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# A MULTIPLE CRITERIA ENERGY DECISION SUPPORT SYSTEM

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**Abstract.** Multiple Criteria Decision Analysis (MCDA) techniques are particularly suitable for Energy and Environment (E&E) decisions due to multiple criteria nature of these types of problems and they have been widely applied in this area. Main points that can be taken into consideration when examining the MCDA literature related to E&E are the selection of appropriate method, selection of criteria to be used and the widely distributed application areas. The motivation behind this study is designing such a Decision Support System (DSS) that enables the energy decision makers to perform analysis using different methods of MCDA and different criteria from various application areas and test the applicability of the system through an application in Turkish Energy Sector. The system includes several methods of MCDA and common parameters from previous studies in order to provide different approaches of evaluating decision problems. With this feature, the system stands on the intersection of MCDA and E&E fields. Moreover, an application of MCDA in Turkish Energy Sector has been performed to test the applicability of the system and some conclusions about electricity distribution in Turkey are put forth.

**Keywords:** Multiple Criteria Decision Analysis, Energy and Environment, Decision Support Systems, Electre, Promethee, Data Envelopment Analysis.

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## 1. Theoretical Background

The oil crisis of the 1970s has served to emphasize the fact that conventional energy resources are depletable and that their use is constrained by many economic, technical and political factors (Diakoulaki *et al.* 1999). Since then, planning has become a more important issue for energy practitioners in order to diminish the effects of rising prices and manage the scarcity. After 1980s, a rising awareness on environmental issues added to this frame as a consequence of massive energy production. In other words, managing the energy production and consumption became an important issue and a source of a concern for the environment. Environmental concerns also yielded to a need for planning in energy sector.

Main issues in energy sector can be divided into macro and micro level problems. There exists extensive research in both levels. Macro level issues related studies can be listed as: energy policy analysis studies (Diakoulaki *et al.* 1999; Georgopoulou *et al.* 1997; Wang and Feng 2002; Kalu 1998), environmental policy analysis studies (Hobbs *et al.* 1997; Georgopoulou *et al.* 2003; Loulou and Kanudia 1999; Vaillancourt and Waaub 2004) and energy investment planning studies (Mills *et al.* 1996; Linares 2002; Voropai and Ivanova 2002). On the other hand, micro level issues related studies can be listed as; energy technology choice studies (Goumas *et al.* 1999; Haralambopoulos and Polatidis 2003; Beccali *et al.* 2003), energy utility operations and management studies (Dunning *et al.* 2001; Dargam and Perz 1998; Pan *et al.* 2000) and energy-related environmental control and management studies (Hokkanen and Salminen 1997; Lahdelma *et al.* 2002; Salminen *et al.* 1998; Ramanathan 2001).

Abovementioned issues are all related to planning. Parallel to the planning needs in the sector, the interest on Energy and Environment (E&E) in the academic world increased. E&E studies have gained an increasing popularity in various research areas, as well as in Operational Research (OR). A variety of techniques have been implemented on many energy and environment related issues since 1970s. One of the areas of Operational Research that E&E studies have been conducted is the Decision Analysis (DA). As mentioned by Zhou *et al.* (2006), E&E issues are generally complex and conflict with multiple objectives and they usually involve many sources of uncertainty, long time frame, capital intensive investment and a large number of stakeholders with different views and preferences, which make the application of DA methods particularly suitable.

Multiple Criteria Decision Analysis (MCDA) is one of the well-known branches of Decision Analysis in Operational Research. MCDA deals with conflicting decision problems under the evaluation of several criteria. MCDA techniques have been widely applied throughout different industries, including public and private sectors. Some recent applications can be found in (Ginevicius and Podvezko 2009; Šliogeriene *et al.* 2009; Arslan and Aydin 2009; Brauers and Zavadskas 2009; Zavadskas *et al.* 2010a, b). MCDA is particularly suitable for energy and environment decisions due to multiple criteria nature of these types of problems. Main points that can be taken into consideration in use of MCDA techniques in E&E are the selection of appropriate method, selection of criteria to be used and the widely distributed application areas.

A variety of MCDA methods exists in the literature that can be used for various purposes such as choosing, ranking, sorting or describing. The decision maker usually decides which method to be used by taking the nature of the problem into consideration. In method selection, the suitability, validity and user-friendliness of the methods are the important factors to be considered (Loken 2007). As a natural result of this, for E&E problems, it can be meaningful to apply more than one method or combination of methods in order to reach a broader decision basis. Application of more than one method can provide decision makers different perspectives and an opportunity to compare results so that a more appropriate final decision can be made. In addition, applying combination of methods such as using output obtained through one method as an input in applying the other method can decrease the level of uncertainty and can yield to more robust decisions.

In addition to method selection, the choice of criteria in applying MCDA methods to E&E problems is another important issue. A literature survey on energy decision making by Wang *et al.* (2009) focuses on criteria selection in MCDA applications of E&E. The study analyses more than 50 works and lists a variety of common criteria. These criteria can be mainly grouped into four classes as technical, economic, environmental and social criteria (Wang *et al*. 2009). Although, some problems may require specific criteria depending on the nature of the problem, generally, there is a consistency and similarity in used criteria throughout many studies of decision analysis in E&E. Acquiring such a list of common criteria through the decision making process can be guiding for decision makers in making criteria selection of their own problems.

Another point to be mentioned about MCDA studies of E&E is the application areas which are widely distributed on many subjects of E&E. The study by Corner and Kirkwood (1991) lists 86 DA studies from 1970 to 1989. In a more recent study, Keefer *et al.* (2004) surveyed 85 articles appearing in 1990–2001. Pohekar and Ramachandran (2004) reviewed more than 90 MCDA studies in sustainable energy planning in 2004. Zhou *et al.* (2006) classified a total of 252 studies of decision analysis studies in E&E published from 1975 to 2004. According to Zhou *et al.* (2006), the majority of decision analysis studies (165 out of 252) in E&E are using MCDA methodologies.

In addition to MCDA methodologies, performance evaluation techniques such as Data Envelopment Analysis (DEA) and its variations are also widely applied in E&E. DEA can be treated as a particular MCDA method and it can also be taken into consideration when examining MCDA literature in E&E. Taking DEA as a separate field of study, Zhou *et al.* (2007) listed 100 publications on DEA in E&E subjects. Trading upon studies of Zhou *et al.* in 2006 on decision analysis and in 2007 on DEA, application areas of MCDA and DEA are provided in Table 1. As seen in Table 1, energy policy analysis and energy-related environmental studies are the most popular application areas of MCDA in E&E with percentages of 31% and 24%, respectively. In DEA side, electricity sector studies (both distribution and generation) have the percentage of 37%, sharing the top with environmental studies.

**Table 1.** Studies of MCDA and DEA in E&E

| MCDA | # of Studies | % | DEA | # of Studies | % |
|---|---|---|---|---|---|
| Energy policy analysis | 51 | 31 | Electricity distribution | 20 | 20 |
| Electricity power planning | 23 | 14 | Electricity generation | 17 | 17 |
| Technology choice and project appraisal | 20 | 12 | Energy efficiency study | 6 | 6 |
| Energy utility operations | 28 | 17 | Environmental Studies | 37 | 37 |
| Energy-related environmental studies | 40 | 24 | Other | 20 | 20 |
| Other | 3 | 2 | | | |
| Total | 165 | | Total | 100 | |

As mentioned earlier, selection of appropriate method, selection of criteria to be used and the various application areas can be considered as main points to be reviewed when examining the MCDA literature in E&E. When all these points are examined in detail, a need for a Decision Support System (DSS) that will enable the energy decision makers to perform analysis using different methods of MCDA and different criteria from various application areas is put forth. A DSS refer to any interactive, flexible and adaptable software systems that integrate models, databases and other decision analysis tools, and package them in a way that decision makers can use (Zhou *et al.* 2006).

The motivation behind this study is designing a system and test the applicability of the system through an illustrative application in Turkish Energy Sector. The first aim is to design the system such that it enables the user to apply more than one technique in order to compare results obtained from different methods. Second aim is to include contributing methods such as combined use of techniques in the system. Thirdly, we aim to create a database consisting of different criteria from different application areas in order to guide the users see and use the common criteria from the literature of MCDA in E&E.

From our discussions with the practitioners of the Energy industry in Turkey, we come up with the conclusion that the decisions about investments are mostly based on simple weighted scoring techniques. The evaluation report of Turkish Energy Sector by World Energy Council Turkish National Committee (2007) strongly states that one of the main problems of the sector is the lack of effective planning based on right and real data. Taking this argument into account, in addition to our primary aim to build a MCDA energy decision support system, we also aim to test this system through various Turkish Energy Sector applications in order to provide insight about the use of analytical decision making and performance evaluation techniques in energy decisions. For this reason, we perform an illustrative application in Turkish Energy Sector both for testing the applicability of our system and bring out contributions in the use of MCDA in Turkish Energy Sector.

The organization of the paper is as follows: The second section gives the structure and main components of our Energy Decision Support System. In this section, techniques that take place in the system are also reviewed briefly. In the third section, an illustrative example application is provided in detail. The final section discusses the conclusions and possible further research directions.

## 2. Main Components of the Energy Decision Support System

The Energy Decision Support System (EDSS) has been built using Microsoft Office Excel together with Visual Basic for Applications (VBA) programming language. EDSS consists of 4 main components; a model base involving various techniques of MCDA, a criteria database covering commonly used inputs, outputs and criteria in energy problems, a report interface standardizing the result reports and a user interface gathering necessary inputs and parameters from the user. The components of the EDSS are summarized with their subcomponents in Figure 1. In the following subsections we discuss the main components of the EDSS.

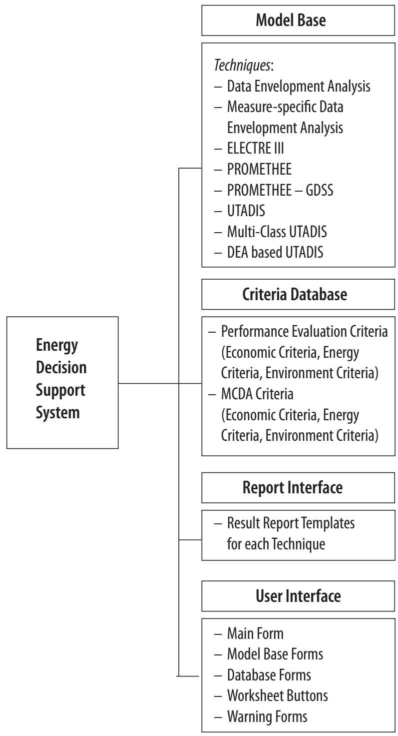


**Fig. 1.** Main Components of EDSS

### 2.1. Model Base

The building of the system starts with programming the various techniques of Performance Evaluation and Multiple Criteria Decision Analysis (MCDA). These efforts constitute the first component of the system; the model base. The model base includes DEA (Data Envelopment Analysis) and its variation Measure-specific DEA as performance evaluation component. For MCDA component, we included ELECTRE (Elimination and Choice Translating Reality), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation), PROMETHEE-GDSS (Group Decision Support System) and UTADIS (Utilities Additives Discriminantes) techniques. Also, two novel approaches are proposed related to the UTADIS and DEA techniques; Multi-Class UTADIS and DEA based UTADIS. Both approaches are also included in the model base.

#### 2.1.1. Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a non-parametric approach for identifying relative efficiency of "Decision Making Units" (DMUs) when there are multiple inputs and outputs (Farrell 1957; Charnes *et al.* 1978; Fare *et al.* 1985). Built upon the earlier work of Farrell (1957) and presented by Charnes *et al.* (1978), DEA is a well established methodology to evaluate the relative efficiencies of a set of comparable entities by some specific mathematical programming models (Zhou 2007). DEA identifies the best-practice frontier of the DMUs, and measures the relative efficiency scores of the less efficient DMUs in relation to the frontier. Also, the technique enables us to assess where the inefficiencies arise and identify target values for DMUs to reach the best-practice frontier. An advantage of DEA is that it does not require specification of a production or cost function (Jamasb and Pollitt 2001). Generally, DEA models can be input or output oriented and Constant or Variable Returns to Scale. In input oriented models, inputs are minimized and outputs are kept their current levels, efficiency scores are between 0-1 and the target values are obtained for inputs. In output oriented models, outputs are maximized and inputs are kept their current levels, efficiency scores are between 1-∞ and the target values are obtained for outputs. In constant returns to scale the best-practice frontier has a line shape, whereas in variable returns to scale models the frontier has a piecewise linear shape. In general, mathematical formulation of input-oriented DEA linear programming model is as follows (Zhu 2002):

$$\begin{aligned} &\text{Min } \theta, \\ &\text{s.t:} \\ &\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io} \qquad i = 1,2,\ldots,m, \\ &\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro} \qquad r = 1,2,\ldots,s, \\ &\sum_{j=1}^{n} \lambda_j \ge 0 \qquad j = 1,2,\ldots,n. \end{aligned} \tag{1}$$

In this model, we have $n$ Decision Making Units, $m$ inputs and $s$ outputs. $x_{ij}$ represents input value and $y_{rj}$ represents output value of a specific unit ($DMU_j$). $\lambda_j$ values are non-negative scalars and the decision variables of the model. The model is run by taking each DMU under evaluation where $x_{io}$ and $y_{ro}$ values represent the input and output values of DMU under evaluation, respectively. The efficiency score for the DMU under evaluation is represented by θ. Above model assumes Constant Returns to Scale, to model it as a Variable Returns to Scale DEA model a convexity constraint which equalizes the sum of $\lambda_j$ values to 1 can be added to the model.

In standard DEA models, target values for inefficient DMUs are in terms of progress in all inputs or all outputs. In some cases, it may be impossible for a DMU to improve all of the inputs or outputs at the same time. For these kinds of situations, a variation of DEA; measure-specific DEA proposed by Zhu (2002) can be used. Measure-specific models take sets of specific inputs or outputs of interest and give the target values for only those factors. The use of these models can be appropriate for the situations where only one or some of the inputs or outputs can be intervened. The DEA model taking any input of interest can be formulated as is following linear programming model (Zhu 2002).

In this model, some inputs are taken of interest and formulation made accordingly. For the inputs that are not of our interest the right hand side value does not include the θ coefficient (the second constraint). In a similar manner with standard DEA models, to obtain a VRS model, we simply add the convexity constraint that equalizes the sum of $\lambda_j$ values to 1.

$$
\begin{aligned}
&\text{Min } \theta,\\
&\text{s.t:}\\
&\sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{io} \qquad i \in I,\\
&\sum_{j=1}^{n} \lambda_j x_{ij} \le x_{io} \qquad i \notin I,\\
&\sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro} \qquad r = 1,2,\ldots,s,\\
&\sum_{j=1}^{n} \lambda_j \ge 0 \quad j = 1,2,\ldots,n.
\end{aligned} \tag{2}
$$

Among the wide spectrum of Energy & Environment (E&E) modelling techniques, DEA has attracted a high level of attention. Along with the wave of deregulation in energy sectors since the late 1980s, DEA has been accepted as a major frontier technique for benchmarking energy sectors in many countries, particularly in the electricity industry (Jamasb and Pollitt 2001; Abbott 2005). Zhou *et al.* (2007) listed more than 100 studies in the field of E&E performed using DEA and its related techniques.

### 2.1.2. Elimination and Choice Translating Reality (ELECTRE)

One of the Multiple Criteria Decision Analysis (MCDA) techniques included in our model base is the Elimination and Choice Translating Reality (ELECTRE) method rooted from the study by Benayoun *et al.* (1966) and presented by Roy (1968). The technique evolved overtime and currently we can mention 7 types of ELECTRE models used for choosing, ranking or sorting purposes. ELECTRE I, ELECTRE Iv and ELECTRE IS are variations of ELECTRE used for choosing among alternatives. ELECTRE II, ELECTRE III and ELECTRE IV are used for ranking purposes. Finally, ELECTRE TRI is a member of ELECTRE family aiming to sort alternatives (Figueira *et al.* 2005). ELECTRE methods are commonly used in many E&E issues mainly in energy planning and project selection. Some examples are the studies of Karagiannidis and Moussiopoulos (1997), Hokkanen and Salminen (1997), Rogers and Bruen (1998) and Beccali *et al.* (2003). Among different types of ELECTRE method, we include ELECTRE III which is used commonly as a ranking tool especially in project selection.

In general, multiple criteria decision problems have an alternative set as $A = (a, b, \ldots n)$ and a criteria set as $G = (g_1, g_2, \ldots g_m)$. The term $g_j(a_i)$ refers to the criteria value of alternative $a_i$ with respect to criteria $g_j$. In ELECTRE III, we have three types of thresholds associated with each criteria to be used in pairwise comparisons: preference threshold $p_j(g_j(*))$, indifference threshold $q_j(g_j(*))$ and veto threshold $v_j(g_j(*))$. These thresholds may be simple numerical constants or they may be functions of the level of performance of one of the options being compared. To use the model these thresholds must be determined by the decision makers for all criteria as well as with the importance ratings (weights) for each of the criteria. Once threshold and weight values are decided, the concordance index $c(a, b)$ is computed with the following function for each pair $(a, b)$ of alternatives according to each criteria.

$$c_j(a,b)=\begin{cases}1, \text{ if } & g_j(a)+q_j(g_j(a))\geq g_j(b),\\ 0, \text{ if } & g_j(a)+p_j(g_j(a))\leq g_j(b),\\ \dfrac{g_j(a)-g_j(b)+p_j(g_j(a))}{p_j(g_j(a))-q_j(g_j(a))}, & \text{otherwise.}\end{cases} \tag{3}$$

This is based on a general comparison of the performances of alternative *a* and alternative *b* over all the criteria. Preference and indifference thresholds decided earlier are used here for comparisons. As a result, we obtain *m* number of $n\times n$ size matrices. After obtaining concordance matrices, we calculate a cumulative concordance matrix which is a kind of combination of concordance matrices according to each criterion by taking the weights of the criteria into account.

$$C(a,b)=\frac{1}{W}\sum_{j=1}^{n} w_j c_j(a,b) \text{ where } W=\sum_{j=1}^{n} w_j . \tag{4}$$

The cumulative concordance matrix is a $n\times n$ size matrix with the values between 0 and 1. A value of 0 indicating that alternative *a* is worse than alternative *b* for all criteria and a value of 1 indicating that there is no criterion for which *b* is better than *a*. It is made up from a weighted comparison of the performances over each criterion taken individually, *cj*(*a*, *b*). After cumulative concordance matrix is constructed, in a similar manner, but this time using the veto thresholds instead of indifference thresholds, the disconcordance matrix is constructed through following function:

$$D_j(a,b)=\begin{cases}0, \text{ if } & g_j(b)\leq g_j(a)+p_j(g_j(a)),\\ 1, \text{ if } & g_j(b)\geq g_j(a)+v_j(g_j(a)),\\ \dfrac{g_j(b)-g_j(a)-p_j(g_j(a))}{v_j(g_j(a))-p_j(g_j(a))}, & \text{otherwise.}\end{cases} \tag{5}$$

The essence of discordance is that any outranking of *b* by *a* indicated by the concordance index can be overruled if there is any criterion for which alternative *b* outperforms alternative *a* by at least the veto threshold. Even if option *a* is better than option *b* generally, there may be some criteria (possibly only one) for which alternative *a* is so much worse than alternative *b* that it moderates any overall preference for alternative *a*. If so, then the discordance index for that criterion reflects this. It can have a value from 0 to 1. A value 0 indicates that alternative *b* is not better than alternative *a* by more than the preference threshold, and a value 1 indicates that alternative *b* is better than alternative *a* by a margin greater than the veto threshold. By using cumulative concordance and disconcordance matrices, a final matrix, the credibility matrix is obtained using the function below:

$$S(a,b)=\begin{cases}C(a,b), \text{ if } & D_j(a,b)\leq C(a,b), \forall j\\ C(a,b)\displaystyle\prod_{j\in J(a,b)}\frac{1-D_j(a,b)}{1-C(a,b)}, & \text{otherwise.}\end{cases} \tag{6}$$

$J(a, b)$ set represents the set of criteria for which $D_j(a, b) > C(a, b)$. Credibility matrix is a $n \times n$ size matrix obtained through concordance and disconcordance matrices. After constructing the credibility matrix, as a final step, by using two kinds of distillation processes (upward and downward distillations), two rankings are obtained as ascending and descending rankings. The full ranking of the alternatives are obtained through intersecting above two rankings (Rogers 2000).

#### 2.1.3. Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) is developed by J. P. Brans in 1982 and presented in 1986 (Brans *et al.* 1986). A considerable number of successful applications have been treated by the PROMETHEE methodology in various fields such as Banking, Industrial Location, Manpower Planning, Water Resources, Investments, Medicine, Chemistry, Healthcare, Tourism as well as Energy and Environment (Brans and Mareschal 2005). In our model base, we include two basic types of PROMETHEE technique used for ranking of alternatives; PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking). Also a special type of PROMETHEE technique for group decision making; PROMETHEE-GDSS (Group Decision Support System) proposed by Macharis *et al.* (1998) is included in our model base.

In PROMETHEE technique, ranking of alternatives is obtained through pairwise comparison according to function types chosen for each criteria. Each function type has a particular parameter and a partial function to obtain the pairwise comparison matrices. For each criterion, a specific preference function must be defined which is used to compute the degree of preference associated with the best alternative in the case of pairwise comparisons. Six types of generalized criterion functions have been suggested by Brans *et al.* (1986) for delimiting the indifference and preference area.

In the mathematical model for PROMETHEE technique, first, the function types for the criteria, parameter values and weights for the criteria are decided by the decision maker. Then, every alternative are compared with other alternatives with respect to each criteria using the following function:

$$P_j(a,b) = \begin{cases} 0, \ g_j(a) \le g_j(b), \\ p(g_j(a) - g_j(b)), \ g_j(a) > g_j(b). \end{cases} \quad (7)$$

Using pairwise comparison matrices, a cumulative π matrix which is a $n \times n$ size matrix is obtained through the following function:

$$\pi(a,b) = \sum_{j=1}^{m} w_j P_j(a,b). \quad (8)$$

As a next step, Positive and Negative preference indices are calculated by simply adding the values in the π matrix:

$$\Phi^+(a) = \sum \pi(a,x) \qquad x = b,c,d,....n, \quad (9)$$

$$\Phi^-(a) = \sum \pi(x,a) \quad x = b,c,d,....n. \quad (10)$$

By making comparisons between $\Phi^+$ and $\Phi^-$ values of alternatives a partial ranking is obtained (PROMETHEE I) Full ranking is obtained through calculation of $\Phi$ score through (PROMETHEE II):

$$\Phi(a) = \Phi^+(a) - \Phi^-(a). \tag{11}$$

With PROMETHEE I, a partial ranking of alternatives is obtained (in partial ranking some alternatives may be incomparable with each other).With PROMETHEE II, a full ranking of the alternatives is obtained through calculating a net score for each alternative (Brans and Mareschal 2005).

### 2.1.4. Utilities Additives Discriminantes (UTADIS)

The last MCDA technique in our model base is a sorting technique, Utilities Additives Discriminantes (UTADIS) which is rooted from the study by Devaud *et al.* (1980) and progressed in the studies of Jacquet-Lagreze and Siskos (1982) and Jacquet-Lagreze (1995). The method is aimed at developing an additive utility model for the classification of a set of alternatives in predefined homogeneous classes with minimum classification error (Diakoulaki *et al.* 1999) Compared to other sorting MCDA methodologies; UTADIS has the strength of requiring minimal information. The method does not require any information regarding the weights, the existing trade-offs, or difference, indifference and veto thresholds. Instead, only a predefined classification of a reference set of alternatives is needed (Zopounidis and Doumpos 1999). The UTADIS method is developed for the sorting/classification of a finite set of alternatives into predefined homogenous ordered groups. This classification is obtained by constructing an additive utility function and utility thresholds, such that all alternatives are assigned to classes with minimum classification error. Estimations of the additive utility function weights and utility thresholds are obtained through the solution of a linear programming model. The linear programming model of UTADIS technique is given below (Zopounidis and Doumpos 1999):

$$\text{Min } F = \sum_{a \in C_1} \sigma^+(a) + \ldots + \sum_{a \in C_k} \left[\sigma^+(a) + \sigma^-(a)\right] + \ldots + \sum_{a \in C_Q} \sigma^-(a), \text{ s.t:}$$

$$\begin{gathered}
\sum_{i=1}^{m} u_i\left[g_i(a)\right] - u_1 + \sigma^+(a) \geq 0 \quad \forall a \in C_1, \\
\sum_{i=1}^{m} u_i\left[g_i(a)\right] - u_{k-1} - \sigma^-(a) \leq -\delta \quad \forall a \in C_k, \\
\sum_{i=1}^{m} u_i\left[g_i(a)\right] - u_k + \sigma^+(a) \geq 0 \quad \forall a \in C_k, \\
\sum_{i=1}^{m} u_i\left[g_i(a)\right] - u_{Q-1} - \sigma^-(a) \leq -\delta \quad \forall a \in C_Q, \\
\sum_{i=1}^{m} \sum_{j=1}^{a_i - 1} w_{ij} = 1, \\
u_{k-1} - u_k \geq s \qquad k = 2,3....,Q-1, \\
w_{ij} \geq 0,\ \sigma^+ \geq 0,\ \sigma^- \geq 0.
\end{gathered} \tag{12}$$

Objective function of the model minimizes the sum of all the misclassification errors. Furthermore, $h_k$ represents the number of alternatives in class $c_k$. First 4 constraints compare each utility $U(x_i)$ with the corresponding utility thresholds $u_k$ and defines the classification errors $\sigma^+(x_i)$ and $\sigma^-(x_i)$.$\delta_1$ and $\delta_2$ are small positive numbers, used to prevent the $U(x_i) = u_k$ equality. Normalization constraint guarantees the $U(x^*) = 1$. $\gamma$ is a small positive number and provides that threshold $u_{k+1}$ is greater than $u_k$. This optimization model determines the values of three variable groups, namely; alternative utilities $U(x_i)$, criterion weights $\mu_j$, and the utility thresholds $u_k$.

In addition to standard UTADIS methodology, in our system, we propose two new approaches based on the use of UTADIS technique. The first approach named as Multiple Classification Criteria UTADIS (MCC UTADIS) designed in a way that the model can handle more than one classification criteria simultaneously which possibly involves different predefined classes for alternatives and it brings a goal programming approach to the technique. In the second approach, named as DEA based UTADIS in our system, we propose to use DEA to obtain a predefined classification. In the model, a set of alternatives firstly evaluated with DEA using some inputs and outputs identified by user and a classification is obtained as the efficient alternatives are assigned to class 1 and the remaining alternatives are assigned to class 2. Then, the model uses this classification obtained through DEA as predefined classification for UTADIS analysis with criteria again identified by the user.

### 2.2. Criteria Database

The second main component of EDSS is the criteria database consisting of commonly used inputs and outputs in performance evaluation with DEA studies and criteria in MCDA studies dealing with energy and environment issues. The database is formed by examining the Energy and Environment (E&E) studies of performance evaluation and MCDA in the literature.

The criteria database consists of two types of parameters. The performance evaluation part includes common input-outputs used in the performance evaluation with DEA studies of E&E. In the MCDA part, commonly used criteria in MCDA studies of E&E literature take place. This part involves various types of criteria that can be grouped into three main types; economic criteria, energy criteria and environment criteria. Various forms are designed in the user interface in order to enable the user to select from these parameters and include in the analysis. Tables 2 and 3 provide some examples of parameters included in performance evaluation database and MCDA database, respectively. As shown in Table 2, DSS can also handle undesirable outputs such as $CO_2$, $SO_2$ emissions.

As seen in Table 2, some of the inputs and outputs are economic parameters such as capital, labour, GDP, Sales, Value added, units sold; whereas there are technical energy parameters such as fuel consumption installed capacity, system losses, number of transformers, generated power. In addition, environmental parameters such as amount of waste, $CO_2$ and $SO_2$ emissions take place as outputs in the database.

**Table 2.** Examples of Inputs and Outputs in Criteria Database

| Commonly Used in Electricity Industry Applications | | Commonly Used in Energy Efficiency Evaluation | |
|---|---|---|---|
| **Inputs:**<br>– Capital<br>– Fuel Consumption<br>– Installed Capacity<br>– Labour<br>– Maximum Demand<br>– Network Size<br>– Operational Expenses<br>– Service Area<br>– System Losses<br>– Transformer Capacity | **Outputs:**<br>– Amount of waste<br>– CO2 Emission<br>– SO2 Emission<br>– Generated Power<br>– Number of Customers<br>– Number of Transformers<br>– Units Sold | **Inputs:**<br>– Capital<br>– Electricity Consumption<br>– Employees<br>– Energy Consumption<br>– Gas Consumption<br>– Labour<br>– Population<br>– Water Consumption | **Outputs:**<br>– Annual Revenue<br>– GDP<br>– Number of Customers<br>– Production<br>– Sales<br>– Value Added |

**Table 3.** Examples of Criteria in the Criteria Database

| Economic Criteria | Energy Criteria | Environment Criteria |
|---|---|---|
| – Contribution to Employment<br>– Customer Satisfaction<br>– Economic Risks<br>– Investment Cost<br>– Land Use<br>– Maintenance Cost<br>– Net Present Value<br>– Number of Employees<br>– Profitability<br>– Return on Investment<br>– Revenues | – Electricity Consumption<br>– Energy Consumption<br>– Energy Production<br>– Energy Saving<br>– Gas Consumption<br>– Fuel Consumption<br>– Installed Power<br>– Security | – Air Pollution<br>– Convenience with Regulations<br>– Environmental Risks<br>– Gas Emission<br>– Impact on Ecosystems<br>– Impact on Environment<br>– Impact on Health<br>– Waste |

Table 3 provides some criteria from our database commonly used in the MCDA studies dealing with problems in the areas such as energy policy analysis, electric power planning, technology choice and project appraisal or energy-related environmental issues. As seen in Table 3, there are economic, energy and environment criteria. Also, it can be observed from the same table that some of the criteria are quantitative such as investment cost, installed power or gas emission; whereas some of them are qualitative especially in environmental criteria such as convenience with regulations, environmental risks or impact on environment.

### 2.3. Report Interface

An important point in building a decision support system is reporting the results. For this purpose, we aim to design a report interface in a manner that results of the analyses can easily be interpreted, compared with each other and exported from the system. Building of report interface includes the efforts to establish a standardized format for result reports.

In our standardized result report format, firstly the input parameters such as technique, number of criteria, number of alternatives, type of the analysis, etc. are summarized. The second part of the result reports include the outputs obtained through the analysis. This part differs according to technique used. For example, DEA the result report includes efficiency scores and target values for DMUs whereas the ELECTRE III result report includes the ranking of alternatives. Table 4 summarizes the given information in the result reports for each technique.

**Table 4.** Result Report Information for Each Technique in EDSS

| Technique | Items in the Result Report |
|---|---|
| Data Envelopment Analysis & Measure-specific DEA | – Efficiency scores for DMUs<br>– Target Values for DMUs to be efficient |
| ELECTRE III | – Descending order of alternatives<br>– Ascending order of alternatives |
| PROMETHEE & PROMETHEE-GDSS | – Positive outranking scores for alternatives<br>– Negative outranking scores for alternatives<br>– Net outranking scores for alternatives (Complete Ranking) |
| UTADIS & MCC UTADIS | – Classes of alternatives<br>– Global utility scores for alternatives<br>– Error values for alternatives<br>– Utility thresholds<br>– Weights of criteria |

### 2.4. User Interface

User interface consists of many types of forms that obtain necessary information from the user. The system starts with a main form from which the user selects the technique used and the method of the analysis (whether a new analysis or the use of templates).

Model base forms are the forms gathering parameter values from the user and specified for each technique in the model base. For each technique, forms are designed to obtain necessary parameter values specified to the technique.

The second type of the forms in our user interface is the database forms from which the user selects some items from the database if the templates mode of the system is selected to be used. The database forms are specified to each problem type. In performance evaluation forms, user selects from inputs and outputs from the database consisting of commonly used ones. Similarly, in MCDA database form, there are commonly used criteria in energy problems listed and the user makes selection among these criteria. Also, the inputs, outputs or criteria which do not included in database can be added to the analysis by simply selecting "Add New" option. Forms of different type can be seen in the illustrative application with UTADIS technique in Turkish Energy Sector in Appendix.

In addition to the model base forms and database forms, the user interface includes a set of Microsoft Office Excel Worksheet buttons and various types of warning forms. The buttons in the Microsoft Office Excel Worksheet enable user to perform actions such as running the analysis, clearing the analysis and starting a new analysis. Warning forms activate if there is a missing parameter or if an irrelevant type of value is entered to a form.

### 2.5. Structure of EDSS

The structure of the system is given in Figure 2. First of all, user makes a selection among various techniques. Secondly, two alternative methods of analysis can be selected; either a new analysis or the use of templates. If the use of templates is selected, the user reaches the criteria database of the system and uses the criteria from the database depending on the type of the problem. In new analysis option, the user is free to enter own criteria and can make analysis using selected technique. After the user enters the model parameters, an appropriate Microsoft Office Excel Worksheet is prepared by the system for inputting the data. When the users input the appropriate datasets, the system performs the analysis through the selected technique and provides a result report including the necessary result information. In the following section, we include an application in Turkish Energy Sector using the UTADIS technique to provide a better understanding of how EDSS works.

## 3. An Illustrative Application with Energy Decision Support System

In this section, we present an illustrative application using our proposed EDSS. This example is a modified version of the application in Ulucan and Atici (2009). We evaluate the Turkish electricity distribution companies with respect to system losses during electricity distribution. In this application, UTADIS technique is used to identify the explanation ability of various criteria over system losses.

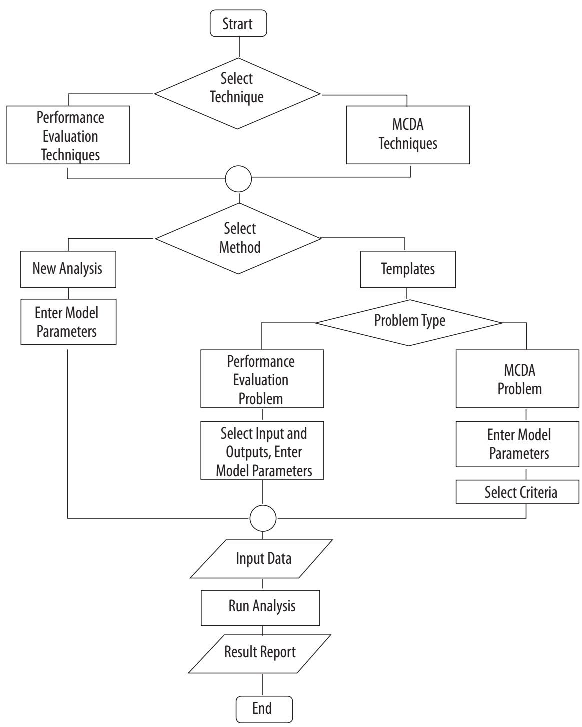


**Fig. 2.** The Structure of EDSS

In Turkey, state-owned TEDAS is the main distribution organization and operates in 20 provinces. A major problem in the distribution sector is the losses of electricity. Electricity losses are 15.5% of generation which is more than twice of 7.3% OECD average in 2006.

The system loss in electricity distribution is viewed as a combination of technical and non-technical losses. Technical loss is related to the physical characteristics and functions of the electrical network. On the other hand, non-technical loss is the electricity lost generally through theft or pilferage in the process of distributing power.

Non technical system losses in 20 Turkish regions for 2006 are illustrated in Table 5. Non-technical losses are generally highest in the under developed and rural provinces. The significant differences between provinces with respect to system losses allow us to divide provincial companies into three discrete classes. Companies with less than 9% system loss are considered as Class 1, companies with a loss value between 9% and 20% are considered as Class 2 and finally, companies with loss values greater than 20% are the Class 3 alternatives. **Table 5.** System losses in 20 Turkish regions (Source: www.tedas.gov.tr)

**Table 5.** System Losses in 20 Turkish Regions (Source: www.tedas.gov.tr)

| Electricity Distribution Company | System Losses (%) | Predefined Classification with Respect to System Losses |
|---|---|---|
| GEDIZ | 6.48 | 1 |
| MENDERES | 7.11 | 1 |
| OSMANGAZI | 7.24 | 1 |
| MERAM | 7.83 | 1 |
| CAMLIBEL | 8.55 | 1 |
| ULUDAG | 8.81 | 1 |
| AKDENIZ | 8.87 | 1 |
| GOKSU | 9.33 | 2 |
| TRAKYA | 9.34 | 2 |
| YESILIRMAK | 9.47 | 2 |
| BASKENT | 9.56 | 2 |
| SAKARYA | 10.12 | 2 |
| AYEDAS | 10.24 | 2 |
| TOROSLAR | 10.85 | 2 |
| FIRAT | 11.68 | 2 |
| BOGAZICI | 12.25 | 2 |
| CORUH | 12.27 | 2 |
| ARAS | 29.42 | 3 |
| DICLE | 57.76 | 3 |
| VANGOLU | 63.83 | 3 |

The problem considered in this application is assignment of 20 electricity distribution companies into predefined 3 system loss classes by evaluating them along a set of 7 criteria. In order to perform this assignment, we use UTADIS MCDA methodology. The UTADIS approach develops an additive utility function based scores of the electricity distribution companies and determine their classification with respect to system losses. The previously given linear programming model of this methodology (see Section 2.1.4), determines the values of three variable groups, namely; electricity distribution companies' utility scores ($U(x_i)$), criterion weights, and the utility thresholds ($u_k$), between system loss classes. The boundaries of the model based classes are formed by these utility thresholds. On the other hand, weight for each criterion represents the explanation power of this criterion on system losses.

Table 6 presents a list of the evaluation criteria used in the analysis. UTADIS requires characteristics of every criterion (Maximum or Minimum). "Maximum" represents higher values of that criterion are favoured; whereas "Minimum" means the opposite. Service Area shows the number of villages in each electricity distribution province. Second criterion represents the number of employees in each electricity distribution company. Number of beneficiaries who have the electricity service in each province is represented as a third criterion. In order to take into account the size of the network in each province in terms of kilometres, fourth criterion is used. Yearly electricity distribution expenditures in each province are used as fifth criterion. Moreover, electricity distribution in terms of Megawatt per hour (MWh) is taken as another criterion. The data of the abovementioned criteria is obtained from TEDAS for the year 2006. On the other hand, due to high system losses in the under developed and rural areas, we add per capita GDP in each region as another criteria. We obtain the data of this criterion from Turkish Statistical Institution. Unfortunately, latest available period for this data for provinces was 2001. Although the actual values of this criterion are probably higher for 2006, we assume the changes in provinces are almost proportional.

**Table 6.** Evaluation Criteria

| ID | Evaluation Criteria | Unit | Characteristic |
|---|---|---|---|
| G1 | Service Area | No of Villages | Max |
| G2 | Employees | Number of | Max |
| G3 | Customers | Number of | Max |
| G4 | Network Size | Km. | Max |
| G5 | Expenditures | TL | Min |
| G6 | Electricity Distribution | MWh | Max |
| G7 | Per capita GDP | USD | Max |

Table 7 shows the data for each of the electricity distribution company in province level. In this illustrative application, we aim to describe how our system operates. The main steps of this application with corresponding screenshots of the EDSS are given in the Appendix. We also provided a brief interpretation for the results obtained through our analysis in EDSS further in this section.

The results obtained through the application of the UTADIS method are shown in Table 8. The global utility scores of the electricity distribution companies, utility threshold values and company classifications based on these results are illustrated in the table. Table 8 also includes the predefined classes of electricity distribution companies for comparative purposes.

**Table 7.** The Data for Each of the Electricity Distribution Company in Province Level

| Electricity Distribution Company | Service Area | Number of Employees | Number of Customers | Network Size | Expenditures | Electricity Distribution | Per capita GDP | System Loss Classification |
|---|---|---|---|---|---|---|---|---|
| GEDIZ | 1518 | 1425 | 2 241 653 | 25620.662 | 43 595 629 | 11608840.54 | 2 837 | 1 |
| MENDERES | 1459 | 945 | 1 387 814 | 43106.82237 | 25 894 718 | 4695083.917 | 2 486 | 1 |
| OSMANGAZI | 1978 | 1026 | 1 211 819 | 16655.118 | 31 067 096 | 4010445.879 | 1 920 | 1 |
| MERAM | 1713 | 1976 | 1 449 915 | 34591.05 | 34 353 274 | 4830047.135 | 1 653 | 1 |
| CAMLIBEL | 2565 | 928 | 705 867 | 16526.403 | 20 310 202 | 1763146.084 | 1 207 | 1 |
| ULUDAG | 2295 | 1526 | 2 156 032 | 27945.9 | 45 798 298 | 7201259.587 | 2 578 | 1 |
| AKDENIZ | 1064 | 1138 | 1 338 249 | 33352.36 | 56 758 461 | 4499105.2 | 1 885 | 1 |
| GOKSU | 990 | 654 | 453 407 | 8816.942 | 17 402 663 | 2768141.949 | 1 251 | 2 |
| TRAKYA | 748 | 570 | 734 268 | 7267.575 | 19 466 837 | 3575210.684 | 2 830 | 2 |
| YESILIRMAK | 3160 | 1458 | 1 419 577 | 48602.517 | 42 311 528 | 3404899.708 | 1 459 | 2 |
| BASKENT | 3293 | 3004 | 2 847 668 | 54544.563 | 80 222 672 | 8836777.19 | 2 002 | 2 |
| SAKARYA | 1590 | 1026 | 1 318 521 | 26901.3025 | 15 990 052 | 4995211.747 | 3 408 | 2 |
| AYEDAS | 99 | 2068 | 1 911 150 | 11678.9 | 19 191 407 | 6971967.948 | 3 063 | 2 |
| TOROSLAR | 2359 | 2412 | 2 516 365 | 51037 | 49 077 685 | 11577352.93 | 1 852 | 2 |
| FIRAT | 1804 | 1189 | 630 235 | 19934.506 | 14 658 612 | 1913075.258 | 1 375 | 2 |
| BOGAZICI | 94 | 1864 | 3 607 318 | 20931.446 | 39 024 509 | 15864197.98 | 3 063 | 2 |
| CORUH | 2110 | 1089 | 950 510 | 30243.571 | 33 945 947 | 1875267.685 | 1 612 | 2 |
| ARAS | 3159 | 1488 | 691 346 | 19937.382 | 32 584 194 | 1408703.282 | 913 | 3 |
| DICLE | 3302 | 1787 | 944 772 | 15384.211 | 30 356 674 | 4763080.593 | 1 045 | 3 |
| VANGOLU | 1449 | 931 | 375 767 | 11450.9 | 18 421 373 | 755965.639 | 730 | 3 |

Utility scores of each alternative are shown in the table with the varying values between 0.9999 and 0.1154. Utility thresholds are determined as, 0.9398 and 0.6414. That means companies with the utility score higher than 0. 9398 are classified as having low system losses, companies with the utility score between 0.9398 and 0.6414 are classified as having medium system losses and companies with the utility score less than 0.6414classified as having high system losses electricity distribution facilities.

**Table 8.** Utility Scores and Utility Thresholds

| Electricity Distribution Company | Utility Scores | Utility Score Based Class | Predefined Class |
|---|---|---|---|
| SAKARYA | 0.99996 | 1 | 2 |
| MENDERES | 0.96866 | 1 | 1 |
| OSMANGAZI | 0.94360 | 1 | 1 |
| TOROSLAR | 0.93996 | 1 | 2 |
| MERAM | 0.93996 | 1 | 1 |
| ULUDAG | 0.93996 | 1 | 1 |
| GEDIZ | 0.93996 | 1 | 1 |
| **Utility Threshold 1** | **0.93986** | | |
| AKDENIZ | 0.93985 | 2 | 1 |
| AYEDAS | 0.93976 | 2 | 2 |
| CORUH | 0.93976 | 2 | 2 |
| YESILIRMAK | 0.93976 | 2 | 2 |
| FIRAT | 0.93976 | 2 | 2 |
| BASKENT | 0.93976 | 2 | 2 |
| BOGAZICI | 0.93976 | 2 | 2 |
| TRAKYA | 0.88145 | 2 | 2 |
| CAMLIBEL | 0.84718 | 2 | 1 |
| GOKSU | 0.64153 | 2 | 2 |
| **Utility Threshold 2** | **0.64143** | | |
| DICLE | 0.64133 | 3 | 3 |
| ARAS | 0.49298 | 3 | 3 |
| VANGOLU | 0.11544 | 3 | 3 |

The objective of the developed model is the minimization of the total classification errors. When the utility scores in Table 8 are analysed, one can easily conclude that there are some companies which are misclassified with respect to predefined classification. For example, Sakarya which is one of class 2 provinces in predefined classification belongs to class 1 according to its utility score obtained through the model. This type of classification errors yield a total error score different than 0. This brings up the prediction ability issue of the model. Here, the prediction ability refers to the degree of consistency between the predefined classes and classes assigned by the model with respect to criteria we used. We measure the prediction ability of model through the comparison of classes assigned by the model with the predefined classes. For this purpose, we count the number of alternatives that have utility scores in accordance with their predefined groups and the number of misclassified alternatives.

Table 9 illustrates the prediction ability of the model. The accuracy of the model's prediction for low system loss companies is 71%, for medium system loss companies is 80% and for high system loss companies is 100%. Overall prediction ability score of model is computed as 80% using weighted average of each class.

Table 10 illustrates the weights of the evaluation criteria estimated by the UTADIS model. According to the marginal utilities, the most important criterion is G7 (per capita GDP) with weight 60.45%. Other ratios that were found significant are G3 (number of customers), G4 (length of network) and G5 (yearly expenditures) with weights 21.68%, 11.80% and 6.02%, respectively. The almost 0% weights of G1, G2 and G6 indicates that service area, number of employees and electricity distribution have no effect on system losses in provinces.

**Table 9.** Prediction Ability of the Model

| | **# of Alternatives** | | **Utility Score Based Class** | | | **Overall Performance** |
|---|---|---|---|---|---|---|
| | | | C1 | C2 | C3 | |
| Predefined Class | 7 | C1 | **71%** | 29% | 0% | **80%** |
| | 10 | C2 | 20 % | **80%** | 0% | |
| | 3 | C3 | 0 % | 0 % | **100%** | |

**Table 10.** Weights of the evaluation criteria

| **ID** | **Evaluation Criteria** | **Weight of the Criteria** |
|---|---|---|
| G1 | Service Area | 0.02% |
| G2 | Employees | 0.00% |
| G3 | Customers | 21.68% |
| G4 | Network Size | 11.80% |
| G5 | Expenditures | 6.02% |
| G6 | Electricity Distribution | 0.02% |
| G7 | Per capita GDP | 60.45% |

## 4. Conclusions and Future Research

By taking the important points in MCDA literature for E&E into account, we identify a need for a Decision Support System (DSS) allowing analysis using different techniques and providing the decision maker a database of commonly used criteria from different application areas.

The motivation behind this study is building such a system and performing an application using the system in Turkish Energy Sector. Using Microsoft Office Excel together with Visual Basic for Applications (VBA), we built an Energy Decision Support System (EDSS) consisting of four main components; model base, criteria database, report interface and user interface.

The model base of the system consists of various techniques of MCDA. The criteria database consists of commonly used parameters (input, output or criteria) in MCDA for E&E issues. We aimed to design a report interface, (the third component of the system) in a manner that results of the analyses can easily be interpreted, compared with each other and exported from the system. The last component is the user interface which includes various forms in order to gather input parameters from users and perform the analysis. We also perform an application in order to test the applicability of the system in Turkish Energy Sector.

Consequently, we can mention main contributions of EDSS and the study as:

- The system built in the study includes various techniques of MCDA (DEA, Measure-specific DEA, ELECTRE, PROMETHEE, PROMETHEE-GDSS, UTADIS).
- The system also includes two contributing approaches of Multi-Class UTADIS and DEA based UTADIS which is a combined use of DEA and UTADIS techniques.
- System includes a criteria database consisting of three types of criteria; economic, energy and environment criteria. The criteria database of the system enables the users to see and add commonly used parameters from different application areas of E&E. With this feature, it combines the area of MCDA and E&E. DSS can also handle undesirable outputs.
- System is applicable for different decision problems from different areas of E&E such as energy policy analysis, electricity planning, technology choice, energy utility operations and energy-related environmental issues.
- Finally, as a part of this study, the system is used for an application using UTADIS technique in Turkish Energy Sector in order to test the applicability of the system.

As a further research, different techniques of MCDA used in E&E studies can be added to the system. In addition, the system can be extended in a way that including stochastic and fuzzy approaches of the methods to deal with more uncertainty. Also, currently, the system includes only PROMETHEE – GDSS (Group Decision Support System) as a group decision making tool. The system can be improved with more group decision making approaches. Finally, additional decision problems from different areas and countries of world energy industry can easily be analysed through the system.

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## Appendix. User Forms of EDSS in an Illustrative Example

The main steps of UTADIS example in section 3 with corresponding screenshots of the EDSS are given below.

***Step 1.*** Selection of technique and method

As seen in Figure 3, the system starts with an initial form including various MCDA techniques and two alternative actions. Here, Templates option enables user to reach the criteria database of the system and use the criteria from the database. In New Analysis option user is free to enter own criteria. For our problem, we select Utadis as the technique and Templates option as seen in Figure 3.

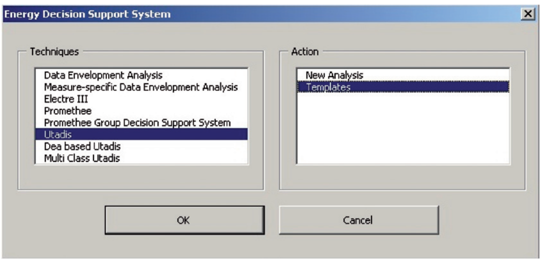


**Fig. 3.** EDSS Initial Form

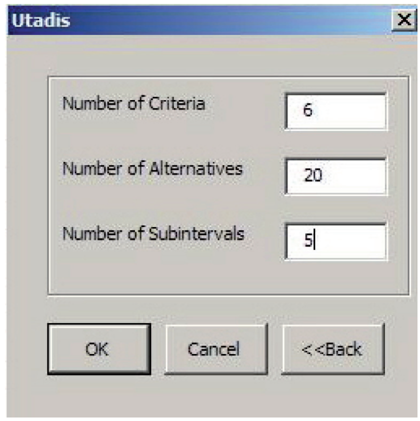


**Fig. 4.** UTADIS Technique Model Base Form

***Step 2.*** Entering the model parameters

After selecting the technique and prefered action, the system brings the relevant input form in order to enter the necessary parameters for the technique to be processed, as shown in Figure 4.

***Step 3.*** Selecting the Criteria

The criteria that will be used in the analysis are selected from the database shown in Figure 5. The form has three groups of criteria; economic, energy and environment. These criteria are all included by reviewing the MCDA studies in Energy and Environment. If we have a criterion that is not included in the database, we can add it simply selecting the "Other" option in the list as seen in Figure 5.

***Step 4.*** Entering the dataset

After all parameters and criteria are obtained from the user, the system creates a relevant area in an Excel sheet for entering the dataset. As seen in Figure 6, alternatives took place vertically and the criteria are placed horizontally in the Microsoft Office Excel Worksheet.

***Step 5.*** Analysis

After the dataset is entered to the appropriate fields, we initiate the system by simply clicking the "Run" button placed on the worksheet. At this point, it is important to mention that system is designed in a way that can warn the user when some inputs are missing such as predefined classification. The analysis take place in the worksheet and necessary calculations are automatically made by the system. For UTADIS analysis, various matrix calculations take place, the linear programming model is set on the worksheet with objective function and constraints, then the system calls the Solver Add-in of Microsoft Excel to solve the model.

As mentioned before, the UTADIS method is developed for the sorting/classification of a finite set of alternatives xi, i = 1,...,m, into o predefined homogenous ordered groups ck, k = 1 ,...,o. This classification is obtained by constructing an additive utility function U(xi) and utility thresholds uk, k = 1,...,o-1, such that xi is assigned to class $c_k'$ with minimum classification error. While constructing the additive utility functions, it uses a piece-wise linear function approach through the use of subintervals. The number of subintervals is specified by the user in our system.

For m criteria, n alternatives, s subintervals, the UTADIS module of the system automatically performs listed calculations below on the worksheet by using necessary Excel and defined functions (values in the brackets represent size of the matrices).

- Calculation of cutting points for subintervals ($s \times n$),
- Calculation of upper and lower limits of subintervals ($n \times m$),
- Identification of subintervals for the alternatives in each criteria ($n \times m$),
- Setting the field for w values ($s\text{-}1 \times m$),
- Calculation of cumulative w values ($s \times m$),
- Calculation of utility function value of alternatives with respect to each criteria ($n \times m$),
- Calculation of additive utility function value for each alternative ($n \times 1$),
- Setting the fields of utility thresholds and error terms,
- Setting the fields of left-hand side and right-hand side of constraints,
- Setting the field of objective function (summation of error terms),
- Entering solver parameters (objective function, decision variables, constraints etc.),
- Solution of the model,
- Creation of result report by copying the necessary fields obtained in the solution into a new worksheet.

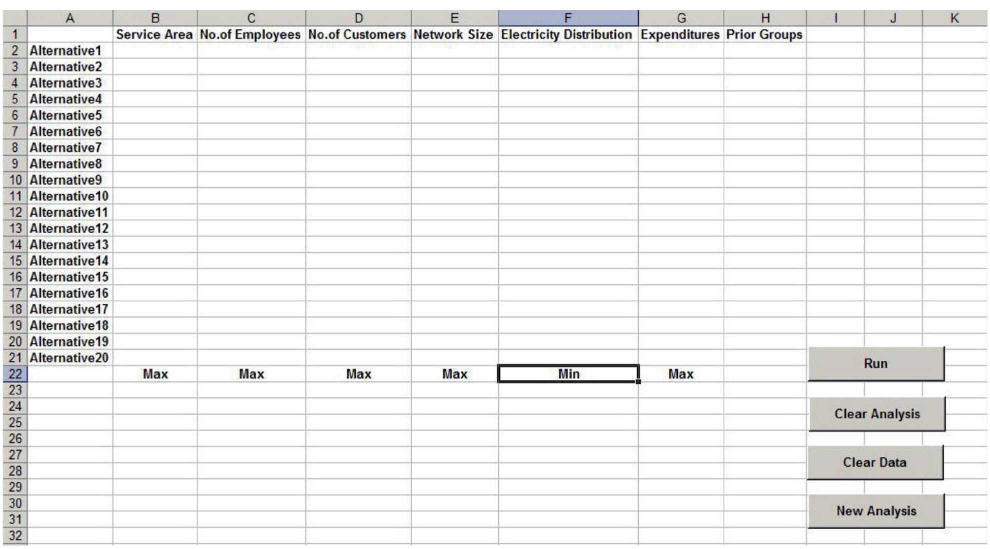


**Fig. 6.** Structure of EDSS Analysis Worksheet for UTADIS

***Step 6.*** Obtaining and interpreting results

When the analysis is completed on the worksheet, a new worksheet for reporting the results is created and necessary results are copied to this worksheet by the system. The result report format obtained for the example analysis in section 3 is shown in Figure 7 below.

RESULT REPORT

| | |
|---|---|
| Technique | UTADIS |
| Number of Criteria | 7 |
| Number of Alternatives | 20 |
| Number of Prior Groups | 3 |
| Number of Subintervals | 5 |

Utility Values & Scores

| Alternatives | Groups | Utility Scores | + Error | - Error | Utility Tresholds |
|---|---|---|---|---|---|
| SAKARYA | 2 | 0.999955 847 | 0 | 0.06 | 0.939856141 |
| MENDERES | 1 | 0.968661188 | 0 | | 0.641434486 |
| OSMANGAZI | 1 | 0.94359635 | 0 | | |
| TOROSLAR | 2 | 0.939964327 | 0 | 2E-04 | |
| MERAM | 1 | 0.939956141 | 0 | | |
| ULUDAG | 1 | 0.939956141 | 0 | | |
| GEDIZ | 1 | 0.939956141 | 0 | | |
| AKDENIZ | 1 | 0.939855422 | 9E-05 | | |
| AYEDAS | 2 | 0.939756141 | 0 | 0 | |
| CORUH | 2 | 0.939756141 | 0 | 0 | |
| YESILIRMAK | 2 | 0.939756141 | 0 | 0 | |
| FIRAT | 2 | 0.939756141 | 0 | 0 | |
| BASKENT | 2 | 0.939756141 | 0 | 0 | |
| BOGAZICI | 2 | 0.939756141 | 0 | 0 | |
| TRAKYA | 2 | 0.8814546 | 0 | 0 | |
| CAMLIBEL | 1 | 0.847175905 | 0.0928 | | |
| GOKSU | 2 | 0.641534486 | 0 | 0 | |
| DICLE | 3 | 0.641334486 | | 0 | |
| ARAS | 3 | 0.49298248 | | 0 | |
| VANGOLU | 3 | 0.11544307 | | 0 | |

Criteria Weights

| | |
|---|---|
| Service Area | 0.02% |
| Number of Employees | 0.00% |
| Number of Customers | 21.68% |
| Network Size | 11.80% |
| Expenditures | 6.02% |
| Electricity Distribution | 0.02% |
| Per capita GDP | 60.45% |

**Fig. 7.** Result Report for Electricity Distribution Companies

**ENERGETIKOS DAUGIAKRITERINĖ SPRENDIMŲ PARAMOS SISTEMA**

**K. B. Atici, A. Ulucan**

**Santrauka.** Daugiakriterinės sprendimų analizės (DKSA) metodai yra ypač tinkami energetikos ir aplinkos (E ir A) sprendimams priimti dėl daugiakriterinio problemų pobūdžio ir šioje srityje metodai buvo plačiai naudojami. Svarbiausi punktai, į kuriuos gali būti atsižvelgta nagrinėjant DKSA literatūrą, susijusią su E ir A, yra tinkamo metodo parinkimas, galimų rodiklių parinkimas ir plačiai paplitusios taikymo sritys. Šio mokslinio straipsnio motyvas yra suformuoti tokias sprendimų paramos sistemas (SPS), kurios leidžia energetikos sprendimus priimantiems asmenims atlikti analizę naudojant įvairius DKSA metodus ir skirtingus rodiklius iš įvairių taikymo sričių bei bandyti pritaikyti šią sistemą remiantis Turkijos energetikos sektoriumi. Sistema apima kelis DKSA metodus ir bendrus parametrus, iš ankstesnių mokslinių straipsnių, siekiant užtikrinti skirtingų požiūrių buvimą vertinant sprendimų priėmimo problemas. Šiame straipsnyje sprendimų sistema yra sankirtoje tarp DKSA bei E ir A. Be to, buvo atliktas DKSA pritaikymas Turkijos energetikos sektoriuje siekiant patikrinti sistemos pritaikomumą bei yra pateikti keli pasiūlymai dėl elektros paskirstymo Turkijoje.

**Reikšminiai žodžiai:** Daugiakriterinė sprendimų analizė, energetika ir aplinka, sprendimų paramos sistemos, ELECTRE, PROMETHEE, duomenų apėmimo analizė.

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