Potential Energy Sources in Electricity Generation: The Case of Turkey[*]

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Abstract

Energy vulnerability and security have become top issues for all countries. As an emerging economy, Turkey's electricity consumption has increased significantly and is expected to follow the same trend in the future. Turkey is likely to confront electricity energy deficiency in 2014-2015. So in order to prevent such a deficiency, Turkey should start to install new power plants as soon as possible by taking into account the long construction periods of power plants. Consequently, Turkey is faced with the problem of ranking and selecting the optimum electricity generation technology for its society from among natural gas combined cycle power plants, coal power combined heat plants, wind onshore power plants, small hydro (run of river) power plants, nuclear power plants and solar PV power plants by taking into account cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatches. The Grey Relational Analysis (GRA) is utilized to solve this multiple attribute decision making (MADM) problem by combining the entire range of performance attribute values. Sensitivity analyses are carried out to determine the best solution in electricity generation for the "Reference Scenario" and the "450 Scenario" of IEA's World Energy Outlook 2009. The empirical results reveal that Turkey should focus on installing small hydro power plants, nuclear power plants and wind onshore power plants. Since hydro power and wind power are related to the natural potentials of a country, Turkey's potential for these resources has been assessed and it is concluded that Turkey has an immense untapped potential for these renewable energy resources.

Keywords: supply security, renewable energy, Turkey, RECABS, grey relational analysis

1.Introduction

Global macro balances of the energy sector have changed dramatically due to factors such as increasing world population, rapid industrialization of emerging economies, climate change and environmental developments in the last two decades. Consequently, energy vulnerability and security has become top issues for all countries. For the structure of the electricity market, the reliability of demand projections, fuel price volatility, import dependency and import concentration for the fuel used in electricity generation play crucial roles in the electricity energy vulnerability of a country. The more a country relies on resources that are costly, volatile, dependent on imports and concentrated to limited suppliers, the more its energy vulnerability is sensitive to adverse shocks. Supply security is the major issue in energy vulnerability of the electricity sector. Supply security is mostly related to how much the primary energy source is dependent on imports and on how concentrated are the foreign suppliers' of this primary energy source.

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As an emerging economy, Turkey's electricity consumption has increased significantly and is expected to follow the same trend in the future. Supply security of electricity energy has appeared as an important issue due to the non-storable nature of electricity and the limited interconnection rates with other countries. Regarding the availability and feasibility of alternative technologies with recent developments, the alternative electricity generation technologies are natural gas combined cycle power plants, coal power combined heat plants, wind onshore power plants, small hydro (run of river) power plants, nuclear power plants and solar PV power plants. Therefore, Turkey has to make an optimum decision by ranking alternative electricity generation technologies and selecting the best technology for future capacity installations with respect to cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatch. The decision making for the best electricity generation technology includes multiple attributes for each alternative technology. Turkey performs relatively worse than the European Union (EU) on average in energy vulnerability indicators since it is more dependent on imports, has a more concentrated nature of energy suppliers, is less efficient in energy consumption, spends more carbon rich fuels and imports from less politically stable countries. Contrary to this negative standing, Turkey has more renewable energy opportunities compared to the European Union and thus exhibits a higher potential to reduce its energy vulnerability for the future.

In addition, increasing global concern for climate change and the EU regulations are expected to force Turkey to recognize the importance of greenhouse gas (GHG) emissions in investment decisions in the near future. Turkey has the highest percentage increase of 119.1% in GHG emissions (excluding LULUCF) among Annex I Parties from 1990 to 2007. Most of the GHG emissions are generated from energy sector and specifically, electricity generation. When all these factors are taken into account, renewable energy becomes a promising alternative. Among renewable energy sources, the penetration of wind energy in the EU and in the world is increasing more than other renewable energy sources. Turkey has the most wind energy capacity in EU countries and aims to increase installed wind power capacity to 20,000 MW by the year 2023. Besides, Turkey's technically and economically available hydroelectric potential will be entirely used in electricity generation. Nuclear energy appears as another promising alternative to combat energy vulnerability and global climate change as well as renewable energy.

The objective of this study is to explore potential energy sources in electricity generation under different scenarios for Turkey by utilizing Grey Relational Analysis (GRA). The decision making process depends on ranking and selecting the best electricity generation technology by taking into account cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatch. So, it is difficult to determine the best alternative by taking into account all possible trade-offs between conflicting attributes. This is a problem of multiple attribute decision making (MADM) in nature. MADM ranks and selects the best from existing alternatives, by taking into account multiple attributes that are usually in conflict. There are several common methodologies for MADM, such as simple additive weighting (SAW), the technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP), data envelopment analysis (DEA) and so on (Kuo, Yang & Huang, 2008). In this study, the grey system, proposed by Deng (1982), is preferred because it has been widely applied to various fields and has been proven to be more competent for dealing with poor, incomplete, and uncertain information (Kuo, Yang & Huang, 2008). The weights of these attributes will change according to different viewpoints on whether it gives more or less priority to cost efficiency or supply security. GRA will propose the best technology for society, not for the private investor. So, government and the policy makers may use the outcomes of this study to incentivize the best technology for society while making this technology the best for the private investor as well.

This study contributes to the literature in the following ways. Firstly, it will help to rank and select the socially best electricity generation technologies in different scenarios and from different viewpoints giving different priorities for the attributes. Secondly it will show which attributes a country should consider when ranking and selecting the best alternative electricity generation technologies. Thirdly, this study will help to compare the unit electricity generation costs of different technologies by using the REcalculator with the assumptions of International Energy Agency's (IEA) Renewable Energy Costs and Benefits for Society (RECABS) project (2007) and fuel price and CO_2 price assumptions of World Energy Outlook 2009. Fourthly, the outcomes of this study will provide guidelines for ranking alternative electricity generation technologies and may serve as a baseline in designing market structure and necessary incentives by the government to encourage private sector investment in the socially best technologies. Lastly, this study will show that the impact of the distinguishing coefficient on the result of Grey Relational Analysis is small.

Sensitivity analyses are carried out to determine the best solution in electricity generation for the Reference Scenario and the 450 Scenario of IEA's World Energy Outlook 2009 and from different viewpoints by giving different priorities to the attributes. Results of simulation analysis reveal that Turkey should focus on installing small hydro power plants, nuclear power plants and wind onshore power plants. Since hydro power and wind power are related to the natural potentials of a country, Turkey's potential for these resources has been assessed and it has been concluded that Turkey has a large untapped potential for these renewable energy resources.

The rest of the paper is organized as follows. Section 2 summarizes the methodology. Section 3 discusses the potential energy sources and their attributes in electricity generation for Turkey. Section 4 presents empirical findings and tests the impact of the distinguishing coefficient on the results of GRA. Section 5 covers the sensitivity analysis in the context of the 450 Scenarios of IEA's World Energy Outlook 2009 and different viewpoints by giving different priorities to the attributes. Section 6 discusses the policy implications of the study. Concluding remarks are given in Section 7.

2. Methodology and the major attributes of the analysis.

Grey Relational Analysis (GRA) procedure is used for ranking these alternative technologies and providing a basis for selecting the best technology. Therefore, the MADM problem takes into account economic costs, externalities and supply security issues and GRA proposes the best technology for society, not for the private investor.

In the literature, GRA is part of grey system theory and GRA has been applied successfully in solving a variety of MADM problems, such as the hiring decision (Olson & Wu, 2006), the restoration planning for power distribution systems (Chen, 2005), the inspection of the integrated-circuit marking process (Jiang, Tasi, & Wang, 2002), the modeling of quality function deployment (Wu, 2002), the detection of silicon wafer slicing defects (Lin et al., 2006), the selection of power plant types (Nenem, 2009), the selection of the best facility layouts and dispatching rule selections (Kuo, Yang & Huang, 2008) etc.

Grey relational analysis (GRA) procedure comprises four stages: grey relational generating, reference sequence definition, grey relational coefficient calculation, grey relational grade calculation (Kuo, Yang & Huang, 2008). In grey relational generating, the performance of all alternatives is translated into a comparability sequence. In reference sequence definition, a reference sequence (ideal target sequence) is defined according to these sequences. In grey relational coefficient calculation, the grey relational coefficient between all comparability sequences and the reference sequence is calculated. In grey relational grade calculation, the grey relational grade between the reference sequence and every comparability sequences is calculated based on the grey relational coefficients. The best alternative choice will be the alternative whose comparability sequence has the highest grey relational grade between the reference sequence and itself. The stages of GRA procedure are as follows:

The units of performance measures may be different for different attributes. Some performance attributes may have a very large range, as well. Also, the goals and directions of different attributes may be different, leading to incorrect results or interpretations. So, all attribute performance values for every alternative should be processed into a comparability sequence, in other words a normalization process should be carried out. This normalization process is called grey relational generating (Kuo, Yang & Huang, 2008).

If there are m alternatives and n attributes, the ith alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \ldots, y_{ij}, \ldots, y_{in})$, where y_{ij} is the performance value of attribute j of alternative i. The term Y_i can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2}, \ldots, x_{ij}, \ldots, x_{in})$ by using one of Equations 1, 2, 3 (Kuo, Yang & Huang, 2008).

$$X_{i,j} = \frac{y_{i,j} - Min\left[y_{ij},\ i=1,2,\ldots,m\right]}{Max\left[y_{ij},\ i=1,2,\ldots,m\right] - Min\left[y_{ij},\ i=1,2,\ldots,m\right]} \qquad \text{for } i=1,2,\ldots,m \quad j=1,2,\ldots,n \quad (1)$$

$$X_{i,j} = \frac{Max\left[y_{ij},\ i=1,2,\ldots,m\right] - y_{i,j}}{Max\left[y_{ij},\ i=1,2,\ldots,m\right] - Min\left[y_{ij},\ i=1,2,\ldots,m\right]} \qquad \text{for } i=1,2,\ldots,m \quad j=1,2,\ldots,n \quad (2)$$

$$X_{i,j} = 1 - \frac{y_{i,j} - y_j^{*}}{Max\left[Max\left[y_{ij},\ i=1,2,\ldots,m\right] - y_{ij}^{\ *},\ y_{ij}^{*} - Min\left[y_{ij},\ i=1,2,\ldots,m\right]\right]}$$

for i=1,2,...,m   j=1,2,...,n (3)

The larger the better attributes use Equation 1, the smaller the better attributes use Equation 2, the closer to the desired value y_j* the better attributes use Equation 3.

As a result of the grey relational generating procedure, all performance values will be scaled into [0, 1]. After the grey relational generating, if the value x_{ij} for an attribute j of alternative i, is equal to 1 or nearer to 1 than the value for any other alternative, the performance of alternative i will be the best one for the attribute j. Therefore an alternative whose performance values are closest to or equal to 1 will be the best choice. The reference sequence

X_0 is defined as (x_{01}, x_{02}, . . ., x_{0j}, . . ., x_{0n}) = (1, 1,..,1), and the alternative whose comparability sequence is the closest to the reference sequence will be the best alternative.

Grey relational coefficient is used for determining how close x_{ij} is to the reference sequence x_{0j}. The larger the grey relational coefficient, the closer x_{ij} and x_{0j} are. The grey relational coefficient can be calculated by Equation 4 (Kuo, Yang & Huang, 2008).

$$\gamma\ (x_{0j}, x_{ij})=\frac{\Delta\min+\zeta\,\Delta\max}{\Delta\,ij+\zeta\,\Delta\max} \qquad \text{for } i=1,2,...,m \quad j=1,2,...,n \qquad (4)$$

In Equation 4, $\gamma\ (x_{0j}, x_{ij})$ is the grey relational coefficient between x_{ij} and x_{0j}

$\Delta_{ij} = \left| x_{0j} - x_{ij} \right|$,

$\Delta_{min} = \text{Min}\ \{\Delta_{ij}, i=1,2,...,m \quad j=1,2,...,n\}$

$\Delta_{max} = \text{Max}\ \{\Delta_{ij}, i=1,2,...,m \quad j=1,2,...,n\}$

ζ is the distinguishing coefficient, $\zeta \in [0,1]$

The distinguishing coefficient aims to expand or compress the range of the grey relational coefficient. The decision maker can adjust the distinguishing coefficient by exercising judgment. Kuo, Yang & Huang (2008) sets the distinguishing coefficient as 0.5 initially, and then tests some other different distinguishing coefficients for analysis. In Kuo, Yang & Huang's (2008) study, the differences between $\gamma\ (x_{0j}, x_{aj})$, $\gamma\ (x_{0j},x_{bj})$ and $\gamma\ (x_{0j}, x_{cj})$ change when different distinguishing coefficients are adopted, but, the rank order of $\gamma\ (x_{0j}, x_{aj})$, $\gamma\ (x_{0j},x_{bj})$ and $\gamma\ (x_{0j}, x_{cj})$ is always the same.

After calculating the entire grey relational coefficient $\gamma\ (x_{0j}, x_{ij})$, the grey relational grade can be then calculated by using Equation 5 (Kuo, Yang & Huang, 2008).

$$\Gamma\ X_0, X_i) = \sum_{j=1}^{n} w_j\, \gamma\ \ x_{oj}, x_{ij} \qquad \text{for } i=1,2,...,m \qquad (5)$$

The grey relational grade Γ (X_0, X_i) represents degree of similarity between the reference sequence and the comparability sequence. w_j is the weight of attribute j and usually depends on decision makers' judgment or the structure of the proposed problem. In addition,

$$\sum_{j=1}^{n} w_j = 1$$

As mentioned above, on each attribute, the reference sequence represents the best performance that could be achieved by any among the comparability sequences. Therefore the comparability sequence for an alternative whose grey relational grade is the highest would be the best choice.

The attributes and performance values of these attributes should be determined for every alternative technology. The major attributes are cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatch.

Cost efficiency considers the cost of generating 1 MWh electricity by taking into account capital (investment) costs, operation & maintenance costs, fuel costs, system integration infrastructure costs and income from heat sales. In this study, the costs per MWh electricity will be calculated on the assumptions and projections of IEA (2007) RECABS project and IEA's World Energy Outlook 2009.

RECABS has been prepared for the IEA's Implementing Agreement on Renewable Energy Technology Deployment by Energy Analyses (Ea). The objective of RECABS is to assess the costs and benefits of electricity from renewable energy sources compared to conventional technologies. All economic and technological assumptions of RECABS project rely on internationally respected sources. Information about RECABS project in this section is obtained from RECABS main report (2007).

RECABS project is an analytical tool that provides a cost-benefit analysis. The cost-benefit analysis can be grouped into two as the financial cost-benefit analysis and economic cost-benefit analysis. The financial cost-benefit analysis takes into account the concerns of a private investor, while the economic cost-benefit analysis takes into account national benefits and costs. The financial cost-benefit analysis includes all taxes and subsidies while the economic cost-benefit analysis ignores all taxes and subsidies, but includes external costs, which have no direct impact on the financial viability of the project. The economic cost-benefit analysis is often used by government agencies to justify subsidies. RECABS project is based on economic cost-benefit analysis.

RECABS uses year 2010 as representing current costs and performances for the technologies decided and ordered in 2007, RECABS was built in, will not be in operation before 2010. This study will use 2015 as representing current costs and performances since technologies decided today in 2010 will be in operation around 2015 for most of the technologies. Since the main difference among capital (investment) costs and O&M costs for different years come from the learning effects for renewable energy technologies, comparing and analyzing alternative technologies for the year 2015 by using the assumptions of RECABS's investment cost and O&M cost assumptions for 2010 would be a more conservative approach for renewable energy technologies and so would lead to more robust conclusions for the year 2015. And, this study will employ other assumptions related to costs such as fuel costs as 2015 price projections of IEA's World Energy Outlook 2009 to reach more reliable conclusions.

RECABS uses the constant-money levelized lifetime cost method. This method provides the costs per unit of electricity generated that is the ratio of total lifetime expenses' net present value to total expected electricity generation (IEA, 2007). The formula to calculate the levelized electricity generation cost is as follows (IEA, 2007):

$$EGC = \frac{\sum_{n=1}^{N} (I_n + OM_n + F_n) * (1 + \frac{r}{100})^{-n}}{\sum_{n=1}^{N} E_N * (1 + \frac{r}{100})^{-n}}$$

where:

EGC = Constant-money levelized lifetime electricity generation cost (€/MWh)

N = Technical lifetime of the power plant (years)

n = The year when the actual costs are incurred (from 1 for the first year of operation to N for the final year of operation)

I_n = Investment expenditures in the year n (€); includes reinvestment and other major rehabilitation costs not accounted for as maintenance costs

OM_n = Operation and maintenance expenditures in the year n (€)

F_n = Fuel expenditures in the year n (€)

r = Discount rate (% per year)

$E_{\mathbf{n}}$ = Net electricity generation in the year n (MWh)

This study will use technical lifetime of each technology as discount periods and economic discount rate like RECABS. Discount rate is very important for the calculation results of RECABS since this directly influences the net present values of expenses and incomes. The economic discount rate may be a rate required by public regulators derived from national macroeconomic analysis; or it may be related to other concepts of the trade-off between costs and benefits for present and future generations (IEA, 2007). Since the economic assessments are based on fixed prices in this study as is the case in RECABS, the discount rate is also determined in real discount rate without the effect of the inflation. This study will use an economic real discount rate of 5% per annum, compatible with RECABS as well. This discount rate can be changed to make sensitivity analysis as well.

This study will use constant money approach and will take the base year 2006 compatible with RECABS. Therefore all costs and benefits will be defined at the price level for 2006 and data obtained in other price levels will be inflated or deflated to 2006 price level. All economic data are in Euro compatible with RECABS. The result of converting exchange rates depends on which date is used for the conversion. Therefore, the purchasing power parity exchange rates are used for being compatible with RECABS. Since purchasing power parity is accepted to be the long-run equilibrium exchange rate of two currencies to equalize the currencies' purchasing power, this approach is compatible with the long run nature of this study. Purchasing power parity of 0.870 USD/EUR in 2006 will be used in this study that is used by RECABS as well.

RECABS analysis assesses costs and benefits of alternative electricity generation technologies in two major groups: Basic costs and Externalities. In RECABS, basic costs consist of capital (investment) costs, fuel costs, operation & maintenance costs and income from heat generation. Externalities taken into account by RECABS are as follows: climate change; other environmental pollution; system integration; security of fuel supply; and local benefits (rural employment).

Within climate change, the cost of reducing GHG emissions is taken into account. In the context of other environmental pollution, the impacts of local air pollution of SOx, NOx and particles from burning of fossil fuels and the impacts of radioactive emissions and nuclear accidents on human health are considered (IEA, 2007). Regarding system integration, costs related to the integration of power plants into the electricity system comprising infrastructure costs, balancing costs and capacity credit costs are taken into account (IEA, 2007). Security of fuel supply covers the macro-economic benefits of using domestic (renewable) energy sources to counter economic losses (inflation and unemployment) from volatile oil prices (IEA, 2007). Rural job creation is focused in the context of local benefits (IEA, 2007).

3. Analysis of Major Attributes and Trends in Electricity Generation: the Case of Turkey

As an emerging economy, Turkey's electricity consumption has increased significantly and is expected to follow an increasing trend in the future. Types of technologies to be assessed in electricity generation are natural gas combined cycle power plants, coal power combined heat plants, wind onshore power plants, small hydro (run of river) power plants, nuclear power plants and solar PV power plants.

Turkish Electricity Transmission Company (TEIAS) prepared the Turkish Electrical Energy 10-Year Generation Capacity Projection (2009-2018) in June 2009 to take necessary measures and to provide important recommendations and guidelines. In TEIAS's (2009) projection, high energy demand scenario assumes increases in gross electricity demand by 4.5% in 2010, 6.5% in 2011, 7.5% in each year during 2012-2015 and 7.4% in each year during 2016-2018, while low energy demand scenario assumes increases in gross electricity demand by 4.5% in 2010, 5.5% in 2011, 6.7% in each year during 2012-2015 and 6.6% in each year during 2016-2018. About capacities under construction, capacities granted by licence by the end of 2008, two scenarios have been assumed in this Projection. In Scenario 1, the plants of which 70% have been constructed are assumed to be in service in 2009, the plants of which 35-70% have been constructed at the end of 2008 are assumed to be in service in 2010 for installed capacities less than 100 MW, in 2011 for installed capacities between 100 MW-1,000 MW and in 2012 for installed capacities more than 1,000 MW (TEIAS, 2009). For the plants of which 10%-35% have been constructed, one year is added to the years above according to their installed capacity projects (TEIAS, 2009). The year the plants will be in service is assumed undetermined for the plants of which less than 10% have been constructed (TEIAS, 2009). In Scenario 2, the same methodology is used by taking into account 15% instead of 10%, 40% instead of 35% and 80% instead of 70% (TEIAS, 2009). According to scenario 1 capacity of 14,864.5 MW and according to scenario 2 capacity of 12,722.8 MW are assumed to be in service during the projection period (TEIAS, 2009).

Based on this Projection, reserve ratios according to firm generation capacities in Scenarios 1 and 2 are as shown in Table 1 and Table 2:

Table 1. Reserve Ratios According to Firm Generation Capacities in Scenarios 1 (TEIAS, 2009)

Scenario 1	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
High Demand	8.0	5.9	3.5	5.5	10.2	2.9	-3.5	-9.1	-15.6	-22.4
Low Demand	8.0	5.9	4.4	7.3	12.9	6.2	0.3	-4.7	-10.9	-17.5

Table 2. Reserve Ratios According to Firm Generation Capacities in Scenario 2 (TEİAŞ, 2009)

Scenario 2	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
High Demand	7.9	5.5	3.0	0.9	3.6	-1.7	-7.9	-13.1	-19.3	-25.9
Low Demand	7.9	5.5	4.0	2.6	6.1	1.4	-4.2	-9.0	-14.8	-21.2

In Scenario 1 electricity energy deficiency is expected in 2015 for high demand series and in 2016 for low demand series. In Scenario 2 electricity energy deficiency is expected in 2014 for high demand series and in 2015 for low demand series.

Since energy deficiency is expected in 2014 according to Scenario 2 for high demand series, TEIAS (2009) proposes from 2010 on to take measures for granting licenses, monitoring investment starting dates and taking them into the system, by taking into account construction periods for new capacities. It is essential to keep capacity and energy reserves on certain levels for reliable operation of the electricity system due to factors that may create uncertainty, such as deficiency in demand side, constraints in the supply and quality of fuel, long term outages at power plants, and delays in plants under construction.

Turkey should decide as soon as possible, from which primary energy resources it will generate electricity, in other words the optimum electricity generation technology. Electricity generation can be provided by non-renewable resources like natural gas combined cycle power plants, coal power combined heat plants, nuclear power plants or renewable resources like wind onshore power plants, hydro power plants, and solar PV power plants. When designing the market framework for the electricity sector, taking the costs and benefits of different energy resources into account with externalities is important in choosing the best alternative for the whole economy and stimulate sustainable investments in the best technologies. Externalities are impacts from the electricity generation that have no financial impacts on the owner of the power plant, but which result in economic costs or benefits to society. The difficulty is to quantify the costs and benefits in terms of money so that the externalities can be included in socio-economic evaluations. RECABS monetizes some of these externalities for different electricity generation technologies and so enables the comparing of them.

The selection of electricity generation technology is vital due to the fact that electricity generation technologies have significant impacts on cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatch. The main attributes can be summarized as follows:

• Cost Efficiency: The cost of generating 1 MWh electricity by taking into account capital (investment) costs, operation & maintenance costs, fuel costs, system integration infrastructure costs and income from heat sales (IEA, 2007).

• Cost Volatility Risk: The risk related to the electricity generation costs arising from fuel price fluctuations.

• Climate Change & Other Pollution: The impacts of alternative technologies on climate change and local air pollution from burning of fossil fuels and the impacts of radioactive emissions and nuclear accidents on human health (IEA, 2007).

• Supply Security: The combined risk of import dependency and import concentration taking into account the share of imports in the consumption of the fuel used in electricity generation and Hirschmann-Herfindahl index of supplier countries.

• Supply-Demand Mismatch: The problems for technologies with intermittent outputs appearing in the form of balancing costs arising from handling deviations from planned production and additional investments in reserves required and capacity credit costs arising from not being able to produce power when the electricity system needs it the most (IEA, 2007).

In this study, the “cost efficiency” attribute will include basic costs defined in RECABS and additionally system integration infrastructure costs. Climate change and other environmental pollution will be aggregated in this study and will be considered as the attribute “climate change & other pollution”. This study will not take into account the security of fuel supply and local benefits. Because, security of fuel supply is somehow related to “cost volatility risk” that is an attribute of this MADM and GRA avoids multiple attributes that are highly correlated. When it comes to local benefits, the assigned values for the alternative technologies considered in this study are assigned 0 in RECABS. So, local benefits will not be considered in this study.

3.1. Cost Efficiency

Cost efficiency is based on capital costs (investment costs), operation & maintenance costs, fuel costs, system integration infrastructure costs (IEA, 2007). Income from heat sales is considered as a negative cost and deducted from these costs. The assumptions related to these costs and technologies are based on RECABS whereas fuel price projections are based on IEA’s World Energy Outlook 2009.

Capital (investment) costs used in this study are the investment costs for commercially proven and best available technologies in 2010 used by RECABS. They include planning and design, feasibility analysis, approvals by authorities, site work, connections of electricity, water, and equipment, transport to arrival port and transport from port to site, assembly and commissioning, etc (IEA, 2007). Interest payments during construction period, costs of land acquisition, costs of project management and administration, taxes and duties, costs of dismantling decommissioned plants are not included (IEA, 2007). Capital costs, full load duration hours and technical lifetime assumptions that will be used in this study are compatible with assumptions of RECABS and are as shown in Table 3:

Table 3. Assumptions About Capital Costs, Full Load Duration Hours and Technical Lifetime of RECABS (IEA, 2007)

	Capital Costs (€/MW)	Full Load Duration Hours/Year or Electricity Efficiency (%)	Technical Lifetime (Years)
Natural Gas Combined Cycle Power Plants	501,000	58%	25
Coal Power Combined Heat Plants	1,400,000	46%	40
Wind Onshore Power Plants	900,000	2,500	20
Small (10-30 MW) Hydro (Run of River) Power Plants	2,400,000	6,000	35
Nuclear Power Plants	2,200,000	7,600	40
Solar PV Power Plants	4,800,000	1,400	30

A major output of RECABS project is the interactive energy calculator, REcalculator. The REcalculator enables the calculation of electricity generation costs for alternative technologies.

When the REcalculator is employed, based on assumptions about capital costs, full load duration hours and technical lifetime in Table 3, capital (investment) costs per MWh for alternative technologies are calculated as shown in Table 4:

Table 4. Capital (Investment) Costs Per MWh For Alternative Technologies

Electricity Generation Technology	Capital Costs (€/MWh)
Natural Gas Combined Cycle Power Plants	6.14
Coal Power Combined Heat Plants	16.24
Wind Onshore Power Plants	28.89
Small Hydro (Run of River) Power Plants	24.43
Nuclear Power Plants	17.09
Solar PV Power Plants	223.03

Operation and Maintenance (O&M) Costs consist of three parts: the fixed O&M costs, variable O&M costs and re-investment costs (IEA, 2007). The fixed share O&M costs (€/MW/year) are independent of the amount of electricity generation and include costs such as administration costs, insurance, etc. The variable O&M costs (€/MWh) are dependent on the amount of electricity generation and include costs such as consumption of auxiliary materials, spare parts, etc. Re-investment costs are incurred at periodic intervals of several years. Since O&M costs change over time, RECABS uses the average costs during the entire lifetime of the technology and this study will use the average costs as well. Operation and maintenance cost assumptions that will be used in this study are compatible with the assumptions of RECABS project and are as shown in Table 5:

Table 5. Assumptions About Operation and Maintenance Costs in RECABS (IEA, 2007)

	O & M Costs (€/MW)
Wind Onshore Power Plants	20,000 €/MW/year
Small Hydro (Run of River) Power Plants	50,000 €/MW/year
Nuclear Power Plants	70,000 €/MW/year
Natural Gas Combined Cycle Power Plants	12,500 €/MW/year + 1.7 €/MWh
Coal Power Combined Heat Plants	18,200 €/MW/year + 2 €/MWh
Solar PV Power Plants	48,000 €/MW/year

When the REcalculator is employed based on assumptions about operation and maintenance costs in Table 5, operation and maintenance costs per MWh for alternative technologies are calculated as shown in Table 6:

Table 6. Operation and Maintenance Costs Per MWh For Alternative Technologies

Electricity Generation Technology	O&M Costs (€/MWh)
Natural Gas Combined Cycle Power Plants	3.86
Coal Power Combined Heat Plants	5.25
Wind Onshore Power Plants	8.00
Small Hydro (Run of River) Power Plants	8.33
Nuclear Power Plants	9.33
Solar PV Power Plants	34.29

Fuel Costs is the most important cost component for conventional technologies such as coal power combined heat plants and natural gas combined cycle power plants. This study uses the economic fuel cost without any subsidies and taxes, while the financial fuel cost is the price at which it is sold and purchased, including all subsidies, taxes. For internationally tradable fuels, the economic costs are normally assumed to be equal to world market prices, since any fuel demand can be met by import at world market prices, and any surplus of domestic fuel production can be exported at world market prices (IEA, 2007). RECABS assumes that fuel price projection for a specific year will be the same for the succeeding years during the technical lifetime of the technology and so REcalculator does not allow to enter different fuel price assumptions for different years. Different from RECABS, this study will use different fuel price assumptions for different years to reach more reliable results and to take into the differences in fuel price projections of IEA World Energy Outlook 2009's Reference Scenario and 450 Scenario fully.

RECABS used fuel price estimates of IEA's World Energy Outlook 2006 for the years 2010 and 2025 in its original project. Today in 2010, it is understood that fuel price assumptions in World Energy Outlook 2006 for 2010 is much lower than the world market prices realized although fuel prices decreased significantly due to the economic crisis in the world. Different from RECABS original project, this study analyses and compares alternative technologies for the year 2015. Also, IEA has revised its fuel price projections upward considerably in World Energy Outlook 2009 for the future. Therefore, this study will employ fuel price projections of IEA's World Energy Outlook 2009 for the year 2015 and succeeding years.

World Energy Outlook 2009 involves two scenarios that are namely the Reference Scenario and the 450 Scenario and so different fuel price projections for each scenario. The Reference Scenario provides a baseline picture of how energy markets would evolve if the underlying trends in energy demand and supply are not changed (IEA, 2009). So, it is assumed that governments are assumed to make no changes to their existing policies and measures insofar as they affect the energy sector. IEA (2009) assumes in the 450 Scenario that governments adopt commitments to limit the long-term concentration of GHGs in the atmosphere to 450 parts per million of CO_2 equivalent, an objective that is gaining widespread support in the world. This study will employ price projections for each scenario separately and then compare the outcomes. The price projections of IEA (2009) in World Energy Outlook 2009 are derived from a large-scale mathematical model, the World Energy Model, that has been updated with the most recent historical data and revised assumptions. The fuel prices are based on ensuring global balance of supply and projected demand. The international fuel prices projections in the Reference Scenario are as shown in Table 7:

Table 7. Fuel Price Projections In the Reference Scenario of the World Energy Outlook 2009, (In Real Terms, 2008 USD) (IEA, 2009)

Fossil Fuels	Unit	2008	2015	2020	2025	2030
Crude Oil Imports	barrel	97.19	86.67	100.00	107.50	115.00
Natural Gas Imports						
United States	MBtu	8.25	7.29	8.87	10.04	11.36
Europe	MBtu	10.32	10.46	12.10	13.09	14.02
Japan LNG	MBtu	12.64	11.91	13.75	14.83	15.87
OECD Steam Coal Imports	tonne	120.59	91.05	104.16	107.12	109.40

The international fuel prices projections in the 450 Scenario are as shown in Table 8.

Table 8. Fuel Price Projections In the 450 Scenario of the World Energy Outlook 2009, (In Real Terms, 2008 USD) (IEA, 2009)

Fossil Fuels	Unit	2008	2015	2020	2025	2030
Crude Oil Imports	Barrel	97.19	86.67	90.00	90.00	90.00
Natural Gas Imports						
United States	MBtu	8.25	7.29	8.15	9.11	10.18
Europe	MBtu	10.32	10.46	11.04	11.04	11.04
Japan LNG	MBtu	12.64	11.91	12.46	12.46	12.46
OECD Steam Coal Imports	Tonne	120.59	85.55	80.09	72.46	64.83

As seen in Table 7 and 8, IEA World Energy Outlook involves fuel price projections for the years, 2015, 2020, 2025 and 2030. However technical lifetime of natural gas combined cycle power plants is assumed to be 25 years and so Europe natural gas price assumptions should be extended beyond 2030 until 2039. Technical lifetime of coal power combined heat plants is assumed to be 40 years and so OECD steam coal price assumptions should be extended beyond 2030 until 2054. Natural gas price assumptions for the years 2031-20039 and steam coal price assumptions for the years 2031-2054 will be derived by using linear extrapolation method taking by creating a tangent line between data points in 2020 and 2030 extending it beyond 2030. Because IEA’s (2009) fuel price assumptions for 2020-2025-2030 show nearly a linear trend. World Energy Outlook 2009 does not involve fuel price projections for the years remaining between 2015-2020-2025-2030. Fuel price assumptions for these years will be derived by using linear interpolation method. Table 9 shows fuel price assumptions between 2015-2054 that will be used in this study, derived from IEA World Energy Outlook 2009 price projections by using linear interpolation and linear extrapolation methods.

Table 9. Fuel Price Assumptions Between 2015-2054 (In Real Terms, 2008 USD)

	Reference Scenario		450 Scenario	
Year	Natural Gas	Coal	Natural Gas	Coal
2015	10.460	91.050	10.460	85.550
2016	10.788	93.672	10.576	84.458
2017	11.116	96.294	10.692	83.366
2018	11.444	98.916	10.808	82.274
2019	11.772	101.538	10.924	81.182
2020	12.100	104.160	11.040	80.090
2021	12.298	104.752	11.040	78.564
2022	12.496	105.344	11.040	77.038
2023	12.694	105.936	11.040	75.512
2024	12.892	106.528	11.040	73.986
2025	13.090	107.120	11.040	72.460
2026	13.276	107.576	11.040	70.934
2027	13.462	108.032	11.040	69.408
2028	13.648	108.488	11.040	67.882
2029	13.834	108.944	11.040	66.356
2030	14.020	109.400	11.040	64.830
2031	14.212	109.924	11.040	63.304
2032	14.404	110.448	11.040	61.778
2033	14.596	110.972	11.040	60.252
2034	14.788	111.496	11.040	58.726
2035	14.980	112.020	11.040	57.200
2036	15.172	112.544	11.040	55.674
2037	15.364	113.068	11.040	54.148
2038	15.556	113.592	11.040	52.622
2039	15.748	114.116	11.040	51.096
2040	-	114.640	-	49.57
2041	-	115.164	-	48.044
2042	-	115.688	-	46.518
2043	-	116.212	-	44.992
2044	-	116.736	-	43.466
2045	-	117.26	-	41.94
2046	-	117.784	-	40.414
2047	-	118.308	-	38.888
2048	-	118.832	-	37.362
2049	-	119.356	-	35.836
2050	-	119.88	-	34.31
2051	-	120.404	-	32.784
2052	-	120.928	-	31.258
2053	-	121.452	-	29.732
2054	-	121.976	-	28.206

Since only one fuel price value can be entered into REcalculator, the fuel price assumptions in Table ? will be converted to a single fuel price that will give the same results in as follows: The fuel price assumptions for each year is discounted by $(1+r)^n$ and these discounted values are summed. Then the sum of these discounted fuel prices will be divided by the coefficient of the annuity formula $[1-(1+r)^{-n}) / r]$. The result will be a single price but will create the same results with the fuel price assumptions in Table 9. This single fuel price for the REcalculator is calculated in Table 10.

Table 10. Calculation of Single Fuel Price for the REcalculator

	Reference Scenario		450 Scenario	
	Natural Gas	Coal	Natural Gas	Coal
Sum of Fuel Prices Discounted by $(1+0,05)^n$	181.043	1,835.479	154.042	1,149.089
Annuity Coefficient for n Years and r=0,05	14.094	17.159	14.094	17.159
Single Fuel Price ($)	12.845	106.968	10.930	66.967

RECABS is based on net calorific values while the gas prices are expressed on gross calorific value basis. The net calorific value of natural gas is usually below the gross calorific value by 10% (IEA, 2007). So, to convert from prices based on gross to net calorific value, gross values will be divided by 0.90. For natural gas, the energy unit MBtu will be converted to GJ with the conversion factor of 1.055 GJ/MBtu (IEA, 2007). For coal, conversion factor of 31.4 GJ/tonne will be used to find net calorific values (IEA, 2007). These conversion factors are compatible with RECABS. For the sake of being compatible with RECABS, the single fuel prices in Table 10 will be converted to prices EUR (2006 price level) per GJ in Table 11 as follows:

Table 11. Conversion* of Fuel Price Projections In the Reference Scenario and the 450 Scenario (In Real Terms, 2006 EUR)

Fossil Fuels	Unit	Reference Scenario	450 Scenario
Europe Natural Gas Imports	EUR/GJ	11.28	9.60
OECD Steam Coal Imports	EUR/GJ	2.84	1.78

*According to Bureau of Labor Statistics, CPI increase in the USA in 2007 and 2008 is 4.3%. So, 2008 $ prices in the World Energy Outlook 2009 has been deflated by 4.3% to reach 2006 $ values.

Fuel costs of nuclear power plants are different from fossil fuels. Fuel costs in nuclear power plants cover full fuel cycle costs including conversion, enrichment and fabrication of natural uranium, reprocessing and wastes disposal (IEA, 2007). This study will employ RECABS default value of 0.50 €/GJ. Since fuel costs comprise only a small cost portion for nuclear power, deviation from these price assumptions do not create significant outcomes.

When the REcalculator is employed, based on assumptions about fuel prices in Table 11, fuel costs per MWh for alternative technologies are calculated as shown in Table 12:

Table 12. Fuel Costs Per MWh For Alternative Technologies

Electricity Generation Technology	Fuel Costs In the Reference Scenario (€/MWh)	Fuel Costs In the 450 Scenario (€/MWh)
Natural Gas Combined Cycle Power Plants	70.28	59.81
Coal Power Combined Heat Plants	22.33	13.99
Wind Onshore Power Plants	0.00	0.00
Small Hydro (Run of River) Power Plants	0.00	0.00
Nuclear Power Plants	6.55	6.55
Solar PV Power Plants	0.00	0.00

System Integration Infrastructure Costs in RECABS involves infrastructure costs, balancing costs and capacity credit costs and are defined as costs related to the integration into the surrounding energy system of technologies with intermittent output such as wind power, solar PV and hydro run of river. Infrastructure costs arise from expanding and adjusting the electricity infrastructure (IEA, 2007). Balancing costs arise from handling deviations from planned production and additional costs for investments in reserves for handling of outages of power plants (IEA, 2007). Capacity credit costs arise from not being able to produce power when the electricity system needs it the most (IEA, 2007). This study will use infrastructure costs within the attribute “cost efficiency” since this is more compatible with the purposes of this study.

This study employs assumptions of RECABS original project for infrastructure costs that will be mentioned as follows: the infrastructure costs for grid connection of wind onshore will be assumed as 8% of total project investment costs that corresponds to infrastructure costs of 2.2 €/MWh; the infrastructure costs for hydro run of river are estimated to be the same as for onshore wind power, that is 2.2 €/MWh; and solar PV may defer transmissions and distribution upgrades investments. This cost avoidance is assumed as 14 €/MWh. Solar PV may also avoid line losses in transmission and distribution grid since production of electricity close to the load and consumption point can reduce these losses (IEA, 2007). This cost avoidance in line losses is assumed as 4.4 €/MWh. So, these infrastructure cost reductions of solar power sum up to 18.4 €/MWh. It is assumed that new nuclear power will be established within the framework of the existing infrastructure and will not need further infrastructure investments that is usually the fact in many cases (IEA, 2007). So system integration infrastructure costs per MWh for alternative technologies are as shown in Table 13:

Table 13. System Integration Infrastructure Costs Per MWh For Alternative Technologies in RECABS (IEA, 2007)

Electricity Generation Technology	System Integration Infrastructure Costs (€/MWh)
Natural Gas Combined Cycle Power Plants	0.0
Coal Power Combined Heat Plants	0.0
Wind Onshore Power Plants	2.2
Small Hydro (Run of River) Power Plants	2.2
Nuclear Power Plants	0.0
Solar PV Power Plants	-18.4

Income From Heat Sales comes as an additional source. In addition to electricity, some technologies produce heat that can be sold to a heating system. This income should be deducted from the costs to reach more reliable results. The value of this heat can be determined in two ways. In the first approach, the value includes all costs of a heat plant since this is the alternative baseline (IEA, 2007). In the second approach, the value includes only the marginal fuel costs since the heat is a waste product of electricity generation (IEA, 2007). This study will use the second approach and assumes like RECABS that district heat will substitute heat generated from a fuel mix of 60% coal and 40% natural gas. When the REcalculator is employed based on assumptions of RECABS, income from heat sales per MWh for alternative technologies are calculated as shown in Table 14:

Table 14. Income From Heat Sales Per MWh For Alternative Technologies (RECABS)

Electricity Generation Technology	Income From Heat Sales (€/MWh)
Natural Gas Combined Cycle Power Plants	-3.05
Coal Power Combined Heat Plants	-4.72
Wind Onshore Power Plants	0.00
Small Hydro (Run of River) Power Plants	0.00
Nuclear Power Plants	0.00
Solar PV Power Plants	0.00

Total Electricity Generation Costs per MWh for each alternative technology by using the REcalculator of RECABS are as shown in Table 15:

Table 15. Performance Values of Cost Efficiency For Alternative Technologies in €/MWh

Electricity Generation Technology	Electricity Generation Cost in the Reference Scenario (€/MWh)	Electricity Generation Cost in the 450 Scenario (€/MWh)
Natural Gas Combined Cycle Power Plants	77.23	66.76
Coal Power Combined Heat Plants	39.10	30.76
Wind Onshore Power Plants	39.09	39.09
Small Hydro (Run of River) Power Plants	34.96	34.96
Nuclear Power Plants	32.97	32.97
Solar PV Power Plants	238.92	238.92

3.2. Cost Volatility Risk

Price volatility is an important factor in assessing the energy vulnerability of a country in that fluctuations in the energy prices increase the vulnerability levels. Reliance on energy types that has more price volatility increases the vulnerability of a country. Fluctuations in fuel prices that will be used in electricity generation alter the marginal electricity generation costs significantly. The uncertainty of the fuel prices during the technical lifetime of the power plants creates significant risk especially when high sunk costs of investment is considered with the long technical lifetime of power plants. This cost risk arising from fuel price volatility stands as a crucial issue in selecting electricity generation technology. Since investment costs are incurred at the beginning of the investment and operational and maintenance costs are much more predictable and small, fuel prices becomes the only input that may change average electricity generation costs significantly. Therefore different fuel price assumptions during the technical lifetime of power plants that are usually more than 20 years, alter the financial indicators of the power plant installation project and may turn a feasible project into an unfeasible one and vice versa. As fuel price volatility changes the financial feasibility of a power plant project significantly for a private investor, it may also change the change economic feasibility of a power plant project for society. So, fuel price volatility stands as a significant risk in assessing alternative electricity generation technologies. Table 16 shows annual averages of natural gas EU CIF prices and coal Northwest Europe marker prices between 1989 and 2008 as follows:

Table 16. Natural Gas EU CIF Prices and Coal Northwest Europe Marker Prices Between 1989-2008 (BP, 2009)

Years	Natural Gas EU CIF Prices (USD/million Btu)	Coal Northwest Europe Marker Prices (USD/tonne)
1989	2.09	n.a.
1990	2.82	43.48
1991	3.18	42.80
1992	2.76	38.53
1993	2.53	33.68
1994	2.24	37.18
1995	2.37	44.50
1996	2.43	41.25
1997	2.65	38.92
1998	2.26	32.00
1999	1.80	28.79
2000	3.25	35.99
2001	4.15	39.29
2002	3.46	31.65
2003	4.40	42.52
2004	4.56	71.90
2005	5.95	61.07
2006	8.69	63.67
2007	8.93	86.60
2008	12.61	149.78

Based on annual average prices in Table 16, the standard deviation of natural gas prices is 2.832 and the standard deviation of coal prices is 28.322. Dividing standard deviations by average prices, calculated by taking averages of prices available during 1989-2008 period, gives more comparable results to assess volatility of natural gas and coal. The volatilities of natural gas and coal as ratio of standard deviations to their average prices are as shown in Table 17:

Table 17. Volatility of Natural Gas and Coal Prices

Natural Gas	Coal
0.681	0.558

Performance values of cost volatility risk for alternative technologies are as shown in Table 18:

Table 18. Performance Values of Cost Volatility Risk For Alternative Technologies

Electricity Generation Technology	Cost Volatility Risk (%)
Natural Gas Combined Cycle Power Plants	68.1%
Coal Power Combined Heat Plants	55.8%
Wind Onshore Power Plants	0.0%
Small Hydro (Run of River) Power Plants	0.0%
Nuclear Power Plants	0.0%
Solar PV Power Plants	0.0%

3.3.Climate Change & Other Pollution

This attribute takes into account the impacts of alternative technologies on climate change and local air pollution from burning of fossil fuels and the impacts of radioactive emissions and nuclear accidents on human health, altogether. In RECABS, climate change and other environmental pollution are two separate externalities considered. But for the purposes of this study it is more compatible to combine these externalities and take them as a single attribute. First of all, climate change and other pollution will be explained and performance values of climate change and other pollution for each alternative technology will be assigned separately. Then performance values of climate change and other pollution will be combined for each alternative technology to create a single attribute.

***Climate Change*,** and particularly the dominating GHG CO_2 is important for electricity generation technologies. The emission is directly related to fuel consumption. Possible other greenhouse gases are converted to CO_2 equivalents. Economic consequences of climate change have been analyzed extensively by the European Commission research project Externalities of Energy (ExternE). ExternE recommends that an avoidance cost, in other words the costs of reducing the emission of greenhouse gases, should be used when pricing the greenhouse gas emissions. RECABS and this study accepts this approach and uses the market value of CO_2 as the cost of reducing GHG emissions. RECABS uses the emission factors recommended by the IPCC as shown in Table 19:

Table 19. Emission Factors of Fuels (IPCC) (IEA, 2007)

Fuel	Emission Factor (tCO2/GJ)
Steam Coal	0.098
Lignite	0.101
Natural Gas	0.056
Gas/Diesel Oil	0.074

The economic value of greenhouse gas emissions from an electricity generating plant (€/MWh) is the specific cost (€/tCO_2) times the emission coefficient (tCO_2/GJ) times the fuel consumption (GJ/MWh). So, the most important variable in calculating the externality of climate change is future prices of CO_2. In the Reference Scenario of World Energy Outlook 2009, CO_2 prices is projected to reach 43$ per tonne in 2020 and 54$ per tonne in 2030 in OECD in 2008 $ values. To contain emissions at the levels required in the 450 Scenario, CO_2 prices are projected to reach 50$ per tonne in 2020 and 110$ per tonne in 2030 in OECD in 2008 $ values. Since the carbon markets in OECD and Other Major Economies will be linked to create a single carbon market in the long run especially after 2030 this is likely to have depressing impacts on carbon prices after 2030 and this study assumes that this will compensate the upward trend in carbon prices leaving carbon prices unchanged after 2030.

In January 2010, European Union Allowance average spot prices is 12.9 € per tonne of CO_2 on European Climate Exchange. According to Eurostat, Harmonized Indices of Consumer Prices (HICP) increased by 5.7% between the end of 2006 and the end of 2009 in the Euro area. So, 12.9 € will be deflated to (12.9 / 1.057=) 12.2 € in 2006 € values. Since the price assumptions in World Energy Outlook 2009 are in 2008 $ values, these price assumptions will be deflated by the 4.3% that is the Consumer Price Index (CPI) increase in the USA in 2007 and 2008 and then will be converted to the Euro at 0.87 $/€. In the Reference Scenario, these are deflated and converted to 35.9 € for 2020 and 45.0 € for 2030. In the 450 Scenario, CO_2 prices is deflated to 41.7 € for 2020 and 91.8 € for 2030. CO_2 prices for the years 2015 and succeeding years until 2030 are derived by using linear interpolation method and CO_2 prices for the years after 2030 are assumed to have the prices in 2030. The average CO_2 prices for natural gas combined cycle power plants are calculated by taking the average of CO_2 prices during 2015-2039 period, and the average CO_2 prices for coal power combined heat plants are calculated by taking the average of CO_2 prices during 2015-2054 period. These average prices for natural gas combined cycle power plants and coal power combined heat plants in the Reference Scenario and the 450 Scenario are as shown in Table 20:

Table 20. Average CO_2 prices During 2015-2039 Period and 2015-2054 Period in the Reference Scenario and the 450 Scenario

Electricity Generation Technology	Average CO_2 Prices In the Reference Scenario (€/MWh)	Average CO_2 Prices In the 450 Scenario (€/MWh)
Natural Gas Combined Cycle Power Plants (2015-2039)	39.7	69.0
Coal Power Combined Heat Plants (2015-2054)	41.4	77.9

When the REcalculator is employed, based on assumptions about the CO_2 prices in Table 20, climate change costs per MWh for alternative technologies are calculated as shown in Table 21:

Table 21. Climate Change Costs Per MWh For Alternative Technologies

Electricity Generation Technology	Climate Change Costs In the Reference Scenario (€/MWh)	Climate Change Costs In the 450 Scenario (€/MWh)
Natural Gas Combined Cycle Power Plants	13.6	24.1
Coal Power Combined Heat Plants	31.9	60.0
Wind Onshore Power Plants	0.0	0.0
Small Hydro (Run of River) Power Plants	0.0	0.0
Nuclear Power Plants	0.0	0.0
Solar PV Power Plants	0.0	0.0

Other Pollution includes air emissions and environmental impact of the nuclear power. Air pollution causes many impacts on ecosystems and human health, with health impacts making up the largest economic externality. The highest costs of the air pollution originate from chronic mortality and the costs largely depend on how increased mortality is valued in the society (IEA, 2007). Value of Statistical Life (VSL) approach argues that the lives of elderly people are as valuable as the lives of younger people whereas Value of Life Years Lost (VLYL) argues that the value should be reduced for the elderly people since they have fewer years left to live (IEA, 2007). RECABS original project and this study uses the VLYL methodology as the reference methodology in accordance with the ExternE project.

In addition to air emissions, RECABS analyses the environmental impact of nuclear power. The environmental impact of nuclear power is very difficult to monetize with high precision. RECABS original project uses 2.5 €/MWh as an estimate for the potential cost of a nuclear accident based on an analysis taking into account historic records especially the Chernobyl accident, and safety probability assessments for new power plants. This estimate takes into account that the future plants are assumed to be considerably safer than the existing plants, and the public anxiety about nuclear power is assigned an economic value (IEA, 2007). The estimate is higher than ExternE's estimates, but this is reasonable since new risks such as terrorism have arisen since ExternE's assessments were made (IEA, 2007). This study will use RECABS default value of 2.5 €/MWh as well. In addition, 1.5 €/MWh is added to take into account the long-term health costs of radioactive emissions from abandoned mill tailings, that applies primarily to Radon 222, which is emitted from mill tailings for a period of at least

10,000 years (IEA, 2007). RECABS estimates the external costs of abandoned uranium mines as 1.5 €/MWh. This study will use this value, too.

When the REcalculator is employed, based on assumptions of VLYL methodology, other pollution costs per MWh for alternative technologies are calculated as shown in Table 22:

Table 22. Other Pollution Costs Per MWh For Alternative Technologies

Electricity Generation Technology	Other Pollution (€/MWh)
Natural Gas Combined Cycle Power Plants	0.4
Coal Power Combined Heat Plants	1.7
Wind Onshore Power Plants	0.0
Small Hydro (Run of River) Power Plants	0.0
Nuclear Power Plants	4.0
Solar PV Power Plants	0.0

To sum up, the performance values of climate change & other pollution attribute for each alternative technology in the Reference Scenario and the 450 Scenario are shown in Table 23:

Table 23. Performance Values of Climate Change & Other Pollution For Alternative Technologies in €/MWh

	The Reference Scenario			The 450 Scenario		
	Climate Change	Other Pollution	Total	Climate Change	Other Pollution	Total
Natural Gas Combined Cycle Power Plants	13.6	0.4	14.0	24.1	0.4	24.5
Coal Power Combined Heat Plants	31.9	1.8	33.7	60.0	1.8	61.8
Wind Onshore Power Plants	0.0	0.0	0.0	0.0	0.0	0.0
Small Hydro (Run of River) Power Plants	0.0	0.0	0.0	0.0	0.0	0.0
Nuclear Power Plants	0.0	4.0	4.0	0.0	4.0	4.0
Solar PV Power Plants	0.0	0.0	0.0	0.0	0.0	0.0

3.4.Supply Security

In the face of the increases in the cost of energy, and the increasing demand for the electricity, many countries are now taking new measures to ensure supply security. Within this scope, the Electricity Energy Market and Supply Security Strategy Paper was drafted by Higher Board of Planning in May 2009 to define and announce the steps necessary for ensuring the supply security, and targets for the resources to be used in the electricity supply in medium and long term.

Since taking effect of Law No 4628 on March 3, 2001, Turkey has taken substantial steps towards creating a competitive and functioning market in the electricity energy sector and implementing market rules that will ensure liberalization of the sector. Being based on the liberalization in the electricity energy sector, the main purpose of the restructuring initiative is to create an investment environment which allows those investments that are required for supply security, and to reflect onto consumers all gains that will be made through efficiency increase to be brought about by a competitive environment (Higher Board of Planning, 2009).

According to this Strategy Paper, the primary objective is to ensure delivery of the electricity, which plays an undisputable role in economic and social lives, to consumers in an adequate, high-quality, uninterrupted, low-cost, and environmentally friendly manner. In structuring of the electricity energy sector, and functioning of the market, the following principles will be adhered to:

- Creation and maintenance of the market structure in a way to ensure supply security;

- Towards a sustainable electricity energy market, taking into consideration the climate change and environmental impacts;

- Minimizing losses during production, transmission, distribution and utilization of the electricity energy; increasing efficiency; reducing electricity energy costs by building a competitive environment based on resource priorities of the energy policy; and using such gains to offer more reasonably priced electricity service to consumers;

- Encouraging new technologies, ensuring the diversity of the resources, and maximum use of domestic and renewable resources in order to reduce external dependency in energy supply;

- Increasing the share of domestic contribution in investments to be made in the sector (Higher Board of Planning, 2009).

Short, medium and long term supply security will be continuously monitored and assessed under Additional Article 3 titled “Supply Security” added to Law No 4628 by Law No 5784, and measures will be taken whenever deemed as necessary. Primary focus in such assessment will be to ensure supply-demand balance with sufficient redundancy, source diversity, external dependency, environmental impacts, sector development which is in line with targets defined according to the price formation in markets, and take measures to redirect the market in case of deviation from targets (Higher Board of Planning, 2009).

The risk of the blackout in the electricity is a very crucial issue in energy vulnerability. The non-storable nature of electricity increases the overall vulnerability that may arise from simpler issues. Moreover, in case of unexpected spike in demand, the risk of electricity supply-demand mismatch that may result in an energy failure stands as a vital issue. Although it may be argued that the unexpected demand can be met from other countries to some degree, reliance on foreign countries for electricity supply poses a very high risk for overall energy vulnerability due to non-storable nature of electricity and limited interconnection rates with other countries may stand as an impediment in electricity imports. This study considers supply security as the combined security risk of import dependency and import concentration for the primary energy source to be used in electricity generation.

Import Dependency is the share of imports in the consumption of the primary energy resource considered. As the share of imports in consumption increases, the supply security decreases and as a result the energy vulnerability of the country increases. Table 24 shows Turkey's energy imports and consumption of natural gas, mineral coal, lignite, total energy consumption and total energy imports between 2003-2007 as follows:

Table 24. Turkey's Energy Imports and Consumption by Fuel Types and Their Total Values Between 2003-2007 in toe (Nenem, 2009) (Ministry of Energy and Natural Resources (MENR), 2008)

Years	Consumption (toe)				Imports (toe)			
	Natural Gas	Mineral Coal	Lignite	General Total	Natural Gas	Mineral Coal	Lignite	General Total
2003	19,450	11,461	9,471	83,826	19,104	10,430	0	63,304
2004	20,426	12,356	9,450	87,818	19,997	10,598	0	67,190
2005	24,726	12,693	9,326	91,074	24,304	11,200	0	70,210
2006	28,867	14,901	11,188	99,642	27,727	13,088	5	77,513
2007	32,683	16,593	14,015	107,625	31,888	14,767	0	82,985

Table 25 shows general energy import dependency of Turkey between 2003-2007 as follows:

Table 25. Import Dependency of Turkey (Nenem, 2009) (MENR, 2008)

Year	Imports (toe)	Consumption (toe)	Import Dependency (%)
2003	63,304	82,074	77.13%
2004	67,190	86,200	77.95%
2005	70,210	89,199	78.71%
2006	77,513	98,138	78.98%
2007	82,985	107,625	77.11%

As seen in Table 25, Turkey is highly dependent on external energy resources and her domestic energy production is far away from being sufficient. This is one of the main problems of Turkey's energy balance. The import dependency of natural gas and coal will be mentioned further as follows:

Natural Gas Import Dependency: The share of natural gas in Turkish energy consumption is 31.2% in 2007 and the share of natural gas in electricity generation of Turkey is 48.5% in

2009 and has never fallen below 45% for the last five years. Therefore, the natural gas is the most important primary energy source used in electricity generation. The import dependency of Turkey for natural gas between 2003-2007 is as follows:

Table 26. Turkey's Natural Gas Import Dependency Between 2003 - 2007

Year	2003	2004	2005	2006	2007
Natural Gas Dependency (%)	97.4%	97.1%	97.5%	96.9%	97.7%

As seen in Table 26, Turkey imports nearly all of her natural gas consumption that poses a very serious, challenging issue in Turkey's energy vulnerability.

Coal Dependency: Coal comprises both mineral coal and lignite. As seen in Table 24, Turkey imports nearly nine tenth of her mineral coal consumption, while she does not import lignite. Since, coal power combined heat plants can use either mineral coal or lignite, the import dependency of the coal will be calculated by using aggregated values of mineral coal and lignite. Table 27 shows the coal import dependency of Turkey as follows:

Table 27. Turkey's Coal Import Dependency Between 2003 - 2007

Year	2003	2004	2005	2006	2007
Coal Dependency (%)	51.2%	50.4%	47.3%	49.3%	48.4%

Turkey's import dependency for natural gas and coal has been assessed above. The other variable that will be taken into account in the supply security is the import concentration. The import concentration of Turkey for natural gas and coal will be assessed as follows:

Import Concentration is as important as the import dependency in evaluating the supply security. Importing energy resources from a small number of suppliers decreases the supply security that increases the energy vulnerability of the country significantly. The import concentration measures the extent of diversity of energy suppliers. In calculating import concentration of a country for an energy resource, Hirschmann – Herfindahl index (HHI) is employed as a technique in the literature (Nenem, 2009).

$$HHI = \sum_{i=1}^{n} s^2$$

where n is the total number of countries that energy resources are imported from and s represents the market share in the energy supply of the country.

Table 28 shows natural gas suppliers of Turkey between 2003-2007.

Table 28. Natural Gas Suppliers of Turkey and Their Shares Within Whole Gas Imports (Nenem., 2009) (TSI, 2008)

Years	Azerbaijan	Algeria	Iran	Nigeria	Russia	Others
2003	0.0%	17.6%	16.3%	6.8%	59.3%	0.0%
2004	0.0%	15.6%	15.5%	4.9%	64.0%	0.0%
2005	0.0%	15.2%	16.4%	3.7%	64.7%	0.0%
2006	0.0%	13.5%	18.8%	3.4%	64.3%	0.0%
2007	1.4%	11.6%	17.6%	3.5%	65.6%	0.3%

As seen in Table 28, Russia has always provided more than half of Turkey's natural gas imports. Algeria and Iran have been the other important natural gas suppliers of Turkey. Table 29 shows the coal suppliers of Turkey between 2003-2007. Russia has been the major coal supplier of Turkey. However, other coal suppliers are quite diversified ranging between 7% and 10% in 2007.

Table 29. Coal Suppliers of Turkey and Their Shares Within Whole Coal Imports (Nenem, 2009) (TSI, 2008)

Years	USA	Australia	South Africa	Canada	Russia	China	Colombia	Others
2003	8.3%	7.8%	13.7%	5.0%	45.3%	7.1%	7.3%	5.5%
2004	8.5%	3.3%	10.3%	5.7%	46.5%	11.8%	7.3%	6.6%
2005	14.9%	6.1%	7.3%	5.7%	40.2%	9.0%	9.9%	6.9%
2006	9.5%	8.4%	9.3%	8.3%	41.3%	9.1%	8.6%	5.5%
2007	8.6%	8.8%	9.6%	7.2%	45.3%	8.7%	6.8%	5.0%

In HHI calculation for an energy resource, the percentage of each supplier country contributing to imports of this energy resource is used (Table 30).

Table 30. HHI Values For Natural Gas and Coal Between 2003-2007

Years	Natural Gas	Coal
2003	4,137	2,483
2004	4,602	2,602
2005	4,704	2,166
2006	4,680	2,191
2007	4,763	2,483

As seen in Table 30, Turkey's natural gas HHI values have always been above 4,000 that are far above the criticalness borderline of 2,500 and Turkey's coal HHI value is very close to the critical value of 2,500 in 2007 (Nenem, 2009).

When high import dependency is combined with high import concentration, the supply security becomes more of an issue. To measure the supply security, this study will multiply the import dependency and the import concentration. Table 31 shows the supply security of natural gas and coal for Turkey between 2003-2007.

Table 31. Supply Security of Natural Gas and Coal For Turkey Between 2003-2007

Years	Natural Gas	Mineral Coal
2003	4,029	1,271
2004	4,469	1,311
2005	4,586	1,025
2006	4,535	1,080
2007	4,653	1,202
Average	4,454	1,178

Natural gas supply is about four times less secure than coal supply, when the combined impact of import concentration and import dependency is taken into account. This comes from the fact that the natural gas import dependency is twice as much as the coal import dependency and the natural gas is twice as concentrated as the coal in terms of supplier diversification. Performance values of supply security for each alternative technology are shown in Table 32:

Table 32. Performance Values of Supply Security For Alternative Technologies

Natural Gas Combined Cycle Power Plants	4,454
Coal Power Combined Heat Plants	1,178
Wind Onshore Power Plants	0
Small Hydro (Run of River) Power Plants	0
Nuclear Power Plants	0
Solar PV Power Plants	0

3.5. Supply-Demand Mismatch

Technologies with intermittent output such as wind power, solar PV and hydro run of river, also have costs related to the integration into the surrounding energy system. Nuclear power also has an impact on system costs due to its large and inflexible nature. These are called system integration costs in RECABS and they involve infrastructure costs, balancing costs and capacity credit costs. As mentioned in the preceding sections, system integration infrastructure costs are taken into account within the attribute of cost efficiency for the purposes of this study. As will be explained further, balancing costs and capacity credit costs are related to the supply-demand mismatch and the supply-demand mismatch is indirectly related to the supply security. Since the supply security is a very key issue in this study, the supply-demand mismatch arising from the intermittent nature of renewable and nuclear energy should be evaluated separately for the purposes of this study rather than taking balancing costs and capacity credit costs into account as simple costs.

The system integration costs largely depend on the technology type, the share of intermittent power in the electricity system, whether the needed alternative flexible resources are already accessible (IEA, 2007). RECABS assumes a typical electricity system based mainly on traditional fossil fuel fired power plants, some hydro power and some intermittent electricity sources up to 10%. Balancing and capacity credit costs are important issues for technologies like wind and hydro (run of river) power since their electricity generation nature is less controllable. However solar PV has a negative system integration cost since their diurnal generation nature fits well with the demand for electricity (IEA, 2007).

Balancing Costs arise from deviations from the planned operation during the day. Also, a certain amount of disturbance reserves should be maintained in the electricity system, to sustain the balance in case of electricity outages (IEA, 2007). These two costs comprise the balancing costs. This study will employ assumptions of RECABS project for balancing costs that will be mentioned as follows: Planning wind power production one day ahead is very difficult because of the unpredictable nature of the wind. RECABS uses 4 €/MWh for balancing costs of onshore wind power, solar PV and hydro run of river by taking into account the studies and researches in this issue. RECABS assumes that these technologies other than nuclear power have a size that can be handled by the existing disturbance reserves. Since nuclear power plants installed become quite large, additional disturbance reserves are required. RECABS estimates this cost roughly as 0.7 €/MWh for the nuclear power.

Capacity Credit Costs are related to the flexibility of the power plants to adjust their production according to the system demand and related to the capacity that must be retained on the system with intermittent generation to maintain a reliable supply during a peak demand (IEA, 2007). The capacity credit cost is a long-term issue and related to system reliability, while the balancing costs are related to the periods from seconds to hours (IEA, 2007).

This study will employ assumptions of RECABS project for the capacity credit costs as follows: RECABS uses 5 €/MWh for capacity credit cost of onshore wind power and hydro run of river by taking into account the studies based on spot prices and required back up capacities; RECABS uses the added benefit of solar PV as 10 €/MWh due to its diurnal electricity generating nature; RECABS uses 5 €/MWh for the capacity credit costs of nuclear power like wind power, due to the fact that the first priority base-load nuclear power plants inflicts capacity constraints on the system and its generation time-profile differs from the electricity demand time-profile so much.

To sum up, the costs for the supply-demand mismatch for different technologies are shown in Table 33 as follows:

Table 33. Supply-Demand Mismatch Costs For Alternative Technologies In €/MWh

	Balancing Costs	Capacity Credit Costs	Total Supply-Demand Costs
Natural Gas Combined Cycle Power Plants	0.0	0.0	0.0
Coal Power Combined Heat Plants	0.0	0.0	0.0
Wind Onshore Power Plants	4.0	5.0	9.0
Small Hydro (Run of River) Power Plants	4.0	5.0	9.0
Nuclear Power Plants	0.7	5.0	5.7
Solar PV Power Plants	4.0	-10	-6.0

Since using negative and positive values for the same attribute is not compatible with the nature of GRA, solar PV's performance value will be taken as the best case of 0, and other technologies' performance values will be increased by 6. Performance values of the supply-demand mismatch for each alternative technology are shown in Table 34:

Table 34. Performance Values of Supply-Demand Mismatch For Alternative Technologies

Natural Gas Combined Cycle Power Plants	6.0
Coal Power Combined Heat Plants	6.0
Wind Onshore Power Plants	15.0
Small Hydro (Run of River) Power Plants	15.0
Nuclear Power Plants	11.7
Solar PV Power Plants	0.0

4. Empirical Analysis and Findings

The main purpose of grey relational generating is transferring the original data into comparability sequences. All performance measures have the smaller the better attribute in this study. So, the grey relational generating process adopts Equation (2) for the data of these performance values. The performance values of attributes for alternative technologies in the Reference Scenario are shown in Table 35.

Table 35. Performance Values of Attributes For Alternative Technologies In the Reference Scenario

Electricity Generation Technology	Cost Efficiency (The Reference Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The Reference Scenario)	Supply Security	Supply-Demand Mismatch
Natural Gas Combined Cycle Power Plants	77.23	0.681	14.0	4,454	6.0
Coal Power Combined Heat Plants	39.10	0.558	33.7	1,178	6.0
Wind Onshore Power Plants	39.09	0.0	0.0	0	15.0
Small Hydro (Run of River) Power Plants	34.96	0.0	0.0	0	15.0
Nuclear Power Plants	32.97	0.0	4.0	0	11.7
Solar PV Power Plants	238.92	0.0	0.0	0	0.0

For example, in the case of the cost efficiency attribute, the maximum value is 238.92 from solar PV power plant and the minimum value is 32.97 from nuclear power plant. Using Equation (2) the results of grey relational generating of wind onshore power plant is equal to (238.92 – 39.09) / (238.92 – 32.97) = 0.97028. The entire results of grey relational generating are shown in Table 36.

Table 36. Results of Grey Relational Generating For The Problem In the Reference Scenario

Electricity Generation Technology	Cost Efficiency (The Reference Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The Reference Scenario)	Supply Security	Supply-Demand Mismatch
X_0	1.00000	1.00000	1.00000	1.00000	1.00000
Natural Gas Combined Cycle Power Plants	0.78509	0.00000	0.58457	0.00000	0.60000
Coal Power Combined Heat Plants	0.97024	0.18062	0.00000	0.73552	0.60000
Wind Onshore Power Plants	0.97028	1.00000	1.00000	1.00000	0.00000
Small Hydro (Run of River) Power Plants	0.99034	1.00000	1.00000	1.00000	0.00000
Nuclear Power Plants	1.00000	1.00000	0.88131	1.00000	0.22000
Solar PV Power Plants	0.00000	1.00000	1.00000	1.00000	1.00000

In Table 36, X_0 is the reference sequence. After calculating Δ_{ij}, Δ_{max} and Δ_{min}, all grey relational coefficients can be calculated by Equation (4). For example,

Δ_{31} = 1- 0.97028 = 0.02972,

Δ_{max} = 1

Δ_{min} = 0, if ζ = 0.5, then γ (x_{01}, x_{31}) = (0 + 0.5 * 1) / (0.02972 + 0.5 * 1) =0.94390.

The entire results for the grey relational coefficients are shown in Table 37.

Table 37. Results of Grey Relational Coefficients For The Problem In the Reference Scenario

Electricity Generation Technology	Cost Efficiency (The Reference Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The Reference Scenario)	Supply Security	Supply-Demand Mismatch
Natural Gas Combined Cycle Power Plants	0.69939	0.33333	0.54619	0.33333	0.55556
Coal Power Combined Heat Plants	0.94382	0.37896	0.33333	0.65404	0.55556
Wind Onshore Power Plants	0.94390	1.00000	1.00000	1.00000	0.33333
Small Hydro (Run of River) Power Plants	0.98104	1.00000	1.00000	1.00000	0.33333
Nuclear Power Plants	1.00000	1.00000	0.80815	1.00000	0.39063
Solar PV Power Plants	0.33333	1.00000	1.00000	1.00000	1.00000

In this process, specific weights are given for each performance attribute according to their importance. The sum of weights of these attributes should be equal to 1. By using Equation (5) the grey relational grade can be calculated. The weights of each attribute should be given according to their importance. Cost efficiency and supply security are the most important attributes and supply-demand mismatch comes after them due to Turkey's limited financial sources and high energy vulnerability. Cost volatility risk, climate change & other pollution are less important than the others. Therefore the weights for each attribute will be given as follows:

Table 38. The Weights For Each Attribute

Attributes	Weight
Cost Efficiency	0.3
Cost Volatility Risk	0.1
Climate Change and Other Pollution	0.1
Supply Security	0.3
Supply-Demand Mismatch	0.2

By using Equation (5) and the weights in Table 38, the grey relational grades are calculated as shown in Table 39:

Table 39. The Results of Grey Relational Analysis For the Problem In the Reference Scenario

Electricity Generation Technology	Grey Relational Grade	Ranking Results of GRA
Natural Gas Combined Cycle Power Plants	0.50888	6
Coal Power Combined Heat Plants	0.66170	5
Wind Onshore Power Plants	0.84984	3
Small Hydro (Run of River) Power Plants	0.86098	1
Nuclear Power Plants	0.85894	2
Solar PV Power Plants	0.80000	4

In the Reference Scenario, small hydro power plants are ranked the first, followed by nuclear power plants and wind onshore power plants as the second and third respectively. Grey relational grades of these attributes are very close to each other ranging between 0.85 and 0.86. Solar PV power plant is ranked the fourth with grey relational grade of 0.80. Coal power combined heat plants and natural gas combined cycle power plants are the least attractive technologies ranking fifth and sixth respectively with grey relational grades of 0.66 and 0.51.

Since renewable energies are often at an early stage of development compared to conventional technologies, renewable energies may become more attractive due to technological progress and learning effect in the long term. Renewable technologies are expected to have the highest learning rates, thereby increasing their competitiveness in the future.

When the REcalculator is employed by using assumptions of RECABS for power plants to be commissioned in 2025, electricity generation cost per MWh decreases by 6.43 €/MWh for onshore wind power, 2.04 €/MWh for small hydro power, 0.49 €/MWh for natural gas combined cycle power plants, 128.66 €/MWh for solar PV power when capital (investment) costs and operation & maintenance costs are considered.

The study also analyzes the impact on the results of GRA when the distinguishing coefficient is set at 0.1, 0.3, 0.5, 0.7, and 0.9, respectively in the “Reference Scenario” (Table 40).

Table 40. The Impact of Distinguishing Coefficient On the Results of GRA For the Problem

Electricity Generation Technology	ζ=0.1		ζ=0.3		ζ=0.5		ζ=0.7		ζ=0.9	
	GR Grade	Rank	GR Grade	Rank	GR Grade	Rank	GR Grade	Rank	GR Grade	Rank
Natural Gas Combined Cycle Power Plants	0.191	6	0.395	6	0.509	6	0.584	6	0.639	6
Coal Power Combined Heat Plants	0.373	5	0.568	5	0.662	5	0.720	5	0.760	5
Wind Onshore Power Plants	0.749	3	0.819	3	0.850	3	0.870	3	0.885	3
Small Hydro (Run of River) Power Plants	0.792	1	0.837	1	0.861	1	0.878	2	0.892	2
Nuclear Power Plants	0.768	2	0.827	2	0.859	2	0.880	1	0.895	1
Solar PV Power Plants	0.727	4	0.769	4	0.800	4	0.824	4	0.842	4

Table 40 shows that the impact of the distinguishing coefficient on the result of GRA is very small. For all tested distinguishing coefficients, alternatives wind onshore, solar PV, coal power combined heat plants and natural gas combined cycle power plants are always ranked the third, fourth, fifth and sixth respectively. The ranks of small hydro power plants and nuclear power plants change between the first and the second depending on the distinguishing coefficients. This change comes from the fact that grey relational grades of small hydro power plants and nuclear power plants are very close to each other and the grey relational grade of nuclear power plants exceed small hydro power plants by only 0.2 and 0.3% when the distinguishing coefficients are 0.7 and 0.9 respectively.

5. Sensitivity Analysis: Grey Relational Analysis for the 450 Scenario

In order to reach robust results, sensitivity analysis are performed for the 450 Scenario in addition to the "Reference Scenario". The performance values of attributes for alternative technologies in the 450 Scenario are shown in Table 41.

Table 41. Performance Values of Attributes For Alternative Technologies In the 450 Scenario

Electricity Generation Technology	Cost Efficiency (The 450 Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The 450 Scenario)	Supply Security	Supply-Demand Mismatch
Natural Gas Combined Cycle Power Plants	66.76	0.681	24.50	4454.00	6.00
Coal Power Combined Heat Plants	30.76	0.558	61.80	1178.00	6.00
Wind Onshore Power Plants	39.09	0.000	0.00	0.00	15.00
Small Hydro (Run of River) Power Plants	34.96	0.000	0.00	0.00	15.00
Nuclear Power Plants	32.97	0.000	4.00	0.00	11.70
Solar PV Power Plants	238.92	0.000	0.00	0.00	0.00

GRA procedure will use the data in Table 41 as follows: After applying grey relational generating procedure, the results of grey relational generating are shown in Table 42.

Table 42. Results of Grey Relational Generating For The Problem In the 450 Scenario

Electricity Generation Technology	Cost Efficiency (The 450 Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The 450 Scenario)	Supply Security	Supply-Demand Mismatch
X_0	1.00000	1.00000	1.00000	1.00000	1.00000
Natural Gas Combined Cycle Power Plants	0.82706	0.00000	0.60356	0.00000	0.60000
Coal Power Combined Heat Plants	1.00000	0.18062	0.00000	0.73552	0.60000
Wind Onshore Power Plants	0.95998	1.00000	1.00000	1.00000	0.00000
Small Hydro (Run of River) Power Plants	0.97982	1.00000	1.00000	1.00000	0.00000
Nuclear Power Plants	0.98938	1.00000	0.93528	1.00000	0.22000
Solar PV Power Plants	0.00000	1.00000	1.00000	1.00000	1.00000

The grey relational coefficients for the problem are shown in Table 43.

Table 43. Results of Grey Relational Coefficients For The Problem In the 450 Scenario

Electricity Generation Technology	Cost Efficiency (The 450 Scenario)	Cost Volatility Risk	Climate Change & Other Pollution (The 450 Scenario)	Supply Security	Supply-Demand Mismatch
Natural Gas Combined Cycle Power Plants	0.74300	0.33333	0.55776	0.33333	0.55556
Coal Power Combined Heat Plants	1.00000	0.37896	0.33333	0.65404	0.55556
Wind Onshore Power Plants	0.92590	1.00000	1.00000	1.00000	0.33333
Small Hydro (Run of River) Power Plants	0.96121	1.00000	1.00000	1.00000	0.33333
Nuclear Power Plants	0.97921	1.00000	0.88539	1.00000	0.39063
Solar PV Power Plants	0.33333	1.00000	1.00000	1.00000	1.00000

The weights for each attribute will be given as follows:

Table 44. The Results of Grey Relational Analysis For the Problem In the 450 Scenario

Attributes	Weight
Cost Efficiency	0.3
Cost Volatility Risk	0.1
Climate Change and Other Pollution	0.1
Supply Security	0.3
Supply-Demand Mismatch	0.2

By using the weights in Table 44, the grey relational grades are calculated as shown in Table 45:

Table 45. The Results of Grey Relational Analysis For the Problem In the 450 Scenario

Electricity Generation Technology (The 450 Scenario)	Grey Relational Grade	Ranking Results of GRA
Natural Gas Combined Cycle Power Plants	0.52312	6
Coal Power Combined Heat Plants	0.67855	5
Wind Onshore Power Plants	0.84444	3
Small Hydro (Run of River) Power Plants	0.85503	2
Nuclear Power Plants	0.86043	1
Solar PV Power Plants	0.80000	4

As seen in Table 45, in the 450 Scenario, nuclear power plants are ranked the first, followed by small hydro power plants and wind onshore power plants as the second and third respectively. Grey relational grades of these attributes are very close to each other ranging between 0.84 and 0.86. Solar PV power plant is ranked the fourth with grey relational grade of 0.80. Coal power combined heat plants and natural gas combined cycle power plants are the least attractive technologies ranking the fifth and sixth respectively with grey relational grades of 0.68 and 0.52. Therefore, different from the outcomes of GRA in the Reference

Scenario, nuclear power plant is ranked the first and small hydro power plant the second in the 450 Scenario. The rankings of other alternative technologies in the 450 Scenario are the same with the rankings in the Reference Scenario.

In the sensitivity analysis, specific weights are given for each performance attribute according to their importance in from different viewpoints. The outcomes of GRA process for the Reference Scenario when the weights of attributes change extremely on behalf of a single attribute or issue .

When supply security and supply-demand mismatch are given the highest importance with 0.35 weight for each and all other attributes are given weight of 0.1, the weights for each attribute are as follows:

Table 46. The Weights of Grey Relational Analysis For the Problem

Attributes	Weight
Cost Efficiency	0.1
Cost Volatility Risk	0.1
Climate Change and Other Pollution	0.1
Supply Security	0.35
Supply-Demand Mismatch	0.35

By using Equation (5) and the weights in Table 46, the grey relational grades are calculated as shown in Table 47:

Table 47. The Results of Grey Relational Analysis For the Problem

Electricity Generation Technology (The Reference Scenario)	Grey Relational Grade	Ranking Results of GRA
Natural Gas Combined Cycle Power Plants	0.46900	6
Coal Power Combined Heat Plants	0.58897	5
Wind Onshore Power Plants	0.76106	4
Small Hydro Power Plants	0.76477	3
Nuclear Power Plants	0.76753	2
Solar PV Power Plants	0.93333	1

As seen in Table 47, in the Reference Scenario, solar PV power plant is ranked first with grade of 0.93. This is followed by nuclear power plants, small hydro power plants and wind onshore power plants as the second, third and fourth respectively. Grey relational grades of these attributes are very close to each other ranging between 0.76 and 0.77. Coal power combined heat plant is ranked the fifth with grey relational grade of 0.59. Natural gas combined cycle power plants are the least attractive technology ranking the sixth with grey relational grade of 0.47.

When cost efficiency is given the highest importance with 0.6 weight and all other attributes are given the weight of 0.1, the weights for each attribute are as follows:

Table 48. The Weights of Grey Relational Analysis For the Problem

Attributes	Weight
Cost Efficiency	0.6
Cost Volatility Risk	0.1
Climate Change & Other Pollution	0.1
Supply Security	0.1
Supply-Demand Mismatch	0.1

By using Equation (5) and the weights in Table 48, the grey relational grades are calculated as shown in Table 49:

Table 49. The Results of Grey Relational Analysis For the Problem In the Reference Scenario

Electricity Generation Technology (The Reference Scenario)	Grey Relational Grade	Ranking Results of GRA
Natural Gas Combined Cycle Power Plants	0.59648	6
Coal Power Combined Heat Plants	0.75848	4
Wind Onshore Power Plants	0.89967	3
Small Hydro (Run of River) Power Plants	0.92196	1
Nuclear Power Plants	0.91988	2
Solar PV Power Plants	0.60000	5

As seen in Table 49, in the Reference Scenario, small hydro power plant is ranked the first, followed by nuclear power plants and wind onshore power plants as the second and third respectively. Grey relational grades of these attributes are very close to each other ranging between 0.90 and 0.92. Coal power combined heat plant is ranked the fourth with grey relational grade of 0.76. Solar PV power plants and natural gas combined cycle power plants are the least attractive technologies ranking the fifth and sixth respectively with grey relational grades of 0.600 and 0.596.

6. Discussion and Policy Implications

In the preceding sections, the problem of ranking and selecting the best electricity generation technology has been analyzed and solutions have been proposed by using grey relational analysis procedure for the Reference Scenario and the 450 Scenario of IEA's World Energy Outlook 2009. The outcomes of GRA procedure have been very similar for both scenarios.

Since supply security and cost efficiency are the most important factors for Turkey due to her high energy vulnerability and limited financial sources, giving the highest weights to these attributes is a reliable and sound option. For the Reference Scenario, when these weights are used, GRA proposed small hydro power plants, wind onshore power plants and nuclear power plants as the first, second and third best technologies respectively with grey relational grades ranging between 0.85 and 0.86. Solar PV power plant is ranked the fourth with grey relational grade of 0.80. Coal power combined heat plants and natural gas combined cycle power plants are the least attractive technologies ranking the fifth and sixth respectively with grey relational grades of 0.66 and 0.51.

The outcomes of GRA have also been tested for the 450 Scenario and nuclear power plant is ranked the first, small hydro power plant the second in the 450 Scenario while the rankings of other alternative technologies are the same with the rankings in the Reference Scenario. Although the rankings of nuclear power plants and small hydro power plants change in the 450 Scenario, their relational grades are very close to each other ranging between 0.85 and 0.86.

The outcomes of GRA has also been tested for two cases with giving extreme priorities on behalf of a single attribute or issue in the Reference Scenario. In the first case, supply security and supply-demand mismatch attributes are given extreme importance and so very high weights compared to other attributes. For this case GRA proposed solar PV power plants, nuclear power plants, small hydro power plants and wind onshore power plants as the first, second, third and fourth best technologies respectively, while ranking coal power combined heat plants and natural gas combined cycle power plants as the worst alternatives. In the second case, cost efficiency attribute is given extreme importance and so very high weight compared to other attributes. For this case GRA proposed small hydro power plants, nuclear power plants and wind onshore power plants as the first, second and third best technologies respectively with grey relational grades very close to each other. Coal power combined heat plants, solar PV power plants and natural gas combined cycle power plants are ranked as the fourth, fifth and sixth with grey relational grades far below the best three alternative technologies.

Considering supply security and cost efficiency attributes as the highest priorities is the most reliable and sound option for Turkey because of her high energy vulnerability and limited financial sources rather than giving an extreme importance to one single attribute. For this case in the Reference Scenario, GRA proposed small hydro power plants, nuclear power plants and wind onshore power plants as the first, second and third best technologies respectively with grey relational grades very close to each other but far above other alternative technologies.

The rankings of these hydro power plants, nuclear power plants and wind onshore power plants have also been tested for different scenarios and for different extreme priorities on single attributes. The grey relational grades of hydro power plants, nuclear power plants and wind onshore power plants are very close to each other and are within the fourth best alternatives even in very extreme priorities on a single issue.

As a conclusion Turkey should focus on installing small hydro power plants, nuclear power plants and wind onshore power plants. Since hydro power and wind power are related to geographic and climatic conditions, Turkey's potential for these sources should be assessed as well.

In the First National Communication of Turkey on Climate Change (2007), economic hydropower potential of Turkey is estimated to be 130 TWh. According to PricewaterhouseCoopers (2009), Turkey has a technical hydroelectricity potential of 37.1 GW. When Turkey's 37.1 GW potential is compared to 13.8 GW installed hydro power capacity at the end of 2008, only 38% of Turkey's technical hydroelectricity potential capacity is utilized. Installed hydropower capacity comprises 33% of Turkey's total 41,817.2 installed capacity at the end of 2008. In 2009, hydro power plants generate 35.904,8 GWh of total electricity generation comprising 18.5% of Turkey's total 194,112.1 GWh electricity generation. This shows that Turkey has an immense untapped potential in hydro power to be utilized.

Turkey has an immense wind power potential due to its climatic and geographic conditions as well. Turkey's technical potential for wind energy is 83,000 MW and 166,000 GWh/year and she has the highest technical potential among the European OECD countries (Erdogdu, 2009). In the First National Communication of Turkey on Climate Change (2007), technical wind power potential of Turkey is estimated to be 88,000 MW, while economically viable potential is 10,000 MW. According to PricewaterhouseCoopers (2009), given the current grid infrastructure constraints, the highest feasible wind-power generation capacity is estimated at 20,000 MW. Despite Turkey's high wind energy potential, her total installed capacity at the end of 2009 is only 801 MW and this generates 1,963 GWh comprising 1% of her total 194,112.1 GWh electricity generation in 2009. This shows that Turkey has an immense untapped potential in wind power to be utilized.

7. Conclusion

Turkey is likely to confront with electricity energy deficiency around 2014-2015 and to prevent such a deficiency Turkey should start to install new power plants as soon as possible when the long construction periods of power plants are considered. Therefore, Turkey has a problem to rank and select the best electricity generation technology for the society from natural gas combined cycle power plants, coal power combined heat plants, wind onshore power plants, small hydro power plants, nuclear power plants and solar PV power plants by taking into account cost efficiency, cost volatility risk, supply security, climate change & other pollution and supply-demand mismatch.

Grey relational analysis procedure has been used to analyze this problem and propose solutions. Because this problem considers both quantitative and qualitative attributes and quantifying qualitative attributes creates grey areas, and the importance of these attributes may change according to the priorities of the decision maker.

This study has analyzed this problem and proposed solutions by using grey relational analysis procedure for the Reference Scenario and the 450 Scenario of IEA's World Energy Outlook 2009. The outcomes of GRA procedure have been analyzed by giving different priorities to different attributes as well. The impact of the distinguishing coefficient on the result of GRA has been tested and concluded that this impact is small. According to the outcomes of GRA, it has been concluded that Turkey should focus on installing small hydro power plants, nuclear power plants and wind onshore power plants. Since hydro power and wind power are related to natural potentials of a country, Turkey's potential for these sources has been investigated and concluded that Turkey has an immense untapped potential for these renewable energy resources.

It should not be forgotten that hydro power plants, nuclear power plants and wind onshore power plants are the best electricity generation technologies from the viewpoint of society. Leaving the electricity market to free market may not create these best solutions to be realized for Turkey because the financially most attractive technologies for the private investors are not likely to be the best ones for society. Therefore, the outcomes of this study may provide guidelines for ranking these alternative electricity generation technologies and may serve as a baseline in designing market structure and necessary incentives by the government to encourage private sector investment in the socially best technologies.

Since renewable energies are often at an early stage of development compared to conventional technologies, renewable energies will be more attractive due to technological progress and learning effect in the long term. Renewable energy technologies are expected to have the highest learning rates, thereby increasing their competitiveness in the future. Fuel prices are likely to increase in the future thereby decreasing the competitiveness of conventional technologies. Supply security and supply-demand mismatch issues for alternative technologies may change in the future as well. Therefore the ranking and selection of alternative electricity generation technologies should be analyzed by using GRA procedure periodically for about five year's periods.

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