | 21 | 2 | 3 | 2 |
| DMU9 | 42 | 12 | 1 | 1 | 1 | 33 | 18 | 2 | 2 | 1 | 31 | 19 | 4 | 2 | 2 | 33 | 17 | 2 | 3 | 2 |
| DMU10 | 34 | 12 | 1 | 1 | 1 | 24 | 19 | 3 | 3 | 1 | 42 | 28 | 2 | 5 | 3 | 28 | 18 | 2 | 3 | 2 |
| DMU11 | 50 | 15 | 2 | 5 | 1 | 18 | 31 | 2 | 3 | 1 | 18 | 34 | 3 | 3 | 2 | 19 | 32 | 2 | 3 | 2 |
| DMU12 | 18 | 21 | 2 | 1 | 1 | 18 | 22 | 2 | 1 | 1 | 25 | 16 | 2 | 1 | 1 | 17 | 19 | 1 | 1 | 1 |
| DMU13 | 5 | 16 | 1 | 1 | 1 | 23 | 25 | 3 | 2 | 2 | 37 | 22 | 4 | 3 | 3 | 15 | 17 | 2 | 2 | 3 |
| DMU14 | 34 | 28 | 2 | 4 | 3 | 32 | 29 | 1 | 1 | 1 | 18 | 15 | 3 | 3 | 3 | 16 | 22 | 2 | 2 | 2 |
| DMU15 | 8 | 13 | 2 | 2 | 3 | 11 | 7 | 1 | 2 | 3 | 12 | 8 | 1 | 1 | 1 | 4 | 9 | 2 | 4 | 3 |
| DMU16 | 36 | 21 | 2 | 3 | 3 | 36 | 14 | 2 | 2 | 1 | 46 | 12 | 5 | 3 | 2 | 32 | 18 | 1 | 2 | 3 |
| DMU17 | 24 | 31 | 3 | 3 | 4 | 21 | 32 | 2 | 2 | 1 | 8 | 15 | 1 | 1 | 1 | 21 | 34 | 2 | 3 | 2 |
| DMU18 | 35 | 9 | 2 | 5 | 3 | 19 | 40 | 2 | 2 | 1 | 50 | 12 | 5 | 5 | 5 | 50 | 34 | 1 | 5 | 3 |
| DMU19 | 31 | 23 | 2 | 3 | 2 | 46 | 9 | 1 | 1 | 1 | 15 | 35 | 5 | 2 | 2 | 32 | 16 | 1 | 2 | 1 |
| DMU20 | 34 | 15 | 4 | 3 | 3 | 42 | 18 | 1 | 2 | 1 | 21 | 34 | 2 | 3 | 3 | 32 | 39 | 2 | 2 | 3 |
| DMU21 | 28 | 32 | 4 | 4 | 3 | 21 | 29 | 3 | 4 | 4 | 33 | 31 | 3 | 4 | 3 | 25 | 24 | 2 | 3 | 3 |
| DMU22 | 23 | 32 | 4 | 4 | 3 | 6 | 38 | 2 | 2 | 1 | 28 | 36 | 5 | 5 | 3 | 12 | 33 | 1 | 3 | 3 |
| DMU23 | 25 | 45 | 5 | 5 | 5 | 31 | 18 | 5 | 3 | 1 | 32 | 17 | 5 | 4 | 3 | 32 | 15 | 5 | 4 | 2 |
| DMU24 | 32 | 50 | 4 | 5 | 5 | 4 | 28 | 2 | 3 | 2 | 34 | 12 | 5 | 4 | 3 | 34 | 10 | 3 | 3 | 2 |
| DMU25 | 16 | 12 | 5 | 5 | 5 | 8 | 12 | 2 | 4 | 1 | 25 | 14 | 1 | 1 | 2 | 21 | 14 | 1 | 1 | 1 |
| DMU26 | 18 | 28 | 3 | 4 | 5 | 6 | 16 | 1 | 3 | 2 | 12 | 3 | 1 | 1 | 1 | 12 | 21 | 1 | 2 | 2 |
| DMU27 | 19 | 27 | 3 | 5 | 4 | 12 | 24 | 2 | 1 | 1 | 4 | 13 | 1 | 1 | 1 | 15 | 18 | 1 | 2 | 3 |
| DMU28 | 14 | 36 | 3 | 5 | 5 | 3 | 24 | 1 | 2 | 3 | 11 | 31 | 4 | 3 | 3 | 11 | 32 | 2 | 3 | 3 |
| DMU29 | 16 | 23 | 5 | 5 | 4 | 23 | 13 | 2 | 3 | 2 | 22 | 10 | 3 | 3 | 3 | 2 | 19 | 2 | 2 | 3 |
| DMU30 | 8 | 18 | 2 | 1 | 2 | 7 | 19 | 2 | 1 | 2 | 9 | 17 | 2 | 1 | 2 | 6 | 16 | 1 | 1 | 1 |

For example, if a five-point scale is used, and DMU #1 is ranked in n=3rd place on ordinal output r=5, then $\gamma_{51}(3) = 1, \gamma_{51}(n) = 0,$ for all other rank positions $n$.

Since this research tries to assess the desirability of some actions in the future based on the efficiency assessment, the outputs of the DMUs which are different from desirability perspectives and are estimated based on the decision-makers' viewpoints will be assessed by the qualitative data. In this regard, the Likert scale is a useful tool for analysts to estimate the outputs of the model in an uncertain future. Likert scales used by researchers are commonly taken by 5, 7 or 9. The use of a 5 point scale seems to be fairly common in many settings since it has consistency with the desirability scores in the robustness analysis approach and particular meaning can be attached to the factors being considered in the assessment. Based on the coordination between desirability assessment of robustness analysis literature and the 5 points Likert scale, the desirability of outputs parameters will be assessed by the terms including 'very desirable', 'desirable', 'neutral', 'undesirable' and 'very undesirable'. In Table 2, Output parameters ($y_i$) including the desirability of each sequence of decisions from the viewpoints of firstly, environment, secondly, organization including managers and employees and thirdly, consumers and society are assigned by the analysts and specialists involved in decision making procedure. Input parameters ($x_i$) including the cost of equipment needed in each sequence of decisions and the cost of the staffs involved in each sequence of decisions are assessed with quantitative data after conducting the interview with the analysts.

As mentioned, the convention ranking method in Cook, 2011 is used in this paper [35]. In this regard, it should be considered that a rating of 1 is "best," and 5 is "worst." For outputs, this means that a DMU ranked at position 1 produces more output than a DMU in position 2. For inputs, a DMU in the first position consumes less input than one in the second position. By combining this convention with desirability in the robustness analysis, this conclusion is obtained that for the outputs, 1 is "very desirable", 2 is "desirable", 3 is "neutral", 4 is "undesirable" and 5 is "very undesirable". In Table 2, the data for inputs and outputs of the model for each sequence of decisions and in each future scenario is available separately. These data are gathered after extensive interviews with specialists of Department of Environments and owners of some mega industries.

The next step in robustness analysis is to compare the decisions in each upcoming future scenario and choose the most efficient decisions. As far as this investigation proposed a methodology for comparing the decisions based on the efficiency scores by means of data envelopment analysis, the results of the efficiency assessment of each decision by considering all input and output parameters can be found in the next section.

## Results and Discussions

The results of robustness analysis based on the DEA efficiency assessment of each sequence of actions for diminishing the environmental pollution of Tehran are summarized in table 3. For comparison point of view, the results of a conventional RA approach by considering just the environmental point of view can be found in Table 4; while, the robustness score of each sequence of actions is considered as the ratio of "very desirable" and "desirable" actions to the total number of actions.

**Table 3:** Results of efficiency assessment

| DMU | Decisions | | Description | Future 1 | Future 2 | Future 3 | Future 4 |
|---|---|---|---|---|---|---|---|
| | | | | Efficiency results | Efficiency results | Efficiency results | Efficiency results |
| DMU1 | Fundamental | Economical | Limiting production in polluted seasons | 0.157 | 0.333 | 0.248 | 0.845 |
| DMU2 | | | Outsourcing the polluted processes | 1.000 | 0.209 | 0.115 | 0.712 |
| DMU3 | | | Applying economic penalties for the polluting industries | 0.537 | 0.348 | 0.149 | 0.678 |
| DMU4 | | | Establishment of environmental subsidies | 0.375 | 0.198 | 0.572 | 1.000 |
| DMU5 | | Geographical | Settle industries in industrial towns | 0.454 | 0.512 | 0.314 | 1.000 |
| DMU6 | | | Create a seasonal factory in other cities | 0.845 | 0.395 | 0.115 | 0.414 |
| DMU7 | | | Implementation of ISO 14000 Environmental Management Certification | 1.000 | 0.812 | 0.109 | 0.875 |
| DMU8 | | | Teleworking | 0.543 | 0.412 | 0.345 | 0.481 |
| DMU9 | Production | Equipment | Green production and Updating contamination reduction equipment | 1.000 | 0.689 | 0.412 | 0.865 |
| DMU10 | | | Install purification systems | 1.000 | 0.814 | 0.219 | 0.904 |
| DMU11 | | Energy | Replacing fossil fuels with clean energy | 0.514 | 0.603 | 0.214 | 0.698 |
| DMU12 | | | Increase productivity in energy consumption | 0.932 | 0.835 | 0.906 | 1.000 |
| DMU13 | | Material | Green supply chain | 1.000 | 0.612 | 0.458 | 0.685 |
| DMU14 | | | Recycling | 0.712 | 1.000 | 0.516 | 0.687 |
| DMU15 | | | Eliminating paper in organizational processes | 0.862 | 0.943 | 1.000 | 0.908 |
| DMU16 | Distribution | Transportation | Disposing old and outdated vehicles | 0.675 | 0.419 | 0.375 | 0.786 |
| DMU17 | | | Forcing to have technical certification for cars | 0.704 | 0.754 | 1.000 | 0.815 |
| DMU18 | | | Using electrical vehicles | 0.331 | 0.267 | 0.214 | 0.187 |
| DMU19 | | Packing | Use of decomposable material in packaging procedure | 0.824 | 1.000 | 0.564 | 0.915 |
| DMU20 | | | Carbon labelling | 0.455 | 1.000 | 0.333 | 0.524 |
| DMU21 | | Marketing | E-commerce/ E-business | 0.608 | 0.256 | 0.188 | 0.712 |
| DMU22 | | | Green marketing | 0.398 | 1.000 | 0.319 | 0.908 |
| DMU23 | Services | Waste management | Landfilling instead of burning | 0.216 | 0.347 | 0.415 | 0.368 |
| DMU24 | | | Prevent landfill in Tehran and move it to the farther places | 0.273 | 0.876 | 0.546 | 0.398 |
| DMU25 | | | Paying cost in exchange for industrial waste | 0.467 | 0.845 | 0.114 | 0.765 |
| DMU26 | | Green space | Expanding urban green space | 0.614 | 0.892 | 1.000 | 0.871 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DMU27 | | | Constructing green spaces in industrial units | 0.746 | 0.276 | 1.000 | 0.975 |
| DMU28 | | Culture | Creating environmental friendly campaigns | 0.571 | 0.842 | 0.618 | 0.550 |
| DMU29 | | | Participation in environmental protection courses | 0.305 | 0.784 | 0.254 | 1.000 |
| DMU30 | | | Training proper patterns of consumption and promoting public awareness | 0.904 | 0.984 | 0.913 | 1.000 |

From the efficiency results in Table 3, it could be considered that the results of efficiency assessment based on the DEA are able to distinguish the efficient actions in each of the future scenarios. From the comparison point of view, the actions whose efficiency scores are one should be considered as the efficient actions in each scenario about the future. As an instance, in F1, the actions of ‘outsourcing the polluted processes’, ‘implementation of ISO 14000 Environmental Management Certification’, ‘updating contamination reduction equipment in order to product greenly’, ‘install purification systems’ and ‘green supply chain’ are the efficient ones. It can be found that the most efficient actions for the first scenario which describe the economic growth conditions are related to the decisions in the area of production and also fundamental decisions. In F2, which concentrates on the consumers' cooperation in environmental issues, actions such as ‘recycling’, ‘use of decomposable material in packing’, ‘carbon labeling’ and ‘green marketing’ acquire the efficiency score of one. It can be seen that in this scenario, the decisions in the area of distribution seem to be more efficient than others. in F3, which is about the economic downturn situations, the actions including ‘eliminating paper in organizational processes’, ‘forcing to have technical certification for cars’, ‘expanding urban green spaces’, ‘constructing green spaces in industrial units’ Classified as the most efficient ones. The results seem logical since, in the third scenario where environmental issue loses its importance because of bad economic conditions, the actions in the area of services seem to be more efficient. Finally, in F4, which concentrates on the government role in environmental issue, ‘establishment of environmental subsidies’, ‘settle industries in industrial towns’, ‘Increase productivity in energy consumption’, ‘participation in environmental protection courses’ and ‘training proper patterns of consumption and promoting public awareness’ are the more appropriate actions based on their efficiency scores. In this scenario, the fundamental actions and the actions in the area of services gain a higher position in efficiency ranking.

As the results of Table 3 showed, some actions such as ‘increase productivity in energy consumption’, ‘eliminating paper in organizational processes’ and ‘Training proper patterns of consumption and promoting public awareness’ are mostly efficient in all the future scenarios and could be considered as the general appropriate actions for diminishing the environmental pollution produced by the production industries apart from what will happen in the future. This outcome coincides with what was expected because these actions which are considered as the efficient actions in most of the scenarios are the actions that do not cost a lot and are easy to implement in comparison to the other actions. Although, this investigation concentrates on the case study of Tehran; but, the results can be extended to other industrial cities world widely and used for diminishing environmental pollution of all industrial cities around the world.

In conclusion, the results suggest that in each scenario for the future, it is more appropriate to concentrate on a specific field of action or in contrast, it is more appropriate to avoid others. In summarized form, the result of Table 3 depicts that the fundamental decisions are appropriate strategy in future scenarios F1 and F4; while, the decisions related to the production processes are more efficient in F1 than other future scenarios. The sequence of decisions related to the distribution are the good ones in F2 and the decisions in the area of services are suitable actions for F3 and F4. By taking a deep look in Table 4, the results are totally different since of considering just one viewpoint during the comparison period which is commonly used in standard RA approach; in other words, neglecting desirability of different viewpoints will result to a superficial analysis. Since the proposed combined methodology of RA and DEA applied all different points of view, the results are more comprehensive and practical than the results of a conventional robustness analysis approach which considers desirability from just a single viewpoint such as Table 4; besides, the combined proposed model benefits from the more discriminatory power than conventional RA approach.

**Table 4:** Results of conventional RA

| Decisions | Future 1 | Future 2 | Future 3 | Future 4 |
|---|---|---|---|---|
| Fundamental | 0.625 | 0 | 0.25 | 0.625 |
| Production | 1 | 0.71 | 0.43 | 1 |
| Distribution | 0.43 | 0.86 | 0.28 | 1 |
| Services | 0.125 | 0.875 | 0.5 | 0.75 |

**Conclusion**

Rapid industrialization has led to severe environmental pollution, which has attracted considerable attention in recent years. The importance of this issue brings the need for practical decisions to be employed regarding environmental protection for future years. Thus, this study aims to help decision-makers in finding the best actions for diminishing the environmental pollution of the industrial cities such as Tehran within 10 future years. Complexity and the rapid changes of the future, lead researches to improve methods and tools for decision making and planning to fit it. Because of the unpredictable nature of the future, the Robustness Analysis (RA) is used for decision aiding. It is an approach that focuses on maintaining useful flexibility under uncertainty by considering single desirability/debility evaluation. But, in real-world messy problems, different perspectives should be considered in a problem-solving procedure, which is more than the standard RA capabilities, especially when various types of conflict may occur between the participants including managers, employees, customers, and environment and so on. During the decision making procedure, each participant considers the desirability/debility from its point of view which may be totally different from the others. Therefore, considering the desirability/undesirability of the decisions with just a single value, which is common in the standard RA approach, may result in an unrealistic analysis and consequently inappropriate results. In the case wherein the decision stage, conflicting perspective and a set of different values for the parameters of the model have to be taken into account, a concept like an efficiency could be used to select the candidates of robust solutions. In this regard, this paper suggests applying the Data Envelopment Analysis (DEA) to determine efficient robust solutions. Besides, since the decision making in an unpredictable future is the issue of this investigation, the combination of robustness analysis and data envelopment analysis is suggested for the first time in this paper. By means of this combination, the decision making in an uncertain future by considering all different viewpoints of problem participants in a simultaneous manner will be achievable.

consequently, this paper enables the ability to consider all participants' viewpoints concurrently during the desirability assessment and provide a comprehensive approach for decision making in an uncertain future which is more powerful than the standard robustness analysis approach based on the experimental results. The main difference of this research with those done in the area of just DEA or RA, is the ability to robust decision making in an uncertain future which is unavailable in standard DEA and the ability to consider all different viewpoints simultaneously which is unavailable in standard RA. For future study, a confluence between soft OR and soft computing methods is suggested because both methods try to add flexibility to the proposed solution of the real world's problem. In this regard, based on the uncertainty about the nature of the future, the inputs and outputs which are estimated by decision-makers in the data envelopment analysis method could be assigned by fuzzy sets which are mathematical means of representing vagueness and imprecise information and is able to handle the concept of uncertainty about the future more properly.

**References**


1. Bayat R *et al*. Health impact and related cost of ambient air pollution in Tehran. Environmental research,2019:176:108547.
2. Eker S, Kwakkel JH. Including robustness considerations in the search phase of Many-Objective Robust Decision Making. Environmental Modelling & Software,2018:105:201-216.
3. Rosenhead J, Mingers J. A new paradigm of analysis. Rational analysis for a problematic world revisited,2001:2:1-19.
4. Faridi S *et al*. Long-term trends and health impact of PM2. 5 and O3 in Tehran, Iran, 2006–2015. Environment international,2018:114:37-49.
5. Yang G, Zhang W, Zha D. Industrial production: Pursuing scale expansion or pollution reduction? Judgment based on the Copeland-Toylor model. Journal of cleaner production,2019:216:14-24.
6. Dong F *et al*. Can industrial agglomeration promote pollution agglomeration? Evidence from China. Journal of Cleaner Production,2020:246:118960.
7. Carlsson Kanyama A, Wikman-Svahn P, Mossberg Sonnek K. "We want to know where the line is": comparing current planning for future sea-level rise with three core principles of robust decision support approaches. Journal of Environmental Planning and Management,2019:62(8):1339-1358.
8. Ackoff RL. The art and science of mess management. Interfaces,1981:11(1):20-26.
9. Rittel HW, Webber MM. Dilemmas in a general theory of planning. Policy sciences,1973:4(2):155-169.
10. Elia G, Margherita A. Can we solve wicked problems? A conceptual framework and a collective intelligence system to support problem analysis and solution design for complex social issues. Technological Forecasting and Social Change,2018:133:279-286.
11. Herman JD *et al*. How should robustness be defined for water systems planning under change? Journal of Water Resources Planning and Management,2015:141(10):04015012.
12. Kwakkel JH, Haasnoot M, Walker WE. Comparing robust decision-making and dynamic adaptive policy pathways for model-based decision support under deep uncertainty. Environmental Modelling & Software,2016:86:168-183.
13. Thissen W *et al*. Dealing with uncertainties in fresh water supply: experiences in the Netherlands. Water resources management,2017:31(2):703-725.
14. Rosenhead J, Mingers J. Rational analysis for a problematic world revisited2001: John Wiley and Sons.
15. Eden, C., Cognitive mapping. European Journal of Operational Research,1988:36(1):1-13.
16. Eden C, Ackermann F. Making strategy: The journey of strategic management, 2013.
17. Checkland P. Soft systems methodology: a thirty year retrospective. Systems research and behavioral science,2000:17(S1):S11-S58.
18. Taket A. Planning Under Pressure: The Strategic Choice Approach (2nd edn). Journal of the Operational Research Society,1998:49(7):771-772.
19. Bennett P, Howard N. Rationality, emotion and preference change Drama-theoretic models of choice. European Journal of Operational Research,1996:92(3):603-614.

20. Smith CM, Shaw D. The characteristics of problem structuring methods: A literature review. European Journal of Operational Research,2019:274(2):403-416.
21. Namen AA, Bornstein CT, Rosenhead J. The Use of robustness analysis for planning actions in a poor Brazilian community. Pesquisa Operacional,2010:30(2):267-280.
22. Van der Heijden K. Scenarios: the art of strategic conversation2011: John Wiley & Sons.
23. Vidal RVV, Rosenhead J, Mingers J. *(E*ds.), Rational Analysis for a Problematic World Revisited, Problem Structuring Methods for Complexity, Uncertainty and Conflict, Wiley, Chichester, 2001, xviii+ 366 pages,@ $22.50. European Journal of Operational Research,2005:2(161):582-583.
24. Lempert RJ, Groves DG. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. Technological Forecasting and Social Change,2010:77(6):960-974.
25. Mosadeghi R *et al*. Uncertainty analysis in the application of multi-criteria decision-making methods in Australian strategic environmental decisions. Journal of Environmental Planning and Management,2013:56(8):1097-1124.
26. Marttunen M, Lienert J, Belton V. Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations. European Journal of Operational Research,2017:263(1):1-17.
27. Witt T, Dumeier M, Geldermann J. Combining scenario planning, energy system analysis, and multi-criteria analysis to develop and evaluate energy scenarios. Journal of Cleaner Production,2020:242:118414.
28. Liu JS, Lu LY, Lu WM. Research fronts in data envelopment analysis. Omega,2016:58:33-45.
29. Charnes A, Cooper WW, Rhodes E. Measuring the efficiency of decision making units. European journal of operational research,1978:2(6):429-444.
30. Emrouznejad A, Yang G. A survey and analysis of the first 40 years of scholarly literature in DEA,1978-20162017.
31. Driouchi T, Leseure M, Bennett D. A robustness framework for monitoring real options under uncertainty. Omega,2009:37(3):698-710.
32. Maier HR *et al*. An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? Environmental Modelling & Software,2016:81:154-164.
33. Mahmoud M *et al*. A formal framework for scenario development in support of environmental decision-making. Environmental Modelling & Software,2009:24(7):798-808.
34. Kotireddy R, Hoes PJ, Hensen JL A methodology for performance robustness assessment of low-energy buildings using scenario analysis. Applied energy,2018:212:428-442.
35. Cook WD. Qualitative data in DEA, in Handbook on Data Envelopment Analysis, 2011, 151-172.
36. Cook WD, Kress, and L.M. Seiford, On the use of ordinal data in data envelopment analysis. Journal of the Operational Research Society,1993:44(2):133-140.
37. Cook WD, Kress M, Seiford LM. Data envelopment analysis in the presence of both quantitative and qualitative factors. Journal of the operational research society,1996:47(7):945-953.
38. Cooper WW, Park KS, Yu G. *IDEA and AR-IDEA: Models for dealing with imprecise data in DEA.* Management science,1999:45(4):597-607.
39. Charnes A, Cooper WW. Programming with linear fractional functionals. Naval Research logistics quarterly,1962:9(3-4):181-186.
40. Banker RD, Charnes A, Cooper WW. *Some models for estimating technical and scale inefficiencies in data envelopment analysis.* Management science,1984:30(9):1078-1092.