COMPARISON OF NATURAL GAS , COAL AND WIND POWER PLANTS WITH RESPECT TO GENERALIZED COST OF ELECTRICITY GENERATION

by

Arzu Tuncer

B.S., Management Engineering, Istanbul Technical University, 2000

Submitted to the Institude for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Industrial Engineering
Boğaziçi University
2010

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my thesis supervisor, Professor İlhan Or, for his invaluable guidance, continuous support and encouragement throughout this study.

I would like to thank to experts, whom I interviewed during this study, for their help and time.

Finally, I would like to thank my family for their invaluable support and encouragement.

ABSTRACT

COMPARISON OF NATURAL GAS, COAL AND WIND POWER PLANTS WITH RESPECT TO GENERALIZED COST OF ELECTRICITY GENERATION

Power plant investment decisions leading to much needed increases in installed capacity play a crucial role in national energy policies. Accordingly, these decisions should consider not only the monetary factors, but other affected aspects as well. The objective of this thesis is to evaluate and compare the 'generalized cost of electricity generation' for natural gas, coal and wind power plants. 'Generalized cost' is the aggregation of all economical and social factors associated with power plants' investments.

The Analytic Hierarchy Process (AHP) methodology is used in this study. In this regard, ten economic, twelve social factors are considered, whose relative importances are determined through a series of hierarchically structured comparisons extracted from twenty experts.

The analysis results give the relative importance of each criterion for the generalized cost of electricity generation. According to the results, importance of economic criteria is equal to importance of social criteria. In economic criteria, the most important factor is investment cost; in social criteria, the most important factor is human health. Group analysis results show how each group perceive the relative importance of the generalized cost factors from their perspective.

Since it is not possible to get all related data for specific power plants, generic power plants are defined for coal, natural gas and wind energy sources for the purpose of comparing specific plants. Wind power plant is at the top of the overall ranking mainly because of having a renewable energy source. Natural gas power plant is in the second position, mainly because of the highest fuel cost which is the most important criterion in

the AHP structure. There are two types of generic coal power plants (coal-1 and coal-2) in the evaluation which differ in their emission control efficiencies and investment costs. Both types of coal power plants rank in the last two positions.

ÖZET

DOĞALGAZ, KÖMÜR VE RÜZGAR SANTRALLERİNİN GENELLEŞTİRİLMİŞ ELEKTRİK ÜRETİMİ MALİYETLERİNE GÖRE KARŞILAŞTIRILMASI

Elektrik santrali yatırım kararı, artan elektrik talebini karşılamak için belirlenecek enerji politikarında önemli rol oynamaktadır. Yatırım kararının verilmesinde maddi yönlerin dışında etkili olan diğer faktörler de gözönünde bulundurulmalıdır. Bu tezin amacı doğalgaz, kömür ve rüzgar santrallerinin ‘genelleştirilmiş elektrik üretim maliyetlerine’ göre değerlendirilmesi ve karşılaştırılmasıdır. ‘Genelleştirilmiş maliyet’ kavramı, elektrik santrali yatırımları ile ilgili ekonomik ve sosyal kriterlerin toplamıdır.

Bu çalışmada ‘Analitik Hiyerarşi Yöntemi’ kullanılmıştır. Bu kapsamda, on ekonomik, on iki sosyal faktör seçilmiş ve göreli önemleri yirmi uzmanla yapılan hiyerarşik yapıdaki karşılaştırmalarla belirlenmiştir.

Analiz sonuçları, genelleştirilmiş elektrik üretim maliyeti için belirlenen herbir kriterin göreceli önemini göstermektedir. Elde edilen sonuçlara göre, ekonomik ve sosyal kriterler eşit öneme sahip. Ekonomik kriterler içinde en önemli kriter yatırım maliyeti; sosyal kriterler içinde ise insan sağlığına olan etkidir. Grup analiz sonuçları, herbir grubun genelleştirilmiş maliyet kriterlerine verdiği göreli önemi göstermektedir.

Belirlenen kriterler için gereken tüm verilerin belirli bir elektrik santrali için sağlanması mümkün olmadığından, genel veriler kullanılarak doğalgaz, kömür ve rüzgar santralleri oluşturuldu. Rüzgar santrali yenilenebilir enerji ile çalışması nedeniyle değerlendirmede ilk sırada; doğalgaz santrali, en yüksek yakıt maliyeti olması nedeniyle ikinci sırada; emisyon kontrol verimlilikleri ve yatırım maliyetleri farklı olan iki kömür santrali ise son iki sırada yer aldı.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION AND PROBLEM DEFINITION

Electricity is essential for economic and social development. Socio-economic factors such as population, economic development, industrialization, urbanization and technological progress affect the electricity demand of a country. As of 2008, total electricity consumption in Turkey reached to 198,085 GWh with a 4,2% annual increase [9].

As electricity demand continues to increase, it becomes crucial to meet this demand with well-prepared energy policies to provide sufficient, good quality, continuous, low-cost electricity in a reliable manner while giving due consideration to environmental impacts. As a part of energy policies, increasing electricity demand requires new power plants investments.

When the electricity sector in Turkey is reviewed from this perspective, it is observed that at the late of 1990s, limited investments due to insufficient public funds caused a serious supply shortage. As a solution, to improve the efficiency and to ensure urgent requirement of funds for necessary investments, electricity sector reform is implemented in 2001. Although the privatization was introduced in the mid of 1980s, the radical change is done by the Electricity Market Law in 2001 [2].

It is crucial to make timely investments to meet the increasing electricity demand of a country. But for new power plant investment decisions, various economic, social and environmental factors should be considered in a balanced fashion.

In energy policies and investment decisions a key factor to thoroughly consider is the fuel used in power generation. In order not to jeopardize electricity generation and/or face serious results of supply shortage, installed capacity planning should include diversification of fuels. Currently, fossil fuels meet the majority of electricity demand worldwide. As electricity demand continues to increase, supplies of fossil fuels are expected to diminish and be more expensive. Due to these trends, many countries increasingly rely on imported fuel at unpredictable cost, sometimes from regions of the world where conflict and political instability threaten the security of supply. The status is also the same for Turkey. As of 2008, natural gas has 32% share in total installed capacity and 48,4% in total electricity production, whereas coal accounts for 25% of the total capacity and 29% of total production; while just 10 years ago (in 1998), the share in installed capacity and actual production of natural gas was 17% and 22,4% and of coal was 28% and 32,2%, respectively [7,8].

Environmental effects of electrical power generation should also be considered in national energy polices. Increasing concerns regarding environmental impacts (such as greenhouse gas effects, acid rains, water & soil pollution) have created considerable awareness of the need to utilize renewable and/or environmentally friendly energy resources for electricity generation. In recent years, especially wind energy technology has developed rapidly, resulting in sharp increase in the installed capacity of wind power plants worldwide. Just in 2008, 27 GW of new wind energy generation capacity is installed worldwide (with a 36% annual growth rate) [17]. In Turkey, (as of 2008) wind power has 0,9% share in total installed capacity and 0,4% in total electricity generation. Currently, projects with 1000MW total capacity are under construction and the target is to reach 15,000MW installed capacity by 2020 [9].

As another social aspect, power plants provide new jobs opportunities both in construction and operation periods. For example, during the construction of Enka Izmir Combined Cycle Power Plant, 5000 people worked in different phases and now for the operation of power plant, 124 people are working in technical and management departments. Although wind energy is a new sector for Turkey, in Europe, wind power electricity production provides 15 new jobs per 1 MW installed turbine [37].

In this thesis, coal, natural gas and wind energy based electricity generation plants are evaluated and compared according to a ‘generalized cost’ metric which includes economic, social and environmental aspects.

Power plants are high cost investments including land, design, construction, equipment costs. Additionally, monetary costs such as their operating costs, which include fuel, labor, maintenance and all other costs (and which can add up to very high values during the lifetime of the plants) also affect investment decisions.

Additionally, for the evaluation of power plants, non-monetary costs as well as these monetary costs should also be considered. Non-monetary costs refer to the costs that the local and global environment and communities (people, the flora, the fauna) face or incur due to the operation of power plants. For example, water, soil and air pollutions due to the emissions of power plants all have negative effects on the environment and should be considered in this context.

Furthermore, besides the environmental effects, there are other difficult to measure and price, important factors to be considered in power plants evaluations: supply stability (which is getting the fuel on time and in required amount without any interruption) is crucial for the continuity of electricity generation. It can be ensured by reduction of imported fuels, diversification of fuel resources and storability of the fuels in great quantities. Contribution to the national economy is another key factor addressing contribution to employment, value-added and know-how issues.

For a comprehensive evaluation of the power plants, all these factors should be considered. In this thesis, these factors make up the 'generalized cost' of the power plants. Generalized cost is the weighted sum of all these factors. By the calculation of 'generalized cost', different factors are converted to a common unit which enables us to compare the relative importance of each factor over the other.

In Chapter 2, in the first section historical development of the Turkish electricity market is summarized. In the second section, the privatization process is discussed with the important milestones. In the third section, current status of the Turkish electricity sector is briefly overviewed. In the last section, selected types of power plants (coal, natural gas and wind power plants) for the generalized cost comparison are described, including their status in the electricity sector, technologies, advantages and disadvantages.

Chapter 3 includes literature survey. First section summarizes some other studies on the evaluation of power plants by multi-criteria decision analysis and presents some case studies. In the second section, various implementations of the AHP methodology to different sectors and then to the energy sector are reviewed.

In Chapter 4, firstly the AHP method is explained including the model structure, judgment and comparison processes. Second section provides details about the AHP model development for the generalized electricity production cost comparison of coal-fired, natural gas and wind power plants. In the model development process, firstly factors that affect the generalized cost of electricity production are identified according to literature survey and experts' opinions. Then, generic power plants for each selected type are determined. Finally, the AHP model is structured with the identified factors and alternative power plants for the evaluation. In the next section, application of the AHP is presented including data gathering, results of the AHP model and group analysis. Last section includes the evaluation of generic power plants.

In the conclusion chapter, Chapter 5, first the overall study performed is summarized. Then, the result of the AHP model, group analysis and generic power plant evaluations are discussed. Finally, suggestions for further studies are made.

2. ELECTRICITY ENERGY IN TURKEY

In this section, firstly historical development of the Turkish electricity market is summarized. Then, privatization period is discussed and milestones are specified. Afterwards, current status of the Turkish electricity sector is summarized. The last part includes the detailed information about coal, natural gas and wind power plants, which are the selected types of power plants for the generalized cost comparison in this thesis.

2.1. Historical Overview of Electricity Market

Historical development of the Turkish Electricity Market can be summarized in five periods [1]:

- Foreign ownership, operation and control period (1923 – 1930): During this period, the electricity industry was heavily administered and controlled by foreign companies. Mostly German, Belgium, Italian and Hungarian companies were in the market generating and distributing electricity.

- Nationalization (1930 – 1950): During this period, governments played important roles on restructuring the electricity industry all over the world. In Turkey, the government implemented a five-year plan in 1933, which suggested that government play an active role in the electricity sector by direct investments in large hydro and thermal power generation facilities. Accordingly, various large state enterprises such as Etibank, Mineral Research and Exploration Institution (MTA), Electrical Power resources Survey Administration (EIE) and the Bank of Provinces and State Hydraulic Works (DSI) were established for planning, designing, building and operating electrical power generation and transmission facilities. Additionally, municipalities were allowed to build and operate power plants by the legislation.

- Monopoly (1960 – 1980): The Ministry of Energy and Natural Resources of Turkey (MENR) was established in December 1963, as the primary state institution responsible for Turkey’s energy policy and supply. This was followed in 1970 by the creation of

Turkish Electricity Administration (TEK), which would have a monopoly in the Turkish electricity sector at all stages. The ownership and control of all generation assets, except the ones owned by Cukurova Elektrik T.A.S and Kepez Elektrik Santralleri T.A.S., were transferred to the TEK. The transmission and distribution operations were left to the local municipalities. From 1970 to 1980, by giving priority to state-owned investments, total installed capacity more than doubled from 2,235MW to 5,199MW. At the end of 1980, 80% of population had direct access to electric power.

- Liberalization and Private Investments (1980 – 2000): During 1980s, liberalization in economy was the dominant trend in the country and incentives were given to the private sector to invest in many sectors. The government enacted the law 2705 in 1982 that transferred all transmission/distribution related assets to TEK from municipals to centralize the industry. This law eliminated TEK and DSI's oligopoly on building power plants and allowed the private sector to build power plant and sell their electricity to TEK. In 1984, the monopolistic powers of TEK were further diluted by allowing private entities to undertake generation, transmission and distribution of electricity. The first law setting up a framework for private participation in electricity industry was enacted in 1984 (law 3096). This law formed the legal basis for private participation through Build Operate and Transfer (BOT) contracts for new generation facilities; Transfer of Operating Rights (TOR) contracts for existing generation and distribution assets and autoproducer system for companies to produce their own electricity. In 1993, TEK was split into two separate state-owned enterprises, namely Turkish Electricity Generation Transmission Co. (TEAS) and Turkish Electricity Distribution Co. (TEDAS), in order to reduce its monopolistic power. Four years later (in 1997), the Build Operate and Own (BOO) Law (no 4283), which opened the way for Treasury guarantees for private sector participation in the construction and operation of new power plants, was enacted [4].

- Restructuring the electricity market (2000 – present): The primary law (namely Electricity Market Law) for the restructuring of the Turkish Electricity Market was enacted in 2001. Target of the restructuring effort was to establish a financially strong, stable, transparent and competitive electricity market under special law provisions, within an independent regulatory and supervisory framework. Additionally, it is aimed to supply sufficient, high-quality, continuous, low-cost electricity in an environment friendly manner. The details are explained in next section (2.2).

2.2. Privatization in Electricity Market

Privatization in the Turkish electricity sector was introduced in 1984 by passing the law 3096. Through this law, private investors were allowed to operate in all segments of electricity sector by the BOT or the TOR arrangement, in which the ownership of the public enterprises remained in the state, or autoproducer status which foresees electricity generation primarily for own needs but also allows sale of surplus electricity (that is electricity generated beyond own needs). Because of various legal and bureaucratic problems, the initiation of the first generation project was realized in 1996.

In 1994, with Treasury guarantees, the BOT projects became more attractive [3]. Until the end of 1999, 22 generators with 2,275MW total capacity started production through the BOT projects; 5,260MW total capacity TOR projects were accepted by government [2].

In 1997, the BOO projects with Treasury guarantees were made possible by the law 4283. In BOO projects, investors retained ownership of the facility at the end of the contact period.

A typical BOT, BOO or TOR generation contract includes “take or pay” obligations with fixed quantities and prices over 15-30 years. So that, the government retained most commercial risks with Treasury guarantees to cover critical commercial take-or-pay payment obligations. The structure of these contracts was a major barrier to the development of competition in the generation sector [6].

In 2001, the Electricity Market Law (EML) provided a new and radically different legal framework for the design of the electricity market [6]. The main objective of the EML was to establish a financially viable, stable, transparent and competitive electricity market and ensure independent regulation and supervision of the market, in order to provide sufficient good quality electricity to consumers at low cost, in a reliable and environment friendly manner. The law was designed to establish a competitive electricity market to promote private participation and to improve efficiency of generation and distribution. The key features of the EML can be summarized as follows [2]:

- Unbundling the electricity sector: In this direction TEAS was restructured as three separate public organizations: a generation company (EUAS), a transmission company (TEIAS) and a central public wholesale company (TETAS). The EML also required separate licenses for each activity (generation, wholesale, transmission, distribution, retail sale) and separate accounts for each license activity.

- Introducing competition in non-monopoly segments: Competition was introduced into the generation and retail sale stages. Some restrictions were placed on private generation companies in order to avoid market concentration and duplication.

- Establishing an independent regulatory authority: In order to ensure transparency and independent regulation over the sector, an administratively and financially autonomous electricity (and gas) regulatory authority the Energy Market Regulatory Authority (EMRA) was established by the EML.

- Allowing open access to distribution and transmission networks: In order to ensure a competitive environment, transmission and distribution companies were required to allow open access to their networks for third parties.

- Establishing a national competitive electricity market: The established Turkish electricity market is based on bilateral contracts between generators, distribution companies, wholesale companies, retail sale companies and eligible consumers and a balancing-settlement mechanism.

- Privatization: It is aimed to apply direct privatization in generation and distribution stages. The national transmission grid was to remain under state ownership. Foreign investment is encouraged but prohibited to have a controlling interest in generation, transmission and distribution sectors.

In March 2004, the government issued the Strategy Paper (SP) concerning electricity market reform and privatization which outlined the major steps to be taken during the period up to 2012 and addressed various technical issues [4]. At the same time; it envisaged a number of important changes to some of the key provisions of the EML. For example, according to the SP, privatization was to start through the privatization of the distribution assets. 21 distribution regions were formed. The privatization of generation plants was to start after significant progress in the privatization of distribution companies [5].

2.3. Current Status of the Electricity Sector in Turkey

2.3.1. The Generation Stage

According to 2008 data from TEIAS, Turkey's total generation capacity is 41,817 MW. In this total, EUAS's share is 23,981 MW, while BOT, BO and TOR power plants contribute 9,200MW and 8,373 MW is due to auto-producers and private generation companies. In other words, state-owned power plants control 57,4% of total generation capacity (Table 2.1).

Table 2.1. Installed Capacity (2008) [7]

Companies	**MW**	**Share (%)**
EUAS	20.146,8	48,2
EUAS's affiliates	3.834	9,2
TORs	650,1	1,5
Mobile PPs	262,7	0,6
BOs	6.101,8	14,6
BOTs	2.449	5,9
Private PPs	4.839,6	11,6
Auto-producers	3.533,2	8,4
TOTAL	41.817,2	100

In total installed capacity, the share of resources are as follows: hydro power plants 33,06%, natural gas 32%, lignite and hard coal 20,42%, imported coal 3,95%, wind 0,87% and the others 10,57% [8].

In 2008, annual total electricity production reached 198,418 GWh (with an increase of 3,5% compared to the previous year). Meanwhile, total electricity consumption grew to 198,085 GWh (with an 4,2% annual increase) [9].

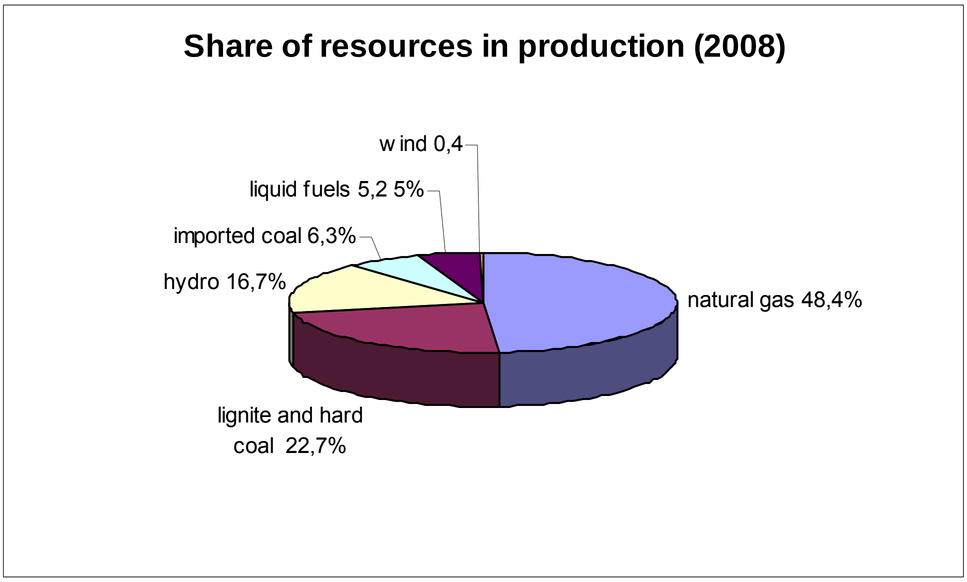


Figure 2.1. Share of resources in production (2008)

Electricity generation in Turkey is mainly based on thermal plants. As of 2008, their share in total electricity production is 82,7% while hydro and wind power plants have 16,7% and 0,4% shares respectively (figure 2.1) [8]. Natural gas fired power plants are the largest single source of generation (with 48,4% share in total production). Lignite and hard coal fired power plants have the second largest share (22,7%) and hydro power plants comes in third (16,7%). 49,3% of total production is provided by EUAS (through 104 hydro and 19 thermal power plants [9]). In 2008, Turkey exported 1,122GWh electricity, while importing 789GWh [7].

According to total electricity consumption forecasts for 2020, it will be 440,1 billion kWh in low increase rate scenario; 483,6 billion kWh in high increase rate scenario (Figure 2.2) and to meet the forecasted demands of 2020, current installed capacity should be enlarged to 80,000MW for the low increase rate scenario and to 96,000MW according the high increase rate scenarios (Figure 2.3) [9].

.

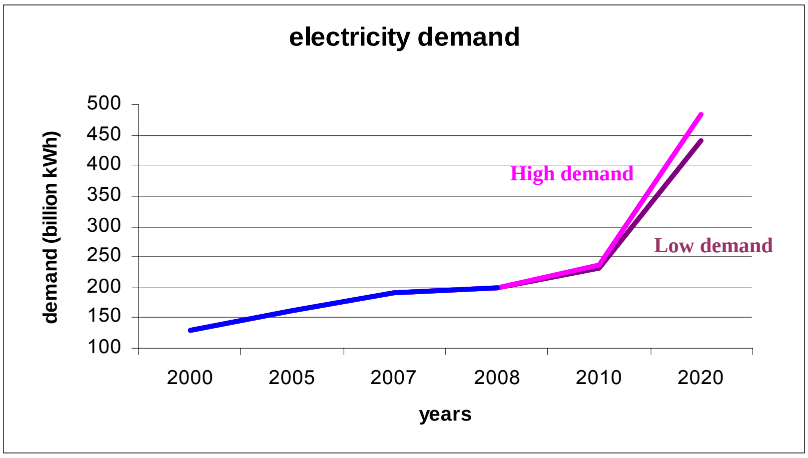


Figure 2.2. Total electricity consumption forecasts

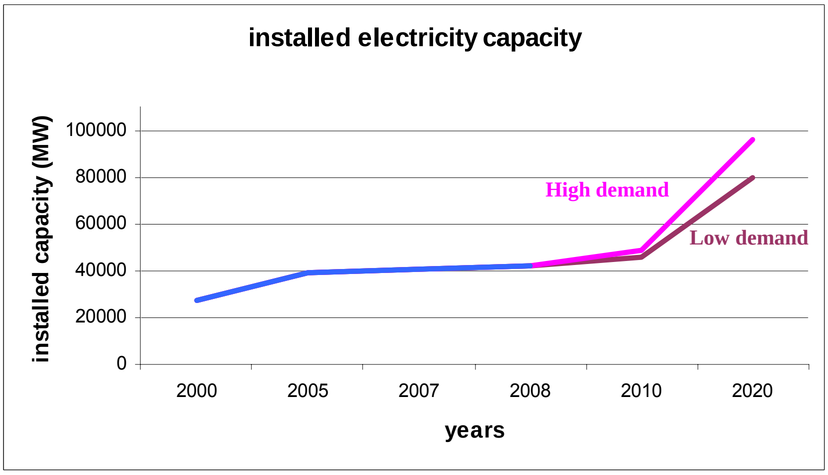


Figure 2.3. Installed electricity capacity forecasts

2.3.2. The Transmission Stage

TEIAS is responsible for the construction, operation and maintenance of the national electric power transmission grid. The transmission system is the backbone of the whole electricity system in Turkey, since most generation is undertaken in the eastern regions, where large hydro plants are located, while most of the consumption takes place in industrialized and urbanized western cities. As of 2008, TEIAS's transmission assets consist of 1241 transformers with total capacity of 89,476MVA and 46,667.1 km of power lines most of which are 380 kV and 154kV transmission lines. Transmission system losses have been 2,3% in 2008 [7].

2.3.3. The Distribution Stage

Distribution companies operate as regional monopolies, subject to regulation with distribution licenses granted by the EMRA. Turkey's distribution network is divided into 21 distribution regions based on geographical proximity, managerial structure and energy demands, as well as legal concerns and other technical/financial factors set out in Strategy Paper. Twenty regions have been placed on the privatization agenda [4]. The operation rights of Menderes Electricity Distribution Co. covering the provinces of Denizli, Aydın and Muğla, have been transferred to Aydem Electricity Distribution Co. on 15.08.2008. Tenders for the privatization of Başkent Electricity Distribution Co. and Sakarya Electricity Distribution Co. were finalized and by a block sale 100% of TEDAŞ's shares are sold to the private companies on 19.09.2008. Tenders for the privatization of Meram Electricity Distribution Co. and Aras Electricity Distribution Co. were finalized on 25.09.2008 and submitted to Privatization High Council for approval [11].

In 2008, the distribution network in Turkey consisted of 945.192 km of lines (40% mid-voltage and 60% low-voltage). There are 323,466 distribution transformers with a total capacity of 106,480 MVA. TEDAS owns 86% of existing distribution lines and 49% of transformers. Electricity losses and illegal consumption is 27,482 GWh [11].

2.3.4. Wholesale Marketing

After the EML, during the transition period (between 2001 and 2006), TETAS's share was 85% in the wholesale market. As of 2008, in line with the targets, it decreased to 43% and the remaining consists of 35 licensed companies [10].

2.4. Selected Types of Power Plants for Generalized Costs Comparison

Coal, natural gas and wind power plants are the selected types of power plants for generalized cost comparison in this thesis. As mentioned previously, natural gas and coal plants meet the majority of the electricity demand in Turkey. Natural gas has 32% share in total installed capacity and 48,4% in the total electricity production whereas coal (including lignite, hard coal and imported coal) accounts for 25% of the total capacity and 29% of total production.

On the other hand, rising costs and reduced reserves of fossil fuels, together with their negative effects on the environment, emphasize the expanding role of renewable energy sources in future energy policies. Wind power is one of the most widely used renewable energy source for electricity in the world. There is also a fast growing trend in Turkey for wind energy. As of 2008, it has 0,9% share in the total installed capacity and 0,4% in the total electricity production in Turkey.

The following sub-sections give general information about coal, natural gas and wind power plants. These selected three types of power plants are reviewed separately according to their status in electricity sector, technologies, advantages and disadvantages.

2.4.1. Coal Power Plants

Worldwide, approximately 40% of total electricity production is provided by coal power plants. Additionally, according to the study of Energy Information Administration-EIA (IEO2008), it is expected that electricity generation from coal power plants will increase 3,1% annually until 2030. But if the general upward trend in petroleum and natural gas prices continues, this rate will be higher especially in the countries having rich coal reserves. However, international agreements to reduce the greenhouse emissions may change this projection [9].

In Turkey, total capacity of coal power plants is 10,465MW, which is 25% of the total installed capacity. Production of these power plants account for 29% of total production (as mentioned in section 2.3.1.). According to the data from TEIAS report [7], coal-fired power plants' capacity is summarized in Table 2.2.

Coal resources are far more abundant than other fossil fuel resources. According to a worldwide evaluation, coal reserves will be exhausted in 133 years, whereas this period is 63 years for natural gas. The status of fossil fuel resources is same for Turkey. There are 10,4 billion tonnes lignite and 1,33 billion tonnes hard coal potential coal reserves in Turkey. Turkey has 1,6% of total lignite reserves in the world. Most of the lignite production is used in thermal power plants [12].

Table 2.2. Capacity distribution for coal-fired power plants

Companies	**Lignite (MW)**	**Hard coal (MW)**	**Imported Coal (MW)**
EUAS	4747	300	-
EUAS's affiliates	2714	-	-
TORs	620	-	-
BOs	-	-	1320
Private PPs	-	-	135
Auto-producers	177,6	255,4	196
TOTAL	8258,6	555,4	1651

Besides its relative abundance, coal is a reliable energy source, since it depends on the domestic reserves. There are already various projects to build an additional 10,000 MW capacity coal plants under different ownership and operation agreements [12].

Coal also has a price advantage compared to other fossil fuel sources. Additionally, a coal plant has a longer working life. However due to their high pollutant and greenhouse gas emissions, coal plants adversely affect the environment and human health.

Since coal is expected to remain an important source of energy for many years, priority should be given to improving the efficiency of coal-fired power plants and to the minimization of their adverse environmental impacts. Therefore, a range of technologies has been developed to tackle the emission of a variety of undesirable substances from coal-fired power plants. These systems are often referred to as Clean Coal Technologies (CCTs). A CCT is a technology which, in an economically viable manner, reduces a coal plant's emissions to enable the facility to meet or exceed the enforced emissions standards. CCTs are becoming increasingly important, as they provide a means for coal-fired plant to meet the requirements of the increasingly stringent environmental legislations applied in many countries [13].

A number of technologies are available or under development to make the process of converting coal into energy less polluting. Technologies that are directly related to generation of electricity in coal-fired power plants are divided into two categories [14]:

- In-situ control technology: It helps to reduce the amount of noxious gases released during the conversion process. In order to reduce the pollutants generated, four in-situ coal conversion systems are available [14]:
  (i) Pulverized Coal (PC) Combustion: finely ground (pulverized) coal is burnt in a furnace to generate steam that expands in a steam turbine to generate electricity.
  (ii) Fluidized Bed Combustion: In a fluidized bed, air is passed through a grate supporting a mass of inert solids at a velocity such that the solid mass behaves as a fluid, giving it the name fluidized bed.
  (iii) Supercritical Boilers: This technology can be applied to conventional PC-fired combustors and fluidized bed combustors. They generate steam at much higher pressures and temperature.
  (iv) Gasification: It is the process of converting the organic material of coal into a gaseous form. *Integrated Gasification Combined Cycle (IGCC)*, gasifies coal into fuel gas to fire a gas turbine and use the waste heat to generate steam to run a steam turbine. In a typical IGCC plant, prepared coal is fed into a gasifier where coal is gasified into CO or H_2. Due to reducing condition in gasification chamber, the majority of the nitrogen and sulphur in the coal is not oxidized, reducing the production of the atmospheric pollutants NO_x and SO_2. *Partial Gasification Combined Cycle (PGCC)*, is much the same as IGCC, the difference is in the gasification of the coal. A partial gasifier uses air instead of oxygen.

- Postconversion technology: It tries to strip harmful gases not eliminated through conversion technology. Control technologies remove SO_2, NO_x, particulates and CO_2 from the flue gas. They are summarized separately for each emission [13]:
  - (i) Sulphur dioxide (SO_2): There are two basic types of control system that remove SO_2 from combustion gases exiting the boiler. Flue gas desulphurization (FGD) systems operate within existing ductwork, primarily in PC plant, and are capable of reducing SO_2 emissions, typically by 50-70%. For larger plants, FGD systems based on scrubber technologies are often used and can achieve reductions more than 95%.
  - (ii) Nitrogen oxides (NO_x): There are essentially three types of technique for controlling and minimizing NO_x formation. In PC plant, NO_x can be controlled through air and fuel staging and special designs of low-NO_x burners, resulting in NO_x reductions by 60%. In "reburning" technique NO_x is broken down into molecular nitrogen and 70% reduction can be achieved. In "selective catalytic reduction" (SCR) and "selective non-catalytic reduction" (SNCR) techniques, NO_x control measures rely on the injection of ammonia or urea into the flue gases. Such techniques can reduce NO_x emissions by up to 90%.

  - (iii) Particulates: Different types of technologies are used to control particulate emissions from coal-fired power plants. Examples of these technologies are:
    - Electrostatic precipitators (ESPs): In this system, particulars in gas stream are collected by suitable electrode via an electric field. They are widely applied in power plants and are capable of achieving collection efficiencies of more than 99.5%.
    - Fabric filters: Particles are hold by the filters as the stream passes through multiple filter bags (manufactured from high-temperature synthetic fibres).
    - Wet particles scrubbers: A large number of variants (foam, film, spray columns, etc) are available, based on the use of a liquid medium to collect flue gas particulates.
    - Hot gas clean-up systems: Particles in the gas stream are trapped as the gas passes through a series of porous filters (tubes, candles and other configurations).

(iv) Carbon dioxide (CO_2): Coal produces more CO_2 than other fossil fuel. There are several methods for controlling and minimizing the amount of CO_2 emitted from coal-fired power plants:

- Improved plant efficiency: Increased plant efficiency means that less coal is burned (producing less CO_2) for the same power output. This can be achieved through the improvement of existing (PC) plants or deploying newer technologies. For instance, fluidized bed combustion (CFBC) power plants are often capable of burning low grade coals much more efficiently than a corresponding PC unit.
- CO_2 capture: The main approach to controlling CO_2 emissions is to capture it from the combustion flue gases. Types of CO_2 capture technologies based on both chemical and physical absorption principles. The majority of chemical-based methods rely on scrubbing systems that utilize amine solutions to remove CO_2 from exhaust gases. Such systems can capture up to 98% of the CO_2 present, and produce a CO_2 stream of up to 99% purity. Physical absorption-based technologies are generally applied to systems operating at higher pressures. These rely on a range of solvents that include methanol and propylene carbonate.

2.4.2. Natural Gas Power Plants

Natural gas, because of its clean burning nature and easy deployment (once its continuous availability is established through sound supply agreements and pipelines), has become a very popular fuel for the generation of electricity. According to the study of Energy Information Administration-EIA (IEO2008), it is expected that electricity generation from natural gas power plants will increase 3,7% annually until 2030 and the share of natural gas power plants in total electricity generation will reach to 25% [9].

In Turkey, total capacity of natural power plants is 14,601 MW which is 32% of the total installed capacity. Production of these power plants account for 48,4% of total production (as mentioned in section 2.3.1.). According to the data from TEIAS report [7], natural gas power plants' capacity is summarized in Figure 2.4.

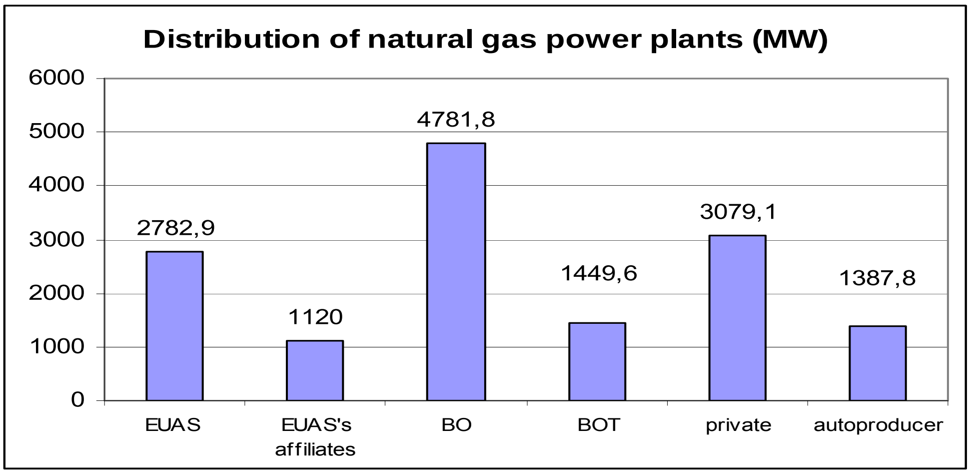


Figure 2.4. Distribution of natural gas power plants

Turkey has 21.86 billion m^3 natural gas reserves and can meet only 4% of its natural gas demand [12]. Turkey comes in second after China, for electricity and natural gas demand growth rates. For this reason, especially in winters when the natural gas demand peaks (because of its triple use in electricity generation, space and industrial heating), any problem in imports can cause serious problems. As a precaution, there are some projects to increase storage capacity.

Since natural gas is cleaner than coal and petroleum, natural gas power plants have significantly lower emissions than other fossil fuel plants. Combustion of natural gas emits up to 80 percent less nitrogen oxides than the combustion of coal; almost 30 percent less carbon dioxide than oil, and just under 45 percent less carbon dioxide than coal. Figure 2.5 shows the CO_2 emissions by fuel types between 1990 and 2030 according to data from EIA Energy outlook report. Emissions of particulates from natural gas combustion are 90 percent lower than from the combustion of oil, and 99 percent lower than burning coal [15].

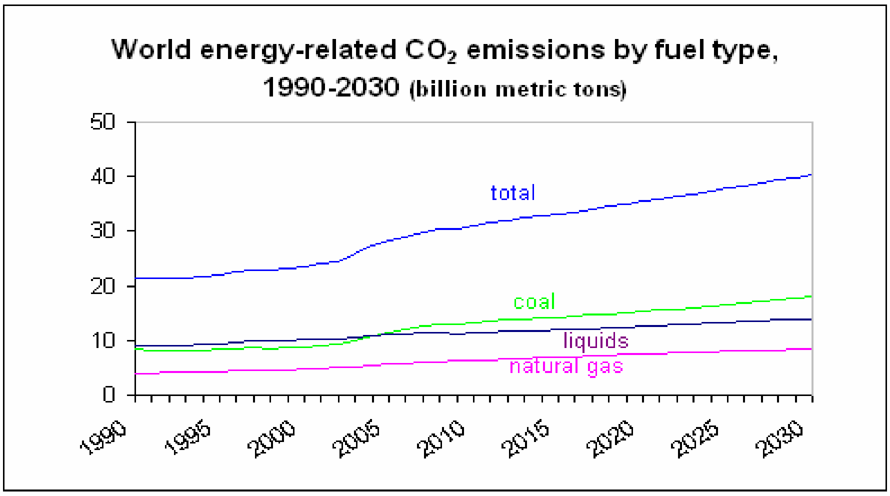


Figure 2.5. CO_2 emissions by fuel types

New technology has allowed natural gas to play an increasingly important role in the clean generation of electricity. Natural gas can be deployed to generate electricity in a variety of ways [15]:

- Steam Generation Units: The most basic natural gas fired electric generation consists of a steam generation unit, where fossil fuels are burned in a boiler to heat water and produce steam, which then turns a turbine to generate electricity. These basic steam generation units have fairly low energy efficiency. Typically, only 33 to 35 percent of the thermal energy used to generate the steam is converted into electrical energy in these types of units.

- Centralized Gas Turbines: Gas turbines and combustion engines are also used to generate electricity. In these types of units, instead of heating steam to turn a turbine, hot gases from burning natural gas are used to turn the turbine and generate electricity. These plants have increased in popularity due to advances in technology. However, they are still slightly less efficient than large steam-driven power plants.

- Combined Cycle Units: Many of the new natural gas fired power plants have combined-cycle units. In these types of generating facilities, there is both a gas turbine and a steam unit, all in one. The gas turbine operates in much the same way as a normal gas turbine, using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed towards generating steam, which is then used to generate electricity much like a steam unit. Because of this efficient use of the heat energy released from the natural gas, combined-cycle plants are much more efficient than steam units or gas turbines alone. Combined-plants can achieve thermal efficiencies of up to 50 to 60 percent.

2.4.3. Wind Power Plants

Reducing reserves of fossil fuels together with their increasing negative effects on the environment have given priority to renewable energy sources. As wind energy is an alternative clean energy source compared to fossil fuels, systems that convert wind energy to electricity have developed rapidly.

Wind energy is clean, domestic and renewable energy with the following advantages compared to fossil fuels [18,19,20] :

- There is no carbon dioxide and sulfur content releases from wind power plants. The most important gain of wind power utilization is the environmental benefit of displacing fossil fuel usage and a reduction in the adverse environmental impacts of fossil fuel consumption.
- Energy sustainability can be better achieved by giving more priority to domestic resources in the energy mix. Wind power contributes to energy diversification strategy.
- Wind power plants have shorter construction times than fossil fuel power plants (6 months for wind compared to 2-3 years for fossil fuels).
- Only 1% to 3% of the total area is occupied by the turbines, remaining is available for other uses such as agriculture and forestry.

On the other hand, there are some disadvantages of wind energy [18,19,20] :

- More than one turbine is needed for large-scale production and wind energy installations require larger areas than conventional power plants.
- Wind is an intermittent power source that is available only when the wind blows.

- Environmental concerns with wind power are related to visual, sound and wildlife impacts of wind farms. For the noise problem, distance plays an important role in the perceived sound level. The noise from a wind turbine can reach moderate levels (< 50dBA) when the distance from the turbine to the receptor is between 200 and 300 m.
- Electromagnetic interference with television and radio signals within 2-3 km of large installations also creates some problems.

The rapid development in the wind energy technology has made it an alternative to conventional energy systems in recent years.

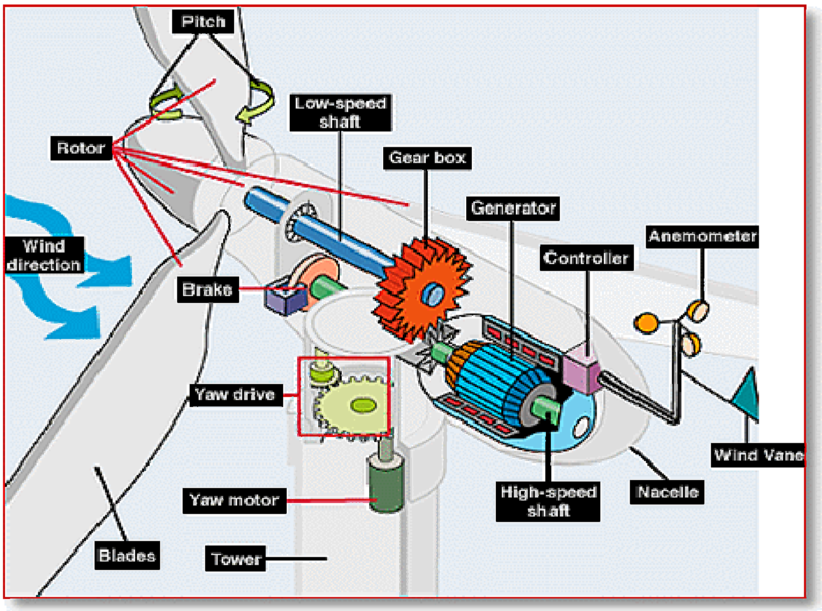


Figure 2.6. Components of a wind turbine

There are three types of wind turbine: *Horizontal axis* which has its blades rotating on an axis parallel to the ground. *Vertical axis* which has its blades rotating on an axis perpendicular to the ground. *Oblique axis* in which there is a specified angle between blades and rotation axis.

The majority of commercial turbines operate on a horizontal axis with three evenly spaced blades. These are attached to a rotor from which power is transferred through a gearbox to a generator. Gearbox and generator are contained within a housing called a nacelle. Components of a horizontal wind turbine are given in Figure 2.6. Some turbine designs avoid a gearbox by using direct drive. Electricity is then transmitted down the tower to a transformer and eventually into the grid network. Wind turbines can operate across a wide range of wind speeds. The majority of current turbine models can adapt and make best use of the constant variations in the wind by changing the angle of the blades through 'pitch control' and by turning or "yawing" the entire rotor as wind direction shifts and by operating at variable speed. Operation at variable speed enables the turbine to adapt to varying wind speeds and increases its ability to harmonize with the operation of the electricity grid. Sophisticated control systems enable fine tuning of the turbine's performance and electricity output [16].

Since the 1980s, when the first commercial wind turbines were deployed, their installed capacity, efficiency and visual design have all improved enormously. Wind turbines have grown larger and taller. The generators in the largest modern turbines are 100 times the size of those in 1980. Over the same period, their rotor diameters have increased eight-fold. The main driver for larger capacity machines has been the offshore market, where placing turbines on the seabed. Turbines with 5 MW and above are now expected to become the standard in the coming years. For turbines used on land, the past few years have seen a leveling of turbine size in the 1.5 to 3 MW range. This has enabled series production of many thousands of turbines of the same design, enabling teething problems to be ironed out and reliability increased. The main design drivers for current wind technology are: reliability, grid compatibility, acoustic performance (noise reduction), maximum efficiency and aerodynamic performance, high productivity at low wind speeds, offshore construction capability. Ongoing innovations in turbine design include the use of different combinations of composite materials to manufacture blades, (especially to reduce their weight) variations in the drive train system to reduce loads and increase reliability; and improved control systems, partly to ensure better compatibility with the grid network [16].

The world's total installed wind energy based generation capacity reached 121 GW at the end of 2008, over 27 GW of which came online in 2008 alone, representing a 36% growth rate in the annual market (as mentioned in Introduction section). Figure 2.7 shows the global cumulative installed capacity between 1996 and 2008. Three regions are continuing to drive global wind development: North America, Europe and Asia, with the majority of 2008's new installations evenly distributed between them (Figure 2.8).

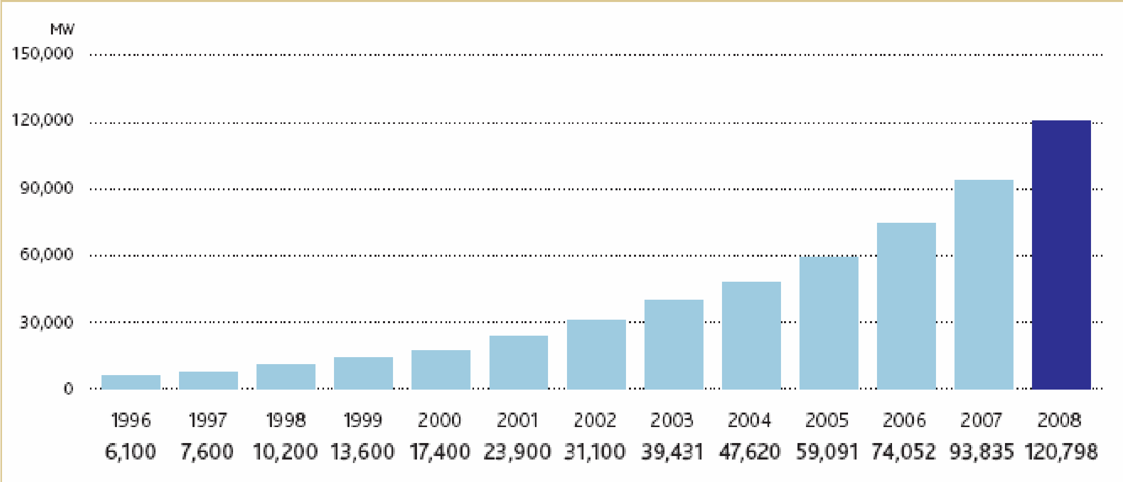


Figure 2.7. Global Cumulative Installed Capacity 1996-2008 [17]

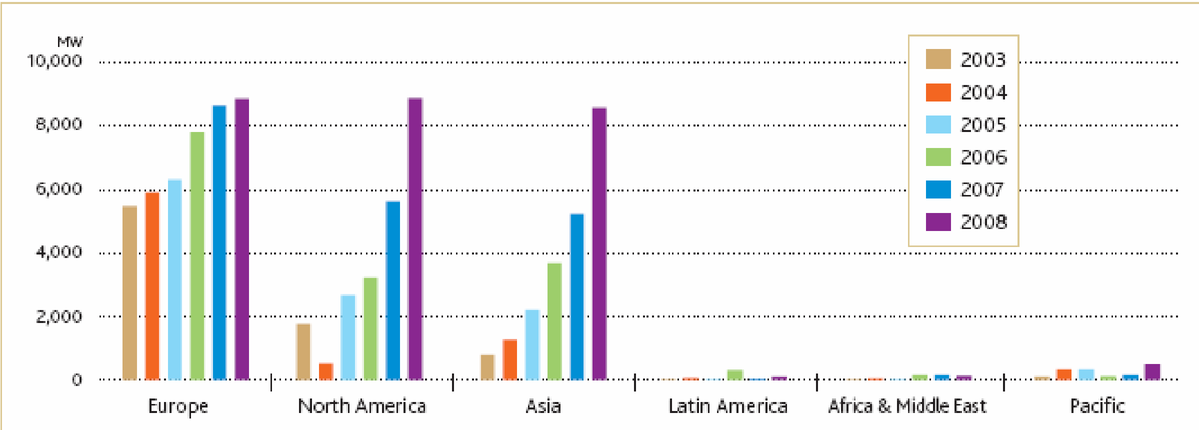


Figure 2.8. Annual installed capacity by region 2003-2008 [17]

In Turkey, first wind power plant was installed in 1998 in İzmir with 1,5MW nominal capacity [18]. Wind power, as a potential energy, has grown at an impressive rate. Installed capacity, which was 18 MW in 2004, reached to 364 MW at the end of 2008 (Figure 2.9) and private sector owns 95% of this capacity.

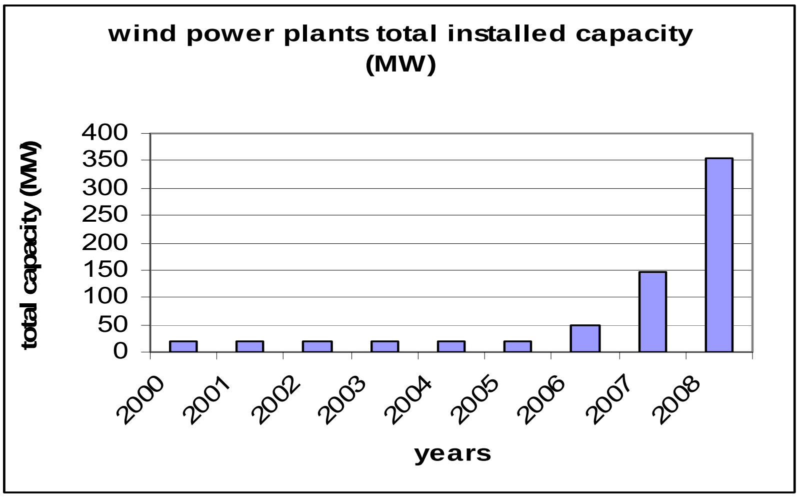


Figure 2.9. Wind power plants total installed capacity between 2000-2008

However, still wind power has just 0,9% share in the total installed capacity and 0,4% in the total electricity production in Turkey (as mentioned in section 2.3.1). After Renewable Energy Law was enacted, 80 new wind power projects were approved and licensed with 2,887 MW total capacity. Currently 1,000 MW of these projects are under construction (Table 2.3) and target is to reach 15,000MW installed capacity in 2020 (as mentioned in Introduction section) [9].

Table 2.3. List of ongoing wind power plant projects

Ongoing Wind Power Plant Projects	
Locations	**Capacity (MW)**
Aydın-Didim	31,5
Hatay-Samandağ	35,1
Hatay-Samandağ	22,5
Osmaniye-Bahçe	135
İzmir - Çeşme	22,5
İzmir - Çeşme	15
Manisa-Soma	140,8
Balıkesir-Susurluk	19
Balıkesir-Bandırma	45
Tekirdağ-Şarköy	28,8
Balıkesir-Havran	16
Çanakkale-Ezine	20,8
Hatay-Belen	30
Manisa-Kırkağaç	25,6
Edirne-Enez	15
İzmir-Aliağa	30
İzmir-Aliağa	90
İzmir-Aliağa	30
İzmir-Foça	30
Balıkesir-Kepsut	54,9
Manisa-Soma-Kırkağaç	90
Balıkesir-Kepsut	142,5
TOTAL	**1070**

According to Turkey Wind Energy Potential Atlas in 2007, wind energy potential is 5,000 MW for the areas where wind speed is 8,5m/s or above; 48,000 MW for the areas where wind speed is over 7,0m/s [12].

3. LITERATURE SURVEY

3.1. Evaluation of Power Plants

Evaluation of power plants should include all related factors both monetary (such as economic factors such as investment costs, operation costs) and non-monetary (such as environmental, health and social effects). For the assessment of the overall situation, numerous criteria depending on several aspects and different groups of stakeholders (involved in or affected from economic, social, environmental factors) should be involved in the process. Therefore, multi-criteria decision analysis is used in most of the studies about the evaluation of power plants.

Multi-criteria decision analysis provides a reliable methodology to rank alternative projects/scenarios in the presence of numerous objectives and constraints. Mostly used multi-criteria analysis methods can be classified as [35]:

- Outranking methods: It is based on the principle that one alternative may have a degree of dominance over another, rather than the supposition that a single best alternative can be identified. The concept was defined by B. Roy in the 1970s. Examples: the ELECTRE , the PROMETHEE I and II methods REGIME Analysis.

- Value or Utility function-based methods: The goal is to find a simple expression for the decision-maker’s preferences. Through the use of utility/value functions or pair-wise comparisons, this method transforms diverse criteria (such as costs, risks, benefits, stakeholder values) into one common dimensionless scale (utility/value). Examples: Multi-Attribute Utility Theory (MAUT), Simple Multi-Attribute Rated Technique (SMART), the Analytic Hierarchy Process (AHP) and the most elementary multi-criteria technique Simple Additive Weighting (SAW)

Several studies have been carried out on power plants evaluation. Some of them focus on particular types of power plants (like renewable energy resources as in the study of Georgopoulou, Lalas and Papagiannakis [28]), some others focus on economic, environmental or technological aspects separately [23]. For these evaluations, different multi-criteria analysis methods are used. Examples of power plants evaluation with different multi-criteria analysis methods (other than the AHP) are summarized in this section.

PROMETHEE (Preference Ranking Organization Methods for Enrichment Evaluations) and ELECTRE are the mostly used out-ranking methods in power plants evaluations. They are introduced by B. Roy and include two phases: construction of an outranking relation and exploitation of this relation. In the first phase, a valued outranking relation based on a generalization of the notion of criterion is considered: a preference index is defined and a valued outranking graph, representing the preferences of the decision maker, is obtained. The exploitation of the outranking relation is realized by considering for each action a leaving and an entering flow in the valued outranking graph [34].

In Georgopoulou, Sarafidis and Diakoulaki's study [33], different types of renewable energy power plants are evaluated in six alternative scenarios according to eight criteria (investment cost, fraction of investment cost paid in foreign currency, cost for imports of fossil fuels, cost of electricity generation, risk of climate change, air pollution, conservation of non-renewable energy sources, contribution to employment). They used PROMETHEE II in their study, and according to their results, the most preferred scenario is solar energy.

Tzeng, Shiau, Lin [25] evaluate eight energy-system alternatives (solar thermal, solar photovoltaics, fuel cells, wind energy, bio-fuels, geothermal energy, ocean energy, hydrogen energy) according to technological, social, environmental and economic criteria. PROMETHEE II is used to rank the alternatives and solar thermal energy is the resulting preferred choice.

Georgopoulou, Lalas and Papagiannakis [28] evaluate eight energy strategies including different power plants (wind, biomass, hydro, solar thermal) according to economic, technical, political and environmental criteria. They used ELECTRE III in their study. In their results, strategies including biomass and wind power plants are preferred over the others.

In Siskos and Hubert’s study [32], oil, coal, nuclear, solar thermal and solar photovoltaic power plants are compared according to social and health aspects. Then, four energy strategies are evaluated by using ELECTRE method in their study.

3.2. Implementation of the Analytic Hierarchy Process (AHP) Methodology

In this thesis, the AHP method is used for the evaluation of power plants. In this section, application areas of the AHP are reviewed and examples of the AHP applications for power plants evaluations are summarized.

3.2.1. Implementation of the AHP Methodology for Different Areas

The AHP is a multi-criteria decision-making approach in which factors are arranged in a hierarchic structure. After the selection of criteria, the AHP model is formulated as a hierarchic structure including the goal at the top level.

The AHP is a methodology for structuring, measurement and synthesis. It has been applied to a wide range of problem situations involving selection among competing alternatives in multi-objective environments regarding the allocation of scarce resources. Application areas of the AHP can be summarized as [30,31,39]:

- Choice: Choice decisions involve the selection of one alternative from a given set of alternatives, usually in a multi-criteria environment, which includes product selection, vendor selection, structure of an organization and policy decisions. For example, Xerox Corporation has used the AHP in major decision situations, such as R&D decisions on portfolio management, technology implementation, engineering design selection, product-market matching, customer requirement structuring [31]. The AHP can also be used in selection of facility location, suppliers and products.

- Prioritization / Evaluation: Prioritization involves determining the relative merit of a set of alternatives, as opposed to selecting one alternative as in choice applications. The AHP derived priorities (weights) are ratio measures, the priorities can be used in selecting a combination of alternatives or in allocating resources such as evaluating education opportunities, performance analysis.

- Resource Allocation: An effective allocation of resources is key to achieving an organization's objectives. Since most organizations have multiple objectives, it is difficult to ascertain the relative effectiveness of resources toward the achievement of the goals. There are multiple perspectives, multiple objectives and numerous resource allocation alternatives in an organization and the AHP can be used for reaching a satisfactory solution. In the AHP process, design alternatives (alternative R&D projects, operational plans for alternative levels of funding for each of the organization's departments, e.g.) are identified. Then, the organization's goals divided into objectives, sub-objectives. On a rational scale, it is measured that how well each alternative contributes to each of the lowest level sub-objectives. Finally, the best combination of alternatives, subject to budgetary, environmental and organizational constraints, is found.

- Benchmarking: Comparison or benchmarking of key business process with other best-of-breed companies is instrumental in gaining a competitive advantage. It involves the evaluation and synthesis of many factors, both quantitative and qualitative. For example, IBM Rochester, Minnesota's computer integrated manufacturing team used the AHP to benchmark their process against best-of-breed companies throughout the world. This effort helped make IBM's AS400 project extremely profitable [31].

- Quality Management: The basic foundations of the AHP (structuring complexity, measurement and synthesis over multiple dimensions) are applicable to numerous aspects of quality management and total quality management. For example, Latrobe Steel Company uses the AHP in its continuous quality improvement program [31]. A hierarchical cause-and-effect AHP model was developed with its focus on the areas that needed to be controlled to improve the process.

- Public Policy: Public policy decisions are complex, not only because they involve competing objectives but also they impact multiple economic sectors. For example, The Environment and Policy Institute, Hawaii uses the AHP in regional seas management for discussing regional seas management problems by experts and policy makers from the countries involved [31].

- Health Care: The case of Madigan Army Medical Center of Tacoma can be considered as a typical example of the application of the AHP to the Health Care sector [31]. This company used the AHP for quick determination of the type of medical personnel to activate and dispatch in case of a disaster. This AHP model centers on the requirements of five different natural disasters. Four different hazard mechanisms (building collapse, fire, etc.) are evaluated with respect to each type of disaster. The lowest level contains seven alternatives for the best medical response team. The model can also be used for medical force planning. The AHP can also be used in medicine such as drug effectiveness, therapy selection.

- Strategic Planning: The AHP can assist an organization in selecting among alternative missions, strategies and allocating resources to implement the chosen strategy.

- Cost and Benefit Analysis: The case of Hong Kong based Electronics Company [39] can be considered as an example of the application of the AHP for cost-benefit analysis. The AHP was used for cost-benefit analysis for the decision whether concurrent engineering could be implemented in the organization or not. A five level model was structured for computing the benefits (effect on the quality, reduced product cost,reduced time to market, customer focus) and the costs (initial investment, the cost of training and development, cost of new technologies, and the costs of risk and uncertainty) incurred by implementing concurrent management. According to the analysis results, it was inferred that overall the benefits were superseding the costs, and hence the concurrent engineering technology can be implemented.

- Forecasting: The AHP can be used for demand forecasting, technological forecasting and financial forecasting in different areas (such as management, finance, government and engineering).

3.2.2. Implementation of the AHP Methodology for the Evaluation of Power Plants

The AHP is an effective tool that can be used for the hierarchical decomposition of a complex problem for evaluation and decision making. The AHP process can be summarized in 4 steps. In the first step, hierarchy is structured including the goal, criteria and decision alternatives. Secondly, criteria weights are calculated. As a third step, decision alternatives for each criterion are evaluated. In last step, numerical values are calculated for each decision alternative, which gives its status for the achievement of the goal [26]. The AHP is used in many studies for power plant evaluation purpose.

Chatzimouratidis and Pilavachi have done various studies about the evaluation of power plants and used the AHP. In one of their studies, they investigated and sought the best power plant according to technology & sustainability and economic criteria. They deployed a five-level model. Level 1 shows the goal which is the choice of the best power plant. Level 2 shows the two main criteria (technology-sustainability and economy). In level 3, technology and sustainability criterion is divided into four subcriteria which are 'efficiency', 'availability', 'capacity' and 'reserves-to-production ratio'. Economic criterion is broken into four subcriteria: 'capital costs', 'operation and maintenance (O&M) cost', 'fuel cost' and 'external cost'. Level 4 shows the components of O&M costs which are fixed and variable costs. Finally, level 5 comprises the ten types of power plants (coal/lignite, oil, natural gas turbine, natural gas combined cycle, nuclear, hydro, wind, photovoltaic, biomass, geothermal) as alternatives. Criteria weights are calculated by the subjective pairwise comparison. For the power plants' scoring against each criterion, data obtained from the International Atomic Energy Agency (IAEA) database is deployed. Their results indicate that, reserves-to-production ratio (sub-criterion of technology & sustainability) is the most important criterion in the model and hydro power plant is the most desirable power plant among the alternatives [21].

The same authors, made the subjective and objective evaluation of non-radioactive emissions from power plants and put this goal in the level 1 in their model. Level 2 includes two criteria: subjective assessment and objective assessment. Level 3 shows the sub-criteria of subjective assessment (human health and environmental effects) and level 4 as final level comprises the 5 non-radioactive emissions (non-methane volatile organic compounds (NMVOCs), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter) from the power plants. According to the result, particulate matter has the highest criterion weight among other non-radioactive emissions. Then ten types of power plant are evaluated according to these emission criteria. According to the results obtained, the less an emission, the better is the overall evaluation of a plant; nuclear power plant has the highest overall score, whereas coal-fired power plant has the lowest [22].

Chatzimouratidis and Pilavachi also investigated the overall impact of power plants on the living standard of local communities. The goal of the AHP model in this case has been the maximization of the living standard caused by the operation of power plants (Level 1). Level 2 shows two criteria: quality of life and socioeconomic aspects. In Level 3, 'quality of life' criterion is broken into four sub-criteria: 'accident facilities', 'non-radioactive emissions', 'radioactivity' and 'land requirement'. 'Socioeconomic aspects' criterion is broken into three sub-criteria: 'job creation', 'compensation rates', 'social acceptance'. Level 4 shows the components of non-radioactive emissions (non-methane volatile organic compounds (NMVOCs), carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and particulate matter). Level 5 comprises ten types of power plant as alternatives. Criteria and sub-criteria weights are calculated according to the pairwise comparison. As a result, radioactivity turned out to be the most important factor for evaluation and geothermal power plant had the highest overall score [23].

Pilavachi, Stephanidis, Pappas and Afgan evaluated hydrogen and natural gas power plants by the AHP. Hierarchy is structured as follows: level 1 is the goal of the study which is the choice of the best energy generation option. Level 2 shows the criteria: efficiency, CO_2 emission, NO_x emission, capital cost, O&M costs, electricity cost and service life. Level 3 comprises options of four different hydrogen and five different natural gas power plant technologies. According to different weightings of the criteria (subjectively distributed weights, equally distributed weights, giving full emphasis to a single criterion, giving different emphasis to the criteria), 19 different scenarios are evaluated. As a result, hydrogen combustion turbine turned out to be in the first place as the most preferred electricity production technology in 15 scenarios [26].

Tzeng, Shiau and Lin evaluated 8 energy systems (solar-thermal, solar photo-voltaics, fuel cells, wind, bio-energy, geothermal, ocean and hydrogen) according to technological, social, environmental and economic criteria. They used the AHP only for the deriving weights of each criterion by pairwise comparison. Another method (PROMETHEE II) is then used for the evaluation of energy systems according to these criteria [25].

As a summary, there are many studies for the evaluation of power plants, but the content of the studies are different. In some studies, power plants are evaluated in details according to one aspect (only for environmental effects, etc.) (Chatzimouratidis and Pilavachi [22,23]). Some studies include different aspects with only the most important factors of these aspects [24,26,27]. For example, in Afgan and Carvalho's study [24] and in Afgan,Pilavachi and Carvalho' study [27], CO_2 is the only factor representing the environment. Regarding the types of power plants considered, some studies evaluate different types of power plants [21,22,23,24,25], whereas some of them focus on a specific type of power plant (natural gas power plants in Afgan,Pilavachi and Carvalho' study [27]). All these studies indicate that there are two main aspects, economic and social, for the evaluation of power plants; but the selected criteria for these aspects are different in each study.

4. THE AHP MODELING OF GENERALIZED COST OF NATURAL GAS, COAL AND WIND POWER PLANT INVESTMENTS

Power plant investment decisions leading to much needed increases in installed capacity play a crucial role in national energy policies. Accordingly, these decisions should consider not only the monetary factors, but other affected aspects as well. The objective of this thesis is to evaluate and compare the 'generalized cost of electricity generation' for natural gas, coal-fired and wind power plants. 'Generalized cost' it is the weighted sum of economical and social factors for power plants' evaluation.

The AHP methodology is used in this study, which is composed of five main stages: AHP model formation, data collection, AHP model analysis, group analysis and evaluation of generic power plants.

For the formulation of AHP model, firstly generalized electricity cost factors are identified and classified. These factors include both possible economic and social impacts resulting from electricity generation activities. Then, expert opinions are taken about this general framework of the model, in order to determine if there are any missing or unnecessary criteria in the model. Next, for each resource, generic plants are determined according to finalized criteria in the model. As a last step, the AHP model is structured.

After the model formulation, interviews are done with different groups of experts, where they are requested to respond to a questionnaire. In the questionnaire, each expert makes pairwise comparisons for each criterion within the hierarchic structure. The experts' subjective judgments obtained through their responses to the questionnaire provide the data for the AHP evaluation.

In the third stage, data is analyzed and assessed. The results give the relative importance of each criterion in the model, which is called as criteria weights.

In the fourth stage, experts are grouped according to their position in energy sector. The group judgments are analyzed and the results show the similarities and differences between the groups.

In the final stage, generic power plants are evaluated. The overall score which is calculated according to the generic plants' score for each criterion and criteria weights, provides the ranking of the power plants according to specified goal.

4.1. The Analytic Hierarchy Process

4.1.1. Introduction

It is usually not a simple task to make a decision for a complex problem featuring many different and interconnected alternatives. The issue is to find a way for evaluating the relative importance of factors properly and prioritization of alternatives accordingly for the best choice. The Analytical Hierarchy Process (AHP), which is based on subjective evaluation of hierarchical pairwise comparisons, is one of the methods for the solution of this kind of complex problems.

Traditional logical thinking may lead to confusion about the choices. The lack of procedure to make decisions is especially troublesome when intuition alone cannot help us to determine which of several options is the most desirable, or the least objectionable. Therefore, a way is needed to determine which objective outweighs another, both in short and long terms. Since the primary concern is real life problems, the necessity for trade-offs to best serve the common interest must be recognized. Therefore, this process should also allow for consensus and compromise [29].

To make a decision, various kinds of subjective and objective knowledge, information and technical data, (which are about the details of the problem), people involved with their objectives and policies; the factors affecting the outcomes; the time horizons, scenarios and constraints, are needed. Saaty explains decision making process by following steps [29]:

- Structure a problem with a model that shows the problem's key elements and their relationships.
- Elicit judgments that reflect knowledge, feelings or emotions.
- Represent those judgments with meaningful numbers.
- Use these numbers to calculate the priorities of the elements of the hierarchy.
- Synthesize these results to determine an overall outcome
- Analyze sensitivity to changes in judgment.

The AHP meets all these steps. The AHP proceeds first by breaking a problem down into its analyzable and comparable components and then aggregating the analysis and evaluation of all the subproblems into a conclusion.

4.1.2. Structure the Hierarchy

In the AHP, a problem is structured as a hierarchy. In this hierarchical structure, the goal is specified at the top level as level 1. Criteria and subcriteria are shown in the following lower levels as level 2 and level 3, respectively for the assessment of the goal. Depending on the problem content and affecting factors, this structure can include more levels for the subriteria. But the alternatives to be assessed should be at the lowest level. The purpose of the structure is to make it possible to judge the importance of the elements in a given level with respect to some or all of the elements in the adjacent level above.

When constructing hierarchies one must include enough relevant detail to represent the problem as thoroughly as possible, but not so thoroughly as to lose sensitivity to change in the elements. Arranging the goals, attributes, issues and stakeholders in a hierarchy serves two purposes. It provides an overall view of the complex relationships inherent in the situation and helps the decision maker assess whether the issue is in each level are of the same order of magnitude, so he can compare such homogenous elements accurately.

The issues and actions that should be taken into consideration in the hierarchy structure [29]:

- Identify the overall goal. What are you trying to accomplish? What is the main issue?

- Identify the subgoals of the overall goal. If relevant, identify time horizons that affect the decision.
- Identify criteria that must be satisfied to fulfill the subgoals of the overall goal.
- Identify subcriteria under each criterion. Note that criteria or subcriteria may be specified in terms of ranges of values of parameters or in terms of verbal intensities such as high, medium, low.
- Identify the actors involved.
- Identify the actors' goals.
- Identify the actors' policies.
- Identify options or outcomes.
- For yes-no decisions; take the most preferred outcome and compare the benefits and costs of making the decision with those of not making it.
- Do a benefit cost analysis using marginal values. Because we are dealing with dominance hierarchies, ask which alternative yields the greatest benefits, for costs, which alternative costs the most and for risk, which alternative is more risky.

4.1.3. Judgment and Comparison

A judgment or comparison is the numerical representation of a relationship between two elements that share a common parent. The set of all such judgments can be represented in a square matrix in which the set of elements is compared with itself. Each judgment represents the dominance of an element in the column on the left over an element in the row on top. It reflects the answers to two questions: which of the two elements is more important with respect to a higher level criterion and how strongly.

In the AHP, criteria and subcriteria are compared with respect to the parent element in the adjacent upper level. Comparison is made according to 1-9 scale shown in Table 4.1.

Table 4.1. The fundamental scale

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	

Judgments in a comparison matrix may not be consistent or there can be redundant comparisons. Redundancy gives rise to multiple comparisons of an element with other elements and hence to numerical inconsistencies. For example, when X is compared with Y and Z, the respective judgments 3 and 5. Now if X=3Y and X=5Z, then 3Y=5Z or Y=5/3 Z. If not, judgments are inconsistent. In fact, we are not sure which judgments are more accurate and which are the cause of the inconsistency. Inconsistency is inherent in the judgment process. It may be considered a tolerable error in measurement only when it is of a lower order of magnitude than the actual measurement itself; otherwise, the inconsistency would bias the result by a sizable error comparable to or exceeding the actual measurement itself.

When the judgments are inconsistent, the decision maker may not know where the greatest inconsistency is. The AHP can show one by one in sequential order which judgments are the most inconsistent, and also suggest the value that best improves consistency. However, this recommendation may not necessarily lead to a more accurate set of priorities that correspond to some underlying preference of the decision makers. Greater consistency does not imply greater accuracy and one should go about improving consistency by making slight changes compatible with one's understanding. If one cannot reach an acceptable level of consistency, one should gather more information or reexamine the framework of the hierarchy.

Development of priorities from judgments is a process of weighting and adding to go from local priorities to global priorities. Local priorities are derived from judgments with respect to a single criterion. If the judgments are perfectly consistent, the local priorities are obtained by normalizing the judgments in any column. If the judgments are inconsistent, but have a tolerable level of inconsistency, priorities are obtained by raising the matrix to large powers, which is known to take into consideration all intransitivities between the elements. The priorities are obtained from the matrix by adding the judgment values in each row and dividing by the sum of all the judgments.

Global priorities at the level immediately under the goal are equal to the local priorities because the priority of the goal is equal to one. The global priorities at the next level are obtained by weighting the local priorities of this level by the global priority at the level immediately above and so on. The overall priorities of the alternatives are obtained by weighting the local priorities by the global priorities of all the parent criteria or subcriteria in terms of which they are compared and then adding. The process is repeated in all the matrices by asking the appropriate dominance or importance question.

4.2. Model Development

Model development process starts with the identification of the factors that affect the generalized cost of electricity generation. After the selection of the factors, generic power plants are determined for evaluation. Finally, the AHP model is structured.

4.2.1. Identification of Generalized Electricity Generation Cost Factors

In this study, after reviews with experts and literature survey, criteria for evaluation of coal, natural gas and wind power plants are identified and grouped as follows:

<u>4.2.1.1. Economic Criteria.</u> Power plants are high cost investments therefore economic criteria are very important for investment decisions. They are evaluated under three sub-criteria: investment cost, investment duration, operation cost.

(i) Investment cost: It includes all the costs from the beginning of the project until start of production. These are:

- Land cost: it is the cost of land on which power plant is to be built and operated. Land cost of generic power plants are measured in $ per kW.
- Design and Planning cost: This cost item includes all design, organization, planning and feasibility study costs to be incurred until the construction time. It is measured in $ per kW.
- Construction cost: This cost item includes all costs related to the construction of power plant. It is measured in $ per kW.
- Equipment cost: This cost item includes the cost of equipment to be used in the power plant. It is measured in $ per kW.

(ii) Investment duration: It is the time period from the beginning of project until start of production. It includes time spent for all design, organization planning and feasibility activities as well as construction duration.

- Design and Planning duration: it is the time period that includes design, organization, planning and feasibility until the construction time. It is measured in years.
- Construction duration: it is the time period from the beginning of construction until the start of operation of the power plant. It is measured in years.

(iii) Operating cost: It includes all costs related to the operation of the power plant which are fuel cost, labor cost, maintenance cost and capacity usage which affects the operation cost of the power plant.

- Fuel cost: it is the cost of the fuel used in the power plant for electricity generation. It is measured in cent per kWh.
- Labor cost: it is the cost of power plant employees. It is measured in cent per kWh.
- Maintenance cost: it includes all the maintenance cost for power plant. It is measured in cent per kWh.

- Capacity usage: it is the capacity usage ratio which shows the availability of power plant for operation (due to equipment failures, routine maintenance, weather conditions or unavailability of fuel, power plants' capacity cannot be %100). It is measured in percentage (%).

Economic Criteria

- Investment Cost: Land cost, Design and Planning cost, Construction cost, Equipment cost
- Investment Duration: Design and Planning duration, Construction duration
- Operating Cost: Fuel cost, Labor cost, Maintenance Cost, Capacity Usage

Figure 4.1. Economic criteria

Contents of the economic criteria deployed in this study are in line with the works of Chatzimouratidis and Pilavachi [21], Pilavachi, Stephanidis, Pappas, Afgan [26] and Georgopoulou, Lalas, Papagiannakis [28], in investment and operation costs aspects. But, the classification deployed is different. Their costs are not broken into subcriteria as done in this study. In the studies of Chatzimouratidis and Pilavachi [21] and Pilavachi, Stephanidis, Pappas, Afgan [26], 'capital cost' criterion represents investment cost; operation and maintenance costs include labor and maintenance costs, whereas fuel cost is also included to operation and maintenance cost in Georgopoulou, Lalas, Papagiannakis' study [28]. Fuel cost is a separate cost in Chatzimouratidis and Pilavachi's study [21], whereas it is included to the 'electricity cost' in Pilavachi, Stephanidis, Pappas, Afgan' study [26]. Chatzimouratidis and Pilavachi include 'availability' in their model, which has same content as 'capacity usage' in this study.

Regarding investment duration, in line with this study, construction duration is included in Tzeng, Shiau and Lin's study [25], but design and planning duration is not.

Classification of economic criteria in the literature is different from this study as follows: Afgan, Carvalho [24], Pilavachi, Stephanidis, Pappas, Afgan [26] and Afgan, Pilavachi, Carvalho[27] included ‘electricity cost’ directly to their models as an economic criterion. Additional to ‘electricity cost’, installation cost (in Afgan and Carvalho’s study [24]); fuel cost (in Afgan, Pilavachi and Carvalho’s study [27]) and capital cost, O&M (operation and maintenance) cost (in Pilavachi, Stephanidis, Pappas and Afgan’s study [26]) are included. In this study, the model is established to represent the (generalize) electricity generation cost. Therefore, not to have a double counting, ‘electricity cost’ is not included.

4.2.1.2. Social Criteria. Social criteria are composed of the power plants’ effects to its environment that are not covered in economic criteria. As mentioned in section 2.4., power plants have negative effects due to their emissions, but on the other hand, they create opportunities for new jobs and acquisition of know-how. From a wider point of view, they provide for economic and technological progress. Additionally, supply stability is also another important point that should be considered, since for the society at large, continuity of electricity generation is crucial for its economic and social well being. Accordingly, social criteria are grouped as environmental impacts, direct impacts on human health, supply stability and contribution to national economy.

(i) Environmental Impacts: This criterion covers emissions and discharges of power plants causing negative effects on the environment (such as climate change, regional impacts on lakes, forests, acid rains). Environmental effects criterion is subdivided into water and soil pollution, CO_2 emission, SO_2 and NO_x emissions, noise and radioactivity subcriterion.

- Water and Soil pollution: it is caused directly by emissions or acid rains triggered by emissions. It is measured according to a scale from 1 to 9 (the more adverse effect, the higher the score)
- CO_2 emission: CO_2 emissions of power plants are primarily caused by the activation/combustion of the energy source deployed in the plant. They are deemed highly undesirable because of their negative effects on climate change (as greenhouse gases). They are measured in this study through kg per MWh.

- SO_2 and NO_x emissions: NO_x is a generic term for the various nitrogen oxides (such as nitrogen oxide,NO, nitrogen dioxide,NO_2, dinitrogen monoxide, N_2O) which are released from the power plant to the atmosphere as a byproduct of the energy conversion process. They cause acid rain when dissolved in atmospheric moisture. SO_2 is a colorless gas with a sharp, irritating odor. It is mainly caused by the combustion of fossil fuels. When it combines with water, it forms sulphuric acid, which is the main component of acid rain. Acid rains damage ecosystem (such as deforestation, damage to aquatic life). These emissions are measured in gram per kWh.
- Noise: If noise level during power plant operation is over a certain limit, it affects the environment negatively. It is measured in dBA.
- Radioactivity: Coal includes small quantities of uranium, radium and thorium. In the process of combustion, most of these radionuclides accumulate in ash. The overwhelming majority of the ash (called as bottom ash or slag) can be kept under control. But some small proportion of the ash, called fly ash, is discharged through the stacks to the environment (in some cases with minimum or no control). It is measured in Becquerel per kilogram ($Bq*kg^{-1}$) for Radium equivalent activity of fly ash. Uniformity of radionuclides with respect to exposure to radiation has been defined in terms of radium equivalent activity to compare specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K.

(ii) Direct Impacts on Human Health: This criterion covers emissions and discharge of power plant causing negative effects on human health (such as cancer, cardiovascular and vision problems, poisonous food chain due to acid rains). Human health effects criterion is subdivided into water and soil pollution, particulate matter, SO_2 and NO_x emissions, noise and radioactivity subcriteria.

- Water and Soil pollution: it is caused directly by emissions or acid rains triggered by emissions. They affect human health negatively through food chain, drinking water. It is measured according to a scale from 1 to 9 (the more adverse effect the higher the score)

- Particulate matter: Particulate matter is a complex mixture of extremely small particles and liquid droplets. It is made up of a number of components, including acids, organic chemicals, metals and soil/dust particles. It is the worst type of emission for human health and causes cardiovascular problems. It is measured in mg per kWh.
- SO_2 and NO_x emissions: As explained in environmental effects, it is mainly caused by the combustion of fossil fuels. When it combines with water, it forms sulphuric acid, which is the main component of acid rain. They affect the food chain negatively, cause damage to aquatic life and acidify waterways. These emissions are measured in gram per kWh.
- Noise: If noise level during power plant operation is over a certain limit, it affects the human health negatively. It is measured in dBA.
- Radioactivity: As explained in environmental effects, combustion of coal causes various levels of radioactive fly ash which affects to human health negatively. It is measured in person-rem per year (for the operation of $1000MW_e$ coal-fired power plant).

(iii) Supply Stability: This criterion covers the opportunities to ensure supply stability for the fuel of power plants. It is very important to get fuel on time and in required amounts without any interruption. Supply stability criterion is subdivided into fuel diversity, import dependence and fuel storage capability subcriteria.

- Fuel Diversity: It represents the capability to supply fuel to the power plant from different resources (locations). It is measured according to a scale from 1 to 9 (the more the diversification, the higher the score)
- Import Dependence: The necessity to import fuels may cause interruption due to physical or political conditions. Therefore, it is preferred to use local sources as much as possible. This subcriterion is also measured according to a scale from 1 to 9 (the less the percentage of fuel imported, the higher the score).
- Fuel Storage Capability: The capability to store fuel in large quantities is an advantage for the continuity of electricity generation (in case of a short or medium interruption, the associated power plants continue

operation by being supplied from the previously stored fuel). It is measured according to a scale from 1 to 9 (the higher the capability for fuel storage, the higher the score).

(iv) Contribution to national economy: This criterion covers the indirect (i.e. other than supplying electricity) benefits of power plants to the national economy. It is subdivided into contribution to employment, value added and know-how subcriteria.

- Contribution to employment: Power plants create opportunities for new jobs. Contribution to employment is measured by the number of people employed in the power plant (number of employment per 100 MW).
- Value added: During the construction and operation of power plant, new business opportunities to the local companies and economy are usually provided. The generated value-added is measured according to a scale from 1 to 9 (the more value-added, the higher the score)
- Know-how: It refers to the technology transfer due to the construction and operation of a power plant. It is measured according to a scale from 1 to 9 (the more know-how, the higher the score).

Social Criteria

- Environmental Impacts : Water & Soil pollution
  - CO_2 emission
  - SO_2 & NO_x emissions
  - Noise
  - Radioactivity
- Direct Impacts on Human Health : Water & Soil pollution
  - Particulate Matter
  - SO_2 & NO_x emissions
  - Noise
  - Radioactivity
- Supply Stability: Fuel Diversity
  - Import Dependence
  - Fuel Storage Capability
- Contribution to national economy: Contribution to employment
  - Value added
  - Know-how

Figure 4.2. Social criteria

In this study, emission effects are evaluated in details in line with the work of Chatzimouratidis and Pilavachi [22] in human health and environment damage aspects. On the other hand, they do not include noise, radioactivity and water&soil pollution factors in their study. In another work, they evaluate power plants according to radioactivity factor [23]. Due to climate change effects, CO_2 is included in most of the works for environmental evaluation of power plants (such as in the works of Chatzimouratidis and Pilavachi [22,23], Afgan and Carvalho [24], Pilavachi, Stephanidis, Pappas and Afgan [26], Afgan, Pilavachi and Carvalho [27]) which is in line with this study. As in the works of Tzeng, Shiau and Lin [25], water and soil pollution effect; and as in the works of Georgopoulou, Lalas and Papagiannakis [28], noise are included to this study as environmental factors. Visual impact which is especially disadvantageous regarding wind power plant is not included to this study. It is a subjective criterion and not included in most of the multi-criteria evaluation of power plants studies. In Chatzimouratidis and Pilavachis's study [23], visual impact is not given as a criterion, but included in the content of land requirement. Although Georgopoulou, Lalas and Papagiannakis [28], include visual impact to their model, during the analysis, they exclude it from their model due to its highly subjective character.

As another important social criterion, job creation is included in the works of Chatzimouratidis and Pilavachi [23], Afgan, Pilavachi and Carvalho [27] (similar to the contribution to employment criterion in this study). Differing from this study, supply stability is not subdivided in Tzeng, Shiau and Lin's study [25]. As another difference from some of the works in the literature, social acceptance criterion is not included in this study (it is included in the work of Chatzimouratidis and Pilavachi [23]) in order to avoid a double counting (because responses of interviewees to the questionnaire, represent their acceptance about the power plants).

4.2.2. Determination of Generic Power Plants

Since it is not possible to get all related data for specific power plants, generic power plants are determined for coal, natural gas and wind energy sources, to exemplify the deployment of the developed AHP model and approach to the evaluation of power plant alternatives.

In this section, data for generic plants against each end-node criterion is explained. These generic power plants are evaluated in Section 4.4.

<u>4.2.2.1. Investment Cost.</u> International Energy Agency (IEA) has a study for projection of electricity generation cost including 131 power plants (coal, natural gas, nuclear, wind, hydro, solar, combined heat and power and other fuels and technologies) from 21 countries [36]. Investment cost data for the generic plants considered in this study are based on this IEA document and International Atomic Energy Agency (IAEA) Reference Technology Database [41]. Table 4.2 displays investment cost of power plants depending on fuels.

Table 4.2. Investment cost of power plants

Type of power plant	Investment cost ($/kW)
Coal	1000-1500
Natural gas	400-800
Wind	1000-2000

Properties of generic power plants compared regarding investment costs can be summarized as below:

- Generic coal power plant-1: It is a pulverized fuel (PF) type power plant and has 422 MW capacity. SO_2 emission control efficiency is 92%; NO_x emission control efficiency is 0% (has low NO_x burners); Particulate emission control efficiency is 99,6%.

- Generic coal power plant-2: It is a pulverized fuel (PF) type power plant and has 427 MW capacity. SO_2 emission control efficiency is 96%; NO_x emission control efficiency is 63%; Particulate emission control efficiency is 99,9%.

- Generic natural gas power plant: It has a combined cycle gas turbine (CCGT) technology and NO_x control system (selective catalytic reduction, SCR) with 280 MW capacity.

- Generic wind power plant: It has 15 MW (10*1,5MW) capacity. Its wind velocity requirement is 6,5m/s at a height of 50m.

Investment cost data for the generic power plants described above is displayed in Table 4.3.

Table 4.3. Investment cost data for generic power plants

Type of power plant	Investment cost ($/kW)	Capacity (MW)
Coal-1 (PF)	1170	422
Coal-2 (PF)	1216	427
Natural gas (CCGT)	599	280
Wind	1144	15 (10*1,5)
PF: pulverised fuel, CCGT:combined cycle gas turbine		

In the AHP structure, investment cost criterion is broken into 4 sub-criteria: land cost, design and planning cost, construction cost and equipment cost. Separate data for each sub-criterion is not available, but they are calculated according to the percentages of sub-criteria in total investment cost. This information (percentage of each sub-criterion) is gathered from the experts during interviews and literature survey. This breakdown of cost data is displayed in Table 4.4.

Table 4.4. Investment cost data distribution for generic power plants

Costs	Coal-1		Coal-2		Natural gas		Wind	
	% in total investment cost	$/kW	% in total investment cost	$/kW	% in total investment cost	$/kW	% in total investment cost	$/kW
Land cost	1	12	1	12	1	6	1	11
Design and planning cost	6	70	6	73	4	24	3	34
Construction cost	23	269	23	280	17	102	6	69
Equipment cost	70	819	70	851	78	467	90	1030
TOTAL	**100**	**1170**	**100**	**1216**	**100**	**599**	**100**	**1144**

4.2.2.2. Investment Duration. Investment duration covers design-planning duration and construction duration. Table 4.5 shows the investment duration of generic power plants. Data is based on the IEA's study, IAEA- Reference Technology Database and interviews. For the wind power plant, time for data collection is included to design and planning duration.

Table 4.5. Investment duration for generic power plants

Type of power plant	Design and planning duration (year)	Construction duration (year)
Coal-1 & Coal-2	1	3
Natural gas	1	2,5
Wind	1	0,5

4.2.2.3. Operating Cost. Operating cost includes fuel cost, labor cost, maintenance cost and capacity usage. Data for fuel cost of generic power plants are based on IEA's study and they are presented in Table 4.6.

Table 4.6. Fuel costs for generic power plants

Type of power plant	Fuel cost ($/GJ)
Coal-1 & Coal-2	2,74
Natural gas	4,67
Wind	0

Regarding labor costs, coal (lignite) and natural gas power plants data are obtained from the TEAŞ Annual Report (2000); relevant wind power plant data are obtained from the study of the European Wind Energy Association, EWEA, The Economics of Wind Energy [37]. They are presented in Table 4.7.

Table 4.7. Labor cost for generic power plants

Type of power plant	Labor cost (cent/kWh)
Coal-1 & Coal-2	0,498
Natural gas	0,04
Wind	0,315

Maintenance cost data for coal and natural gas power plants are gathered from the journal 'Enerji Dünyası' [38]; for the wind power plant, data is obtained from the EWEA's The Economics of Wind Energy [37]. They are presented in Table 4.8.

Table 4.8. Maintenance cost for generic power plants

Type of power plant	Maintenance cost (cent/kWh)
Coal-1 & Coal-2	0,8
Natural gas	0,4
Wind	0,39

Data for capacity usage of generic power plants are based on the IEA's study and IAEA- Reference Technology Database. They are presented in Table 4.9.

Table 4.9. Capacity usage for generic power plants

Type of power plant	Capacity usage (%)
Coal-1 & Coal-2	85
Natural gas	85
Wind	23,8

4.2.2.4. Environmental Impacts. They include water and soil pollution, greenhouse gas (CO_2) emissions, SO_2 and NOx emissions, sound pollution (noise) and radioactivity. In the questionnaire given to the selected experts, power plants are evaluated according to water and soil pollution effects to environment on a scale from 1 to 9 (the more the adverse effect, the higher the score). Data gathered from the questionnaires are presented in Table 4.10 (the values provided are the geometric averages of the individual expert responses).

Table 4.10. Water and soil pollution effects to environment

Type of power plant	Water & soil pollution effect
Coal-1 & Coal-2	7,46
Natural gas	4,45
Wind	1,1

CO_2 emissions of generic power plants are based on the IEA's study and IAEA-Reference Technology Database. They are presented in Table 4.11.

Table 4.11. CO_2 emissions of generic power plants

Type of power plant	CO_2 emissions (kg/MWh)
Coal-1	837
Coal-2	790
Natural gas	372
Wind	0

SO_2 and NOx emissions data of generic power plants is based on the IAEA Reference Technology Database and they are presented in Table 4.12.

Table 4.12. SO_2 and NO_x emissions of generic power plants

Type of power plant	SO_2 emissions (g/kWh)	NO_x emissions (g/kWh)
Coal-1	1,42	1,86
Coal-2	0,67	0,61
Natural gas	0,002	0,039
Wind	0	0

Noise effect is primarily considered for wind power plants; however, distance plays an important role in the perceived sound level. The noise from a wind turbine can reach moderate sound pressure levels (< 50 dBA which is equivalent to private business office noise level) when the distance from the turbine to the receptor is between 200 and 300 m. For the generic power plants, distance assumed from residential areas is more than 300m, so noise level for wind turbines is considered to be within the national noise standards (70 dBA for day and 60 dBA for night in Turkey). There is no specific data for coal and natural gas power plants noise levels. Accordingly, noise level data for all types generic power plants are assumed to be the same and within the national noise standards which is 55 dBA.

Among the selected types of power plants in this study, radioactivity effect is valid for only coal-fired plants. Data is based on the work of Cevik, Damla and Nezir [40] and is presented in Table 4.13.

Table 4.13. Radioactivity effects of generic power plants

Type of power plant	Radioactivity (Raeq-Bq*kg-1)
Coal-1 & Coal-2	238,92
Natural gas	0
Wind	0

<u>4.2.2.5. Direct Impacts on Human Health.</u> They include water and soil pollution, particulate matter, SO_2 and NOx emissions, sound pollution (noise) and radioactivity. In the expert questionnaires, power plants are evaluated according to water and soil pollution

impacts on human health on a scale from 1 to 9 (the more adverse effect, the higher the score). Data gathered from the questionnaire is presented in Table 4.14 (the values provided are the geometric averages of the individual expert responses).

Table 4.14. Water and soil pollution impacts on human health

Type of power plant	Water & soil pollution effect
Coal-1 & Coal-2	7,37
Natural gas	4,09
Wind	1,06

Particulate Matter (PM) emission data is based on the IAEA Reference Technology Database and they are presented in Table 4.15.

Table 4.15. Particulate matter emission data for generic power plants

Type of power plant	PM (mg/kWh)
Coal-1	123
Coal-2	36
Natural gas	7
Wind	0

.

Radioactivity data is based on the Chatzimouratidis and Pilavachi's study [3] and is presented in Table 4.16.

Table 4.16. Radioactivity effects of generic power plants

Type of power plant	Radioactivity (person-rem/year (1000MW$_e$ power plant))
Coal-1 & Coal-2	490
Natural gas	0
Wind	0

Data used for SO_2 and NO_x emissions and noise levels regarding impacts on human health are same data used in environmental impacts.

4.2.2.6. Supply Stability. It includes issues such as fuel diversity, import dependence and fuel storage capability. In the questionnaire, power plants are evaluated on a scale from 1 to 9 according to fuel diversity (the more the diversification, the higher the score); import dependence (the less the percentage of fuel imported, the higher the score); fuel storage capability (the higher the capability for fuel storage, the higher the score). Data gathered from the questionnaires is presented in Table 4.17 (the values provided are the geometric averages of the individual expert responses). Wind power plant is not included in the questionnaire because it is not possible to store or import wind. Accordingly, for import dependence, it is assigned the maximum value (9); for fuel storage capability, it is assigned the minimum value (0). Although it is not possible to diversify fuel source for wind energy, regarding the supply stability aspect, there is no risk for fuel supply interruption as in the case of coal and natural gas. Availability or non-availability of wind energy depends on only weather conditions (which is considered and evaluated under the 'capacity usage' subfactor). As a result, regarding fuel diversity, value of wind should be considered at least as good as that of coal (which is 4,43).

Table 4.17. Evaluation of power plants according to supply stability

Type of power plant	Fuel Diversity	Import Dependence	Fuel Storage Capability
Coal-1 & Coal-2	4,43	6,41	5,21
Natural gas	2,99	1,42	2,5
Wind	4,43	9	0

4.2.2.7. Contribution to National Economy. It includes considerations such as contribution to employment, economic value-added and know-how gain. Contribution to employment data is measured by the number of people employed (in the generic power plants) and is taken as the average of such employment figures in the equivalent power plants in Turkey. Table 4.18 presents the data, (the values presented are the number of employees for 100MW power plant).

Table 4.18. Employment data for generic power plants

Type of power plant	# of employment / 100 MW
Coal-1 & Coal-2	114
Natural gas	8
Wind	47

In the questionnaire, power plants are evaluated on a scale from 1 to 9, regarding their economic added values (the more the value-added, the higher the score); know-how (the more the potential know-how transfer, the higher the score). Data gathered from the questionnaires is presented in Table 4.19 (the values provided are the geometric averages of the individual expert responses).

Table 4.19. Evaluation of power plants according to value-added and know-how

Type of power plant	Value-added	Know-how
Coal-1 & Coal-2	4,1	2,05
Natural gas	3,59	3,08
Wind	3,36	6,17

Finally, for the generic power plants analysis, the values used in the Expert Choice (the AHP software) are obtained by two ways. First way, for the criteria which have actual values (such as investment cost, operating cost criteria), priorities are calculated and these priority values are inserted into the software. As an example, calculation of 'land cost' criterion priority is displayed in Table 4.20. Generic power plant having less land cost is preferred among the all alternatives; therefore priority of 'land cost' is calculated by normalizing the inverse of 'land cost' values. Second way, for the remaining criteria, which are obtained from the evaluation of generic power plants on a scale from 1 to 9, a linear function is presented in the Expert Choice for each criterion. Values for the analysis are calculated by the Expert Choice according to related criterion's data and presented linear function. As an example, for 'value-added' criterion, generic power plant having more economic added values preferred among the all alternatives; therefore an increasing linear function (minimum value is 1, maximum value is 9) is presented in the Expert Choice. Values for generic power plants are calculated by the Expert Choice according to this specified linear function and data in Table 4.19. Generic power plant analysis results are presented in Section 4.4.

Table 4.20. Calculation of ‘land cost’ priority

Type of power plant	Land cost ($/kW)	1/Land cost	$W_{land\ cost}$
Coal 1	12	0,083	0,196
Coal 2	12	0,083	0,196
Natural gas	6	0,167	0,393
Wind	11	0,091	0,214
TOTAL	**41**	**0,424**	**1,000**

4.2.3. Structuring the AHP Model

Table 4.21 presents the general framework of the AHP model for the estimation of generalized cost of electricity generation. The goal is a multi-dimensional comprehensive comparison of alternative power plants, according to their generalized cost of electricity generation.

Table 4.21. The AHP model for the estimation of generalized cost of electricity generation

	1st Level	2nd Level	3rd Level
GOAL	Economic Criteria	Investment Cost	Land Cost
			Design and Planning Cost
			Construction Cost
			Equipment Cost
		Investment Duration	Design and Planning Duration
			Construction Duration
		Operating Cost	Fuel Cost
			Labor Cost
			Maintenance Cost
			Capacity Usage
	Social Criteria	Environmental Impacts	Water & Soil Pollution
			CO_2 emission
			SO_2 & NO_x emissions
			Noise
			Radioactivity
		Direct Impacts on Human Health	Water & Soil Pollution
			Particulate Matter
			SO_2 & NO_x emissions
			Noise
			Radioactivity
		Supply Stability	Fuel Diversity
			Import Dependence
			Fuel Storage Capability
		Contribution to National Economy	Contribution to Employment
			Value-added
			Know-how

Alternatives
Coal Power Plant-1
Coal Power Plant-2
Natural Gas Power Plant
Wind Power Plant

4.3. Analysis of the AHP Model

4.3.1. Data Compilation

After structuring the AHP model, next step is collection of data for the analysis. For data collection, firstly, a questionnaire is prepared (Appendix A). In this questionnaire, the interviewee is requested to make pairwise comparisons between the generalized cost factors with respect to a higher level criterion and then, scale the importance of one factor over another from 1 (equal) to 9 (extremely more important). These pairwise comparisons constitute the data set. Some of the questions in the questionnaire are given below as examples:

- Which of the following two factors is more important than the other with respect to generalized cost of electricity generation: economic factors or social factors? Scale the importance from 1 to 9. (Descriptions of economic and social factors are provided based on the definition given in Section 4.2.1.)

- In each of the following pairs of economic criteria, state the one that is relatively more important than the other. Scale the importance from 1 to 9: investment cost versus investment duration; investment cost versus operating cost; investment duration versus operating cost. (Descriptions of economic criteria are provided based on the definition given in Section 4.2.1.)

- In each of the following pairs of investment costs criteria, state the one that is relatively more important than the other. Scale the importance from 1 to 9: land cost versus design & planning cost; land cost versus construction cost; land cost versus equipment cost; design & planning cost versus construction cost; design & planning cost versus equipment cost; construction cost versus equipment cost. (Descriptions of investment costs criteria are provided based on the definition given in Section 4.2.1.)

- Which of the following two factors is more important than the other with respect to investment duration: design & planning duration or investment duration? Scale the importance from 1 to 9. (Descriptions of investment duration criteria are provided based on the definition given in Section 4.2.1.)

- In each of the following pairs of social criteria, state the one that is relatively more important than the other. Scale the importance from 1 to 9: environmental impacts versus direct impacts on human health; environmental impacts versus supply stability; environmental impacts versus contribution to national economy; direct impacts on human health versus supply stability; direct impacts on human health versus contribution to national economy; supply stability versus contribution to national economy. (Descriptions of social criteria are provided based on the definition given in Section 4.2.1.)

- In each of the following pairs of environmental impacts criteria, state the one that is relatively more important than the other. Scale the importance from 1 to 9: water & soil pollution versus CO_2 emission; water & soil pollution versus SO_2 & NO_x emissions; water & soil pollution versus noise; water & soil pollution versus radioactivity; CO_2 emission versus SO_2 & NO_x emissions; CO_2 emission versus noise; CO_2 emission versus radioactivity; SO_2 & NO_x emissions versus noise; SO_2 & NO_x emissions versus radioactivity; noise versus radioactivity. (Descriptions of environmental impacts criteria are provided based on the definition given in Section 4.2.1.)

- In each of the following pairs of supply stability criteria, state the one that is relatively more important than the other. Scale the importance from 1 to 9: fuel diversity versus import dependence; fuel diversity versus fuel storage capability; import dependence versus fuel storage capability. (Descriptions of supply stability criteria are provided based on the definition given in Section 4.2.1.)

After the preparation of questionnaire for the actual data extraction, a number of interviewees are selected from different groups of experts. Twenty interviews have been accomplished and distribution of the interviewees according to professions and expertise is summarized in Table 4.22.

Table 4.22. Distribution of the interviewees

# of interviewee	Profession
7	Professionally working in private energy generation/ distribution companies at different management levels
4	Academicians in the fields of energy and/or environment at different universities
6	Professionals in the energy sector employed in energy consultancy companies
3	Active members of nongovernmental organizations (NGO) interested in the energy sector

4.3.2. Results of the AHP Model

After completion of the interviews, for each pairwise comparison, the overall and group geometric means of the responses are calculated. This data set is processed with the Expert Choice (the AHP software). Initially, comparisons of operating cost versus investment cost and equipment cost versus design-planning cost do not have tolerable inconsistency level, which is less than 0,10. Accordingly, comparisons are reviewed and only one value in each comparison is changed from 9 to 8. Finally, tolerable level of inconsistency is achieved for all pairwise comparisons and the overall model. Figure 4.3 shows the results obtained from the ‘overall’ averages (L: local priority, represents the percentage of the parent node's priority that is inherited by the child. G: global priority, the priority of each node relative to the Goal) and they are summarized in below.

According to the results, regarding the generalized cost of electricity generation, the importance of economic criteria is equal to the importance of social criteria. This single observation very much validates the need and importance of this study: It indicates that feasibility studies and other selection methods, regarding power plant investments, based on just financial analysis (without considering social factors) could be quite insufficient and misleading.

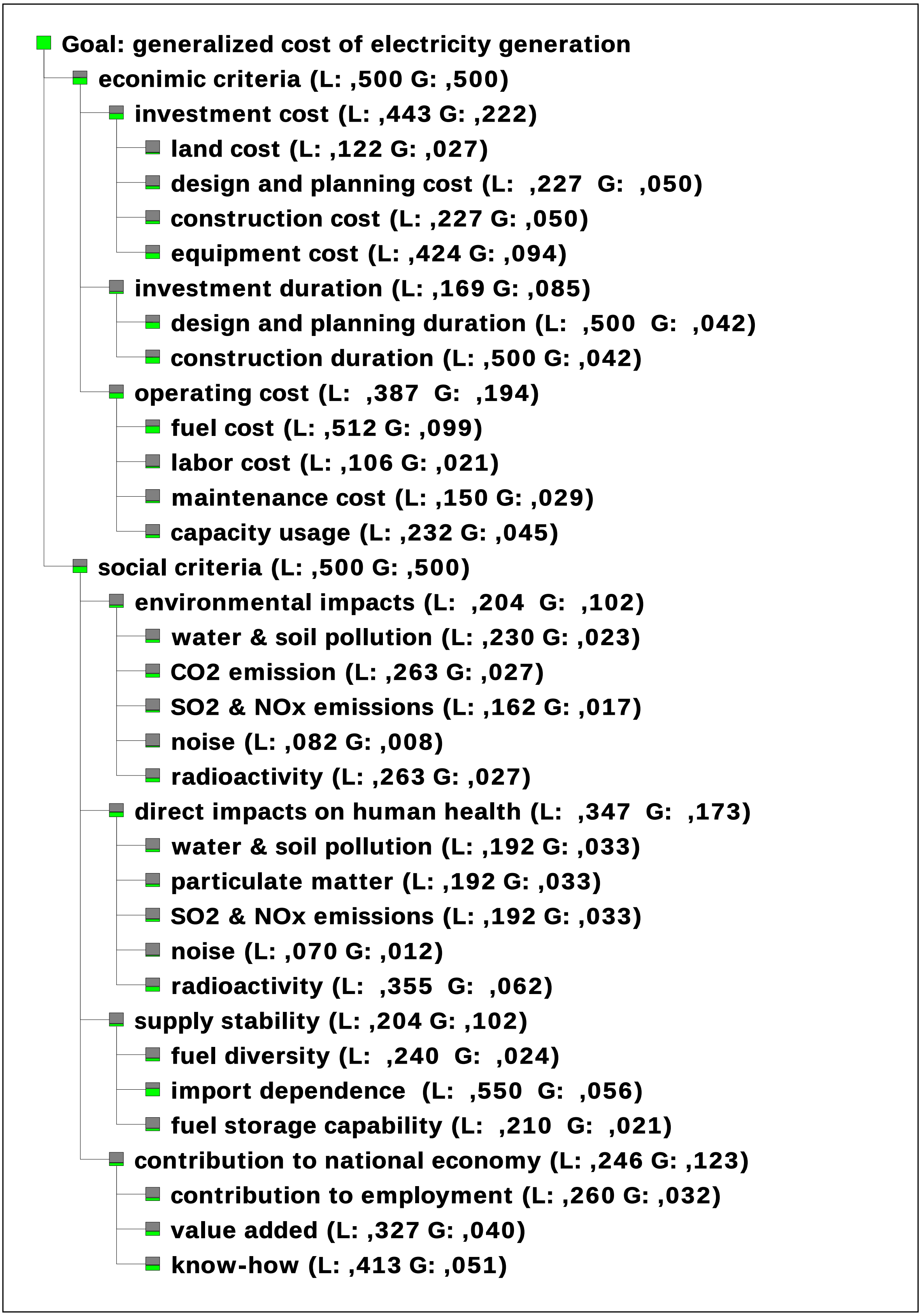


Figure 4.3. Analysis results of the AHP Model with local and global weights

As displayed in Table 4.23, investment cost is the most important second-level factor which is followed by operating cost and direct impacts on human health, respectively. It is an expected result because investment cost is primarily considered factor for investment decisions. Environmental impacts and supply stability have equal importance. This result emphasizes that incessant fuel supply is very important for electricity generation, but at the same time required precautions should be taken for minimizing adverse environmental and human impacts of power plants.

Table 4.23. Global weights of second-level factors

Second level factors	Global percentage weights (%)
Investment cost	22,2
Investment duration	8,5
Operating cost	19,4
Environmental impacts	10,2
Direct impacts on human health	17,3
Supply stability	10,2
Contribution to national economy	12,3

In economic criteria, the most important factor is investment cost; in social criteria, the most important factor is direct impacts on human health.

Regarding third-level factors, as displayed in Table 4.24, equipment cost is the most important factor in investment cost. It is an expected result because during the interviews, experts mentioned that equipment cost compose the majority of investment cost. Design-planning cost and construction cost have equal importance and land cost is the least important factor. During the interviews with private sector, it is pointed that the government provides land incentive for power plant constructions; therefore land cost is the least important factor in investment costs. Design-planning duration and construction duration are equally important factors in investment duration. It is also an expected result because delay in any time frame increases the investment cost. Fuel cost is the most important factor in operating cost which is followed by capacity usage, maintenance cost and labor cost. This result is in line with the relative economic value of these subfactors.

Table 4.24. Third-level economic factors

Third-level Economic Factors					
Investment Costs	**Global percentage weights (%)**	**Investment Duration**	**Global percentage weights (%)**	**Operating Costs**	**Global percentage weights (%)**
Land cost	2,7	Design & Planning duration	4,2	Fuel cost	9,9
Design & planning cost	5			Labor cost	2,1
Construction cost	5	Construction duration	4,2	Maintenance cost	2,9
Equipment cost	9,4			Capacity usage	4,5

CO_2 and radioactivity are two of the most important factors in environmental impacts. In direct impacts on human health, radioactivity is the most important factor. Water & soil pollution, PM and SO_2 & NO_x have equal importance. Noise is the least important factor both in environmental and human health impacts (Table 4.24). These are also expected results, because noise effect is primarily considered for wind power plants and as explained in different studies [16,19,20] distance plays a critical role in the perceived sound level. The noise from a wind turbine is reduced to ordinary (background) sound pressure levels (< 50 dBA, which is equivalent to private business office noise level) when the distance from the turbine to the receptor is between 200 and 300 m.

Import dependence is the most important factor in supply stability whereas fuel diversity is the second and fuel storage capability is the third important factor (Table 4.25). It is an expected result because for imported fuel, conflict and political instability threaten the security of supply. Accordingly, diversification of imported fuel sources cannot ensure supply stability. Regarding contribution to national economy criterion, know-how is the most important; contribution to employment is the least important factor (Table 4.25). It is an expected result because know-how gain can provide more opportunities (such as addition of new sectors to national economy, improvement of existing technologies, new job opportunities) than other factors, whereas number of people employed in any power plant is relatively very small.

Table 4.25. Third-level social factors

Third-level Social Factors							
Environmental Impacts	**Global percentage weights (%)**	**Direct Impacts on Human Health**	**Global percentage weights (%)**	**Supply Stability**	**Global percentage weights (%)**	**Contribution to national economy**	**Global percentage weights (%)**
Water & soil pollution	2,3	Water & soil pollution	3,3	Fuel diversity	2,4	Value-added	4
CO_2 emission	2,7	Particulate matter	3,3	Import dependence	5,6	Contribution to employment	3,2
SO_2 and NO_x emissions	1,7	SO_2 and NO_x emissions	3,3				
Noise	0,8	Noise	1,2	Fuel storage capability	2,1	Know-how	5,1
Radioactivity	2,7	Radioactivity	6,2				

Global percentage weights of the end node criteria of the AHP hierarchy are displayed in Figure 4.4. According to the end node criteria (third-level) evaluation, fuel cost is the most important factor in the generalized cost of electricity generation. Equipment cost is the second important factor. Labor cost is the least important economic factor which ranks in 20^{th} place.

Another interesting observation regarding the global percentage weights is that radioactivity and water & soil pollution impacts are more important than most of the economic factors (they rank the third and fourth place, respectively). Additionally, PM emissions (unique to human health impacts) is considered to be more important than CO_2 emissions (unique to environmental impacts). Noise pollution is the least important factor.

On the other hand, import dependence is in the fifth place whereas other supply stability factors are lower in order (fuel diversity is 19^{th}; fuel storage capability is 21^{st} place in ranking). Know-how, is the most important ‘contribution national economy’ sub-factor, taking the sixth place in overall evaluation whereas value-added is 13^{th}; contribution to employment is 15^{th} place in ranking.

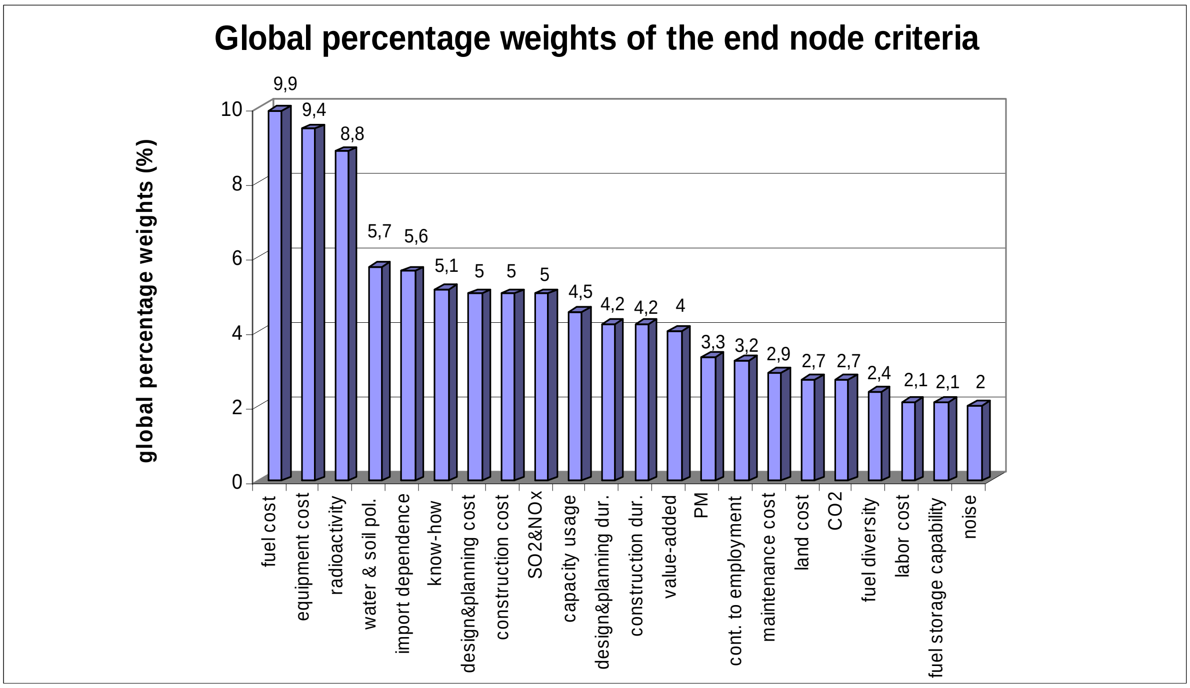


Figure 4.4. Global percentage weights of the end node criteria

Analysis results (criteria weights) depend on the AHP structure and subjective evaluation of the interviewees. Accordingly, there are differences when the results of this study are compared with the other studies in the literature (mentioned in Section 4.2.1). On the other hand, there are also similar results.

Regarding economic criteria, in Chatzimouratidis and Pilavachi's study [21], criterion weight for 'availability' (same content with 'capacity usage in this study) is 7,92%, whereas it is 4,5% for 'capacity usage' in this study. In the same study, criteria weights are 1,7% for 'O&M' and 9,75% for 'capital cost' (same content with 'investment cost' in this study), whereas it is 5% (sum of labor cost 2,1% and maintenance cost 2,9%) and 22,2%, respectively in this study. On the other hand, 'fuel cost' criterion weight is 9,75% which is very close to the result in this study (9,9%). In another study of the same authors, 'job creation' criterion weight is 6,44% [23]; whereas 'contribution to employment' (same content as 'job creation') weight is 3,2% in this study.

Regarding environmental criteria, Chatzimouratidis and Pilavachi [22] evaluated the non-radioactive emissions of power plants. Criteria weights are 45,4% for PM, 17,5% for CO_2-eq, 15,6% for NO_x and 14% for SO_2. In another study of the same authors, criteria weights are 17,75% for PM, 6,85% for CO_2-eq, 6,09% for NO_x, 5,46% for SO_2 and 22,23% for radioactivity [23]. In this study, economic and social criteria are evaluated together and criteria weights are 3,3% for PM, 2,7% for CO_2, 5% for SO_2 and NO_x and 8,8% for radioactivity.

4.3.3. Group Analysis

Each expert responded to the questionnaire based on his/her individual subjective judgment. For group analysis, interviewees are grouped according to their expertise/profession and data set for each group is represented by the geometric mean values of each group. The groups are:

- Group Experts: This group contains six experts working in different energy consultancy companies.
- Group University: This group contains four academicians from various universities.
- Group Private Sector (PS): This group contains seven people working in energy generation/distribution companies, at different management levels.
- Group Environment: This group contains three members of various nongovernmental organizations focusing on environmental protection.

Each group analysis has tolerable inconsistency level, so that evaluations of groups are continued with current data set without any change. The results show how each group perceive the relative importance of the generalized cost factors from their perspective (Appendix B). Groups' results are compared to each other and the similarities and differences are summarized below.

4.3.3.1. Comparison of the PS and the Environment Groups.

- Economic criteria are of equal importance with social criteria for the PS Group, whereas for the Environment Group, social criteria turn out to be more important than economic criteria (by a factor of three). (Actually the fact that people from Environmental NGO give more priority to social criteria over economic criteria, when compared to people from industry is not surprising.)
- Human health is the most important second-level factor for both groups.

- For the PS Group, investment cost is the most important factor in economic criteria, whereas for the Environment Group, operating cost is the most important economic criteria.
- Both groups find the equipment cost as the most important investment cost item and the land cost is the least important one. (During the interviews with the PS Group, it was pointed out that the government provides substantial land incentives for power plant construction; therefore land cost is not considered to be an important investment cost.)
- Importance of the design-planning duration is equal to importance of the construction duration for both groups. (This is probably because delays in either time periods increase the cost and other negative effects in a similar fashion; therefore, according to the analysis results, the PS and the Environment Groups cannot differentiate between them.)
- Fuel cost is the most important factor under the operating cost for both groups. Additionally, the ordering of the remaining operating cost factors (capacity usage, maintenance cost, labor cost) is also same for both groups.
- Radioactivity is the most important; while noise is the least important factors regarding environmental effects for both groups.
- Regarding human health, radioactivity and PM are the most important factors for the PS Group, whereas radioactivity is more important than PM for the Environment Group. Noise is the least important factor both groups.
- Regarding supply stability, storability of the fuels is the most important factor for the PS Group, whereas reduction of imports is the most important factor for the Environment Group. (In other words, the Environment Group gives more priority to the deployment of local reserves for continuity of fuel supply.)
- Know-how is the most important factor in contribution to national economy for the PS Group, whereas value added is the most important factor for the Environment Group. (In other words, the PS Group believes that technology transfer provides more business opportunities than value-added and contribution to employment factors.)
- Regarding the end node criteria evaluations, equipment cost is the most important factor in the generalized cost of electricity generation for the PS Group, whereas radioactivity is the most important factor for the Environment Group.
- Land cost is the least important factor for both groups.

- When the end node criteria are sorted according to global weights, the PS Group features five social factors (radioactivity, know-how, water&soil pollution, PM, SO_2 & NO_x emissions) in the first ten factors; while, the Environment Group features just one economic factor (fuel cost). (In other words, the Environment Group gives far more priority to social criteria over economic criteria)

4.3.3.2.Comparison of the PS and the University Groups.

- Importance of economic criteria is equal to importance of social criteria for the PS Group, whereas for the University Group, economic criteria turn out to be more important than social criteria.
- Human health is the most important second-level factor for the PS Group, whereas investment cost and operating cost are two of the most important second-level factors for the University Group.
- Regarding economic criteria, investment cost is the most important factor for the PS Group, whereas both investment cost and operating cost are two of the most important economic factors for the University Group.
- Both groups find the equipment cost as the most important investment cost item.
- Importance of the design-planning duration and the construction duration is equal for the PS Group, whereas construction duration is more important than design-planning duration for the University Group.
- Fuel cost is the most important factor under the operating cost for both groups.
- Human health is the most important factor under social criteria for the PS Group, whereas human health and supply stability are two of the most important social factors for the University Group.
- Regarding environmental effects, radioactivity is the most important factor for the PS Group, whereas CO_2 emission is the most important factor (it is slightly more important than radioactivity) for the University Group. Noise is the least important factor for both groups.
- Radioactivity is the most important factor in human health effects for the University Group, whereas radioactivity and PM are the most important factors for the PS Group.
- Regarding supply stability, storability of the fuel is the most important factor for the PS Group, whereas reduction of imports is the most important factor for the University Group.

- Regarding contribution to national economy, know-how is the most important factor for the PS Group, whereas both know-how and value added are the most important factors for the University Group.
- Regarding the end node criteria evaluations, fuel cost is the most important factor in the generalized cost of electricity generation for the University Group, whereas equipment cost is the most important factor for the PS Group.
- Land cost is the least important factor for the PS Group, whereas noise is the least important factor for the University Group.

4.3.3.3. Comparison of the PS and the Expert Groups.

- Economic criteria are more important than social criteria for the Expert Group, whereas importance of economic and social criteria is equal for the PS Group. (People from energy consultancy companies focus on financial assessment of energy investments; therefore they give more priority to economic criteria over social criteria, when compared to people from industry.)
- Human health is the most important second level factor for the PS Group, whereas investment cost is the most important second-level factor for the Expert Group.
- Investment cost is the most important economic criteria for both groups.
- Equipment cost is the most important and the land cost is the least important investment cost for both groups. (Investment cost is the primary factor considered in investment decisions; on the other hand, since the government provides substantial land incentives for power plant construction, land cost is not considered to be an important investment cost)
- Importance of the design-planning duration is equal to importance of the construction duration for both groups. (Both groups consider that delays in either time periods increase the cost and other negative effects in a similar fashion.)
- Both groups find fuel cost as the most important operating cost item. Labor cost is the least important operating cost for the PS Group, whereas maintenance cost is the least important operating cost for the Expert Group.
- Human health is the most important factor under social criteria for both groups.
- Regarding environmental effects, water & soil pollution is the most important factor for the Expert Group, whereas radioactivity is the most important factor for the PS Group. Noise is the least important factor for both groups.

- Radioactivity is the most important factor in human health for the Expert Group, whereas both radioactivity and PM are the two of most important factors for the PS Group.
- Regarding supply stability, storability of the fuel is the most important factor for the PS Group, whereas reduction of imports is the most important factor for the Expert Group.
- Regarding contribution to national economy, know-how is the most important factor for both groups.
- Regarding the end node criteria evaluations, equipment cost is the most important factor in the generalized cost of electricity generation for the PS Group, whereas fuel cost (which is in the fifth place for Private Sector) is the most important factor for the Expert Group.
- Land cost is the least important factor for the PS Group, whereas noise is the least important factor for the Expert Group.
- End node criteria evaluation of the Expert Group indicates that first five factors in the priority list, namely fuel cost, equipment cost, design-planning cost, construction cost and capacity usage (all are economic criteria), contribute by 56,7% to the total weighting of the 22 end node criteria. On the other hand, end node criteria weightings are very close to each other for the PS Group. (This can be explained as the Expert Group giving more priority to economic criteria over social criteria, when compared to people from industry.)

4.3.3.4. Comparison of the Environment and the University Groups.

- Social criteria are more important than economic criteria for the Environment Group whereas economic criteria are more important than social criteria for the University Group.
- Human health is the most important second-level factor for the Environment Group, whereas investment cost and operating cost are the most important factors for the University Group.
- Regarding economic criteria, operating cost is the most important factor for the Environment Group, whereas both operating and investment costs are the most important factors for the University Group.
- Both groups find the equipment cost as the most important investment cost item.

- Construction duration is more important than design-planning duration for the University Group, whereas construction duration is of equal importance with design-planning duration for the Environment Group.
- Regarding operating cost, fuel cost is the most important factor for both groups.
- Regarding social criteria, human health is the most important factor for the Environment Group, whereas both human health and supply stability are the most important factors for the University Group.
- Regarding environmental effects, radioactivity is the most important factor for the Environment Group, whereas CO_2 emission is the most important factor for the University Group. Noise is the least important factor for both groups.
- Both groups find radioactivity as the most important factor under human health.
- Regarding supply stability, import dependence is the most important factor for both groups.
- Regarding contribution to national economy, value added is the most important factor for the Environment Group, whereas know-how and value added are the most important factors for the University Group.
- Regarding end node criteria evaluations, radioactivity is the most important factor in the generalized cost of electricity generation for the Environment Group, whereas fuel cost is the most important factor for the University Group (radioactivity is the 7th for the University Group).
- Land cost is the least important factor for the Environment Group, whereas noise is the least important factor for the University Group.
- Most of the economic factors take precedence over social factors for the University Group. This situation is reversed for the Environment Group.

4.3.3.5. Comparison of the Environment and the Expert Groups.

- Economic criteria are more important than social criteria for the Expert Group, whereas social criteria are more important than economic criteria for the Environment Group. (Actually the fact that people from Environmental NGO give more priority to social criteria over economic criteria, when compared to people from energy consultancy companies is not surprising.)

- Investment cost is the most important second-level factor for the Expert Groups, whereas human health is the most important second level factor for the Environment Group.
- Regarding economic criteria, operating cost is the most important factor for the Environment Group, whereas investment cost is the most important factor for the Expert Group.
- Regarding investment cost, equipment cost is the most important factor and the land cost is the least important factor for both groups.
- Design-planning duration is of equal importance with the construction cost duration for both groups.
- Both groups find the fuel cost as the most important operating cost item.
- Regarding social criteria, human health is the most important factor for both groups.
- Regarding environmental effects, water & soil pollution is the most important factor for the Expert Group, whereas radioactivity is the most important factor for the Environment Group.
- Both groups find radioactivity as the most important factor under human health.
- Regarding supply stability, import dependence is the most important factor for both groups. (In other words, both groups believe that local reserves are more important in avoiding interruptions in electricity generation due to fuel supply problems.)
- Regarding contribution to national economy, know-how is the most important factor for the Expert Group, whereas value-added is the most important factor for the Environment Group.
- Regarding end node criteria evaluations, radioactivity is the most important factor in the generalized cost of electricity generation for the Environment Group, whereas fuel cost is the most important factor for the Expert Group (radioactivity is in the 8th place).
- Land cost is the least important factor for the Environment Group whereas noise is the least important factor for the Expert Group.
- For the Environment Group, first six factors contribute by 59% to the total weighting of 22 end node criteria (fuel cost is the only economic criteria in first six factors), whereas for the Expert Group, first five factors contribute by 57% to the total weighting (all items are economic criteria). (This result indicates that people from

energy consultancy companies give more priority to economic criteria over social criteria, when compared to people from Environmental NGO.)

4.3.3.6. Comparison of the University and the Expert Groups.

- Economic criteria are more important than social criteria for both groups.
- Investment cost is the most important second-level factor for the Expert Group, whereas both investment and operating costs are the most important factors for the University Group.
- Regarding economic criteria, investment cost is the most important factor for the Expert Group, whereas investment and operating costs are the most important factors for the University Group.
- Regarding investment costs, both groups find the equipment cost as the most important factor. Design-planning cost is more important than construction cost for the Expert Group, whereas construction cost is more important than design-planning cost for the University Group.
- Design-planning duration is of equal importance with the construction duration for the Expert Group, whereas construction duration is more important than design-planning duration for the University Group.
- Regarding operating costs, fuel cost is the most important factor for both groups. Labor cost is more important than maintenance cost for the Expert Group, whereas maintenance cost is more important than labor cost for the University Group.
- Regarding social criteria, human health is the most important factor for the Expert Group, whereas human health and supply stability are the most important factors for the University Group.
- Regarding environmental effects, water & soil pollution is the most important factor for the Expert Group, whereas CO_2 emission is the most important factor for the University Group. Noise is the least important factor for both groups.
- Both groups find radioactivity as the most important human health effect and noise is the least important one.
- Regarding supply stability, import dependence is the most important factor for both groups.

- Regarding contribution to national economy, know-how is the most important factor for the Expert Group, whereas both know-how and value-added are two of the most important factors for the University Group.
- Fuel cost is the most important factor in the generalized cost of electricity generation for both groups.
- Noise is the least important factor for both groups.
- Ranking of end node criteria is very similar for both groups. There are four common factors in the first five and in the last five factors.
- CO_2 emission is less important than most of the environmental and human health factors for both groups. (During the interviews, it is mentioned that CO_2 emission does not have local effects as the other factors. Accordingly, water & soil pollution, PM, SO_2 & NO_x emissions, which have local effects, are rated as more important than CO_2 emission.)

Comparisons of the group judgments highlight some important points. Interviewees primarily choose the factors that are related to their expertise as the more important generalized cost factors. For example, according to the Environment Group, social criteria are more important than economic criteria, whereas for the Expert Group, economic criteria are more important than social criteria.

Another important observation is the existence of common judgments by all groups. For example, equipment cost is the most important factor in investment costs; fuel cost is the most important factor in operating costs; land cost is the least important factor in investment costs. In social criteria, human health is the most important factor. Radioactivity is the most important and noise is the least important factor in human health. These common judgments further underline the criticality or non-criticality of the related criteria.

Furthermore, it is also important that interviewees working in energy companies (responsible for power plant investments and operations), (i.e.the PS Group) give considerable priority to social criteria. Group results show that economic criteria are of equal importance with social criteria. Human health is the most important second-level factor. According to the end node criteria evaluations, there are four social factors (know-how, water&soil pollution, PM, SO_2 & NO_x emissions) in first ten factors.

Tzeng, Shiau and Lin [25] also made group analysis in their study. 14 experts (working in state enterprises, energy companies and university) are grouped into four according to their expertise. When weights of common criteria are compared, there are similar results for some groups. Regarding construction duration, criterion weight for each group is 8,5%, 1,9%, 4,7%, 5%, respectively; whereas it is 1,6 for the Environment Group, 3,8% for the Expert Group, 6,5% for the PS Group and 10,7% for the University Group in this study. Regarding supply stability, criterion weight for each group is 3,9%, 2,6%, 6,8%, 6,5%, respectively; whereas it is 4,5% for the Expert Group, 7% for the PS Group, 9,8% for the University Group and 20,3 for the Environment Group in this study. Water and soil pollution are separate criteria in their model and sum of these two criteria weights is 5,9%, 23,8%, 12,4%, 21%, respectively; whereas it is 5,7% for the PS Group, 8% for the Environment Group, 3,1% for the University Group and 4,2% for the Expert Group in this study.

4.4. Evaluation of Generic Power Plants

4.4.1. Analysis Results

Generic power plants are evaluated according to the data given in Section 4.2.2. This data set is processed with the Expert Choice (the AHP software). The details of the power plants’ performance according to end node criteria are given in Appendix C. Expert Choice calculates the priorities of alternatives, with respect to the goal, as a percentage. The sum of priorities (percentages) of alternatives is equal to 100.

According to analysis results, for the generalized cost of electricity generation, wind power plant is in the first position with 38,9%; natural gas power plant is in the second position with 27% ; coal power plant-2 is in the third position with 18,6% and coal power plant-1 ranks in the last position with 15,5% (Figure 4.5).

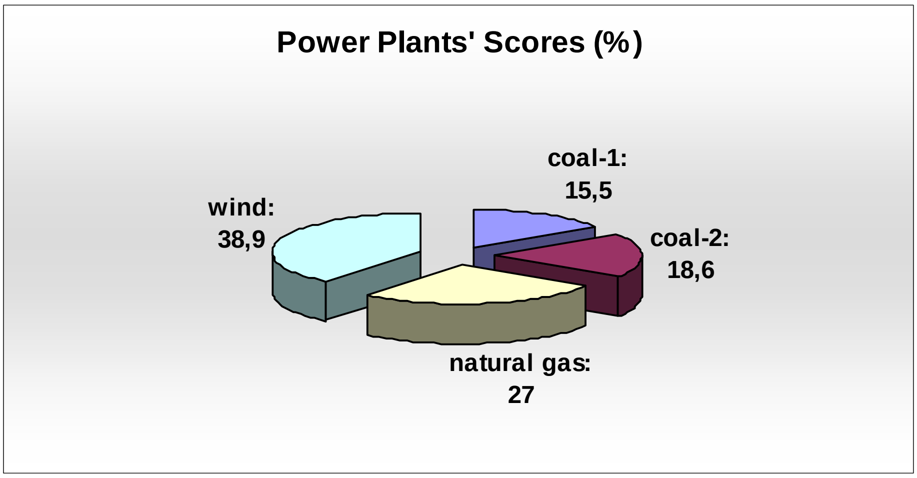


Figure 4.5. Power plants' performance results

Analysis results show the advantages and disadvantages of each power plant which affect their score for generalized cost of electricity generation. Table 4.26 presents the summary of power plants performance per end node criterion.

Table 4.26. Summary of power plants performance per end node criterion

	Coal-1 15,5 %	Coal-2 18,6 %	Natural gas 27 %	Wind 38,9%
Land cost	0,3	0,3	0,7	0,4
Design and planning cost	0,5	0,5	1,4	1
Construction cost	0,4	0,4	1	1,5
Equipment cost	1,4	1,3	2,4	1,1
Design and planning duration	0,7	0,7	0,7	0,7
Construction duration	0,3	0,3	0,4	1,8
Fuel cost	2,9	2,9	0,4	6,5
Labor cost	0,1	0,1	1	0,1
Maintenance cost	0,3	0,3	0,6	0,6
Capacity usage	0,9	0,9	0,9	0,3
Water&soil pollution	0,7	0,7	2,2	3,8
CO_2 emission	0	0,1	1	1,8
SO_2&NO_x emissions	0,6	2,2	3,3	3,3
Noise	0,3	0,3	0,3	0,3
Radioactivity	0	0	5,8	5,8
Particulate matter	0	1,5	2,1	2,2
Fuel diversity	0,7	0,7	0,4	0,7
Import dependence	2,5	2,5	0,2	3,7
Fuel storage capability	0,7	0,7	0,3	0
Contribution to employment	0,8	0,8	0,1	0,3
Value-added	1	1	0,9	0,8
Know-how	0,4	0,4	0,9	2,2

Wind power plant is at the top of the overall ranking mainly because of having a renewable energy source. It is a clean, domestic and zero cost fuel for electricity generation. Accordingly, it has the highest score for human health and environmental impacts criteria (totally 17,2%), import dependence (3,7%) and fuel cost which adds 6,5% to its overall performance. Due to its short construction period, wind power plant also has the highest score for construction duration (1,8%). Furthermore, wind power energy is a new sector for Turkey and improves rapidly. This situation contributes to its highest know-how score (2,2%).

Disadvantages of wind energy affect wind power plant performance negatively but do not prevent it being in the first position. Equipment cost is the second most important criterion in the AHP structure (presented in Section 4.3.2). Wind power plants having the highest equipment cost among all types of power plants, have the lowest score for this criterion. Capacity usage is another criterion in which wind power plant has the lowest score, since wind is an intermittent power source and its availability depends on weather conditions. Additionally, it is not possible to store wind and wind power plants' score is zero for 'fuel storage capability' criterion.

Natural gas power plants have the second position mainly because of their highest fuel cost, which is the most important criterion in the AHP structure (presented in Section 4.3.2). Since national natural gas reserves are inadequate, it is imported for electricity generation. When compared to coal, diversity and storage of the fuel possibilities are also low for natural gas. Therefore, natural gas power plants have the lowest supply stability score. Contribution to employment is another criterion in which natural gas power plants have the lowest score.

On the other hand, regarding human health and environmental impacts criteria, natural gas power plants have quite the same scores with wind power plants, except water & soil pollution, CO_2, particulate emission factors. Since natural gas power plants have the lowest investment cost, it has the highest scores for land, design-planning and especially for equipment costs.

There are two types of generic coal power plants (coal-1 and coal-2) in the evaluation which differ in their emission control efficiencies and investment costs. Although coal power plants-2 have higher scores for human health and environmental impacts criteria, both types of coal power plants rank in the last two positions, mainly because of these two criteria. They also have the lowest scores for investment costs (except equipment cost) and construction duration criteria. However, their high scores for fuel cost, capacity usage, supply stability and contribution to employment criteria contribute to the coal power plants' performance.

4.4.2. Comparison of Generic Power Plants

It is not possible to get all related data for specific power plants; therefore, as mentioned in Section 4.2.2, generic power plants are determined for coal, natural gas and wind energy sources. In this section, these generic power plants are compared according to analysis results in section 4.4.1.

Figure 4.6 presents the comparison of generic power plants according to their investment cost scores (the less the investment cost the higher the score for a power plant type). Investment cost of power plants mostly depends on equipment cost, which is the second important factor in the AHP structure (presented in Section 4.3.2). The share of land cost in total investment cost is very low due to land incentive provided by the state in Turkey.

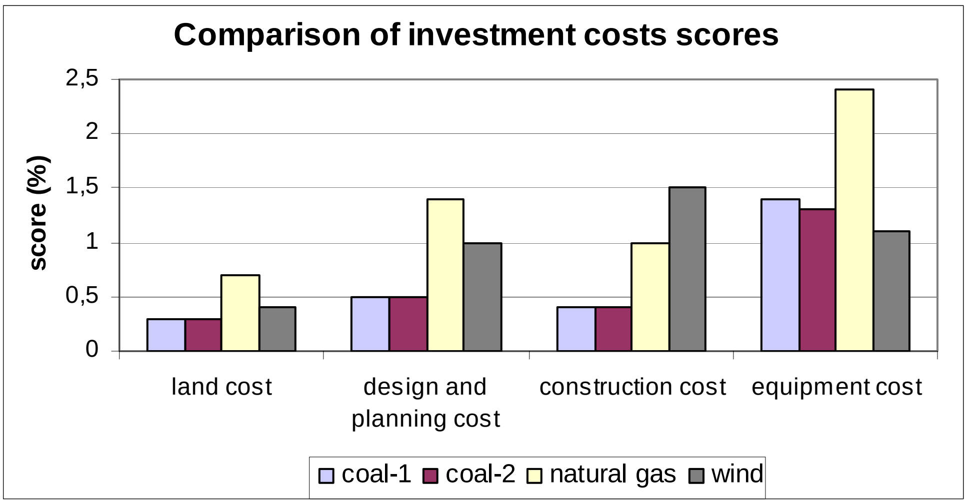


Figure 4.6. Comparison of generic power plants according to investment cost scores

Due to their lowest land, design-planning and equipment costs, natural gas power plants have the highest scores regarding investment cost criterion. Only for the construction cost criterion, wind power plants have the highest score. Although coal power plants (coal-1 and coal-2) have the highest investment cost, their equipment costs are less that of the wind power plants. This is because wind power plant investment cost almost totally depends on equipment cost.

Design-planning durations of power plants are similar, however their construction durations show large variation. Figure 4.7 presents the comparison of generic power plants' investment duration scores (the less the investment duration the higher is the related score). Since wind power plants have the shortest period for construction, they have the highest scores in this criterion.

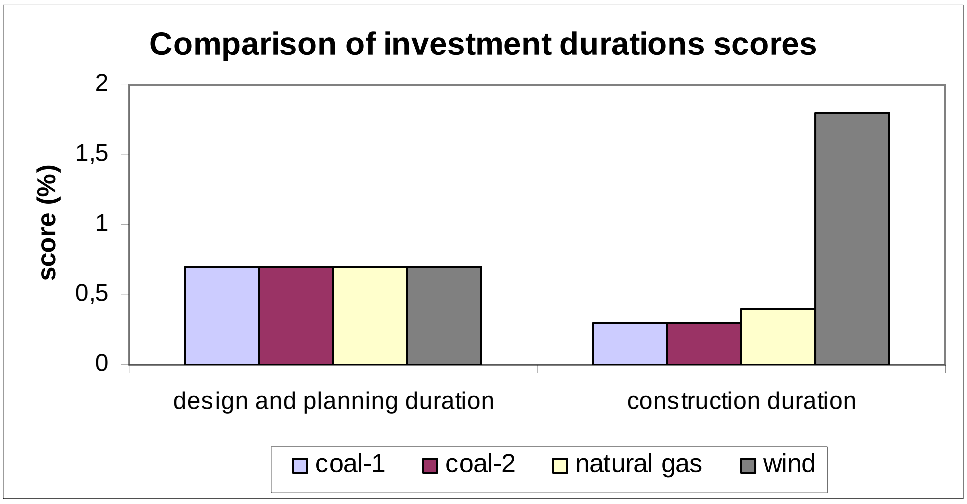


Figure 4.7. Comparison of generic power plants according to investment duration scores

Figure 4.8 presents the comparison of generic power plants according to their operating cost scores (the less the operating cost the higher the score is for a power plant type). Fuel cost is the most important factor in the AHP structure (presented in Section 4.3.2) and affects the generic power plants' scores more than other criteria. Accordingly, with zero fuel costs, wind power plants have dramatically higher score among the all generic power plants. Regarding labor cost, natural gas power plants have the highest score and for maintenance costs, both natural gas and wind power plants have the highest scores.

On the other hand, due to their total reliance on the continuous availability of wind, wind power plants have the lowest score in the capacity usage criterion.

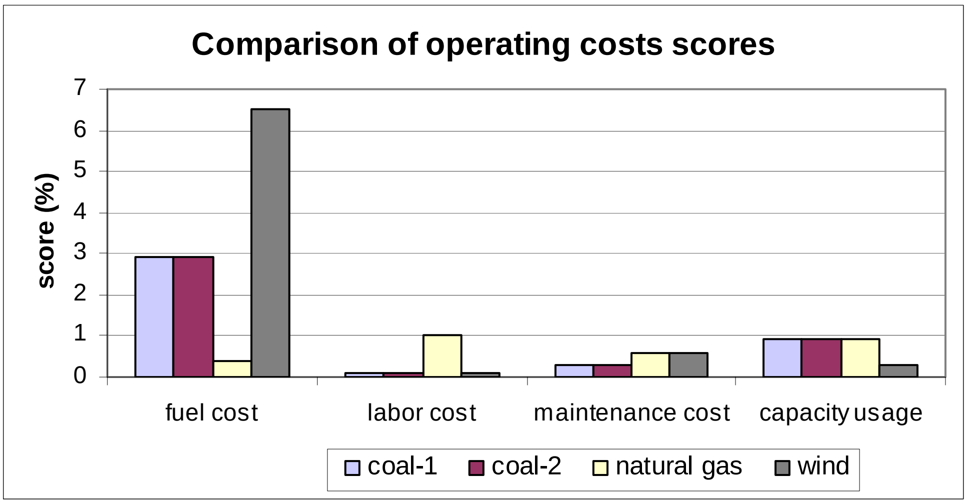


Figure 4.8. Comparison of generic power plants according to operating cost scores

Figure 4.9 presents the comparison of generic power plants according to their environmental impacts scores (the less the adverse environmental impacts, the higher the related score for a power plant type). Wind power plants have the highest scores for environmental impacts criteria due to having a renewable and non-polluting energy source. Coal power plants (Coal-1 and Coal-2) have the lowest scores because of their higher emission values than other power plant types. But emission control efficiencies for SO_2 & NO_x are different for coal power plants 1 and 2 (as informed in Section 4.2.2). Due to higher emission control efficiency, coal power plants-2 have higher scores for SO_2 & NO_x emission criterion. Coal power plants-2 also have higher score than Coal power plants-1 regarding CO_2 emission criterion. On the other hand, generic natural gas power plant emission values are very low and their score is close to that of the generic wind power plant score. Radioactivity is the third important factor in the AHP structure (presented in Section 4.3.2) and due to their zero radioactive emission, generic natural gas and wind power plants have considerably higher scores than that of coal plants in this criterion.

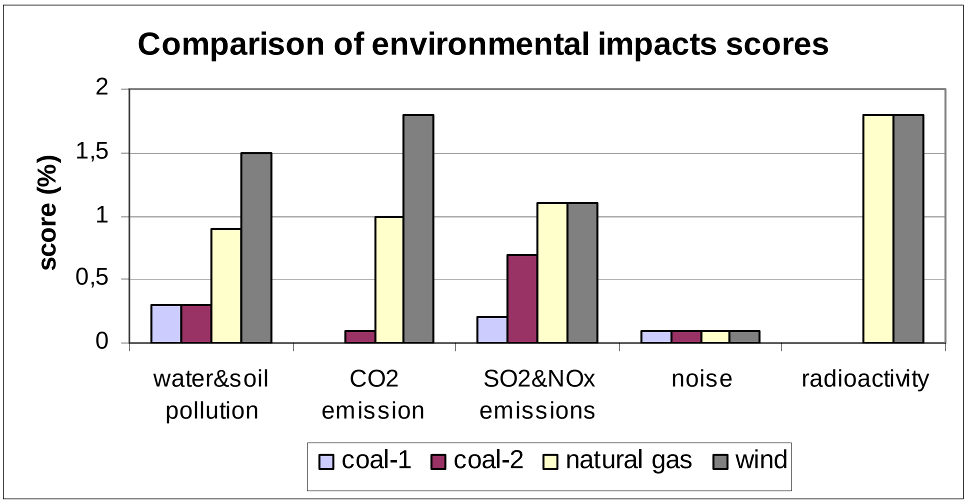


Figure 4.9. Comparison of generic power plants according to environmental impacts scores

Figure 4.10 presents the comparison of generic power plants according to their human health impacts scores (the less the adverse effects, the higher is the related score for a power plant type). Similar to the environmental impacts case, generic wind power plants have the highest scores for human health impacts. Ranking of generic power plants are the same in environmental and human health impacts. Emission control technologies have an important role in power plants effects to environment and human health. Additional to SO_2 & NO_x, Coal power plants-2 have higher emission control efficiency for PM (as informed in Section 4.2.2) and have higher scores than Coal power plants-1 regarding PM emission criterion. On the other hand, generic natural gas and wind power plants have quite same scores for human health impacts criteria (except water & soil pollution, CO_2 emission criteria).

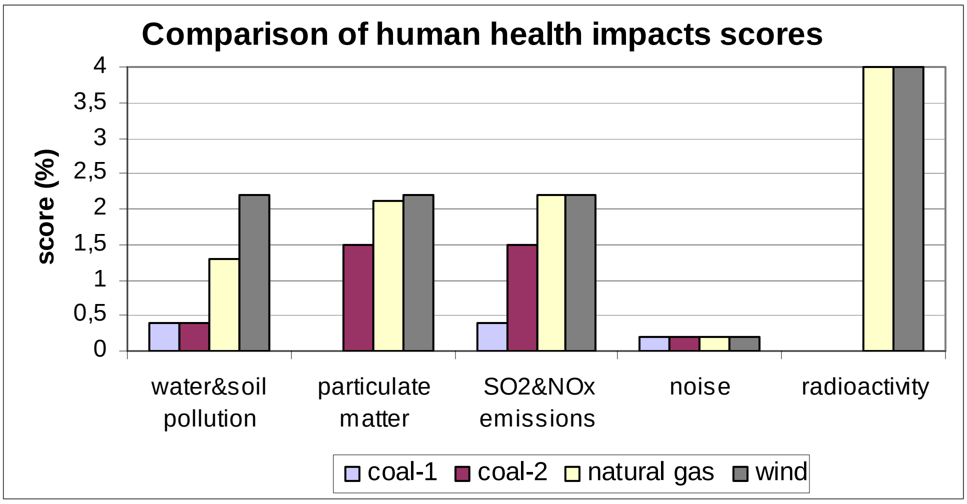


Figure 4.10. Comparison of generic power plants acc. to human health impacts scores

Figure 4.11 presents the comparison of generic power plants according to their supply stability scores (the higher the possibility for stable fuel supply, the higher is the related score for a power plant type). Coal power plants (Coal-1 and Coal-2) have an advantage in supply stability due to large quantity of local reserves in different locations and high storage capacity. Therefore, generic coal plants have the highest scores for supply stability criteria except import dependence. Depending on the properties of wind energy (not possible to store and import wind), generic wind power plants have the highest score for import dependence criterion and the lowest score for fuel storage capability criterion. Additionally, wind and coal power plants have equal scores for fuel diversity criterion. In natural gas power plants imported fuel is used for electricity generation and there are not many choices to increase the fuel diversity. Compared to coal, storage capacity of natural gas is very low. Accordingly, generic natural gas power plants have the lowest scores for supply stability criteria except fuel storage capability criterion.

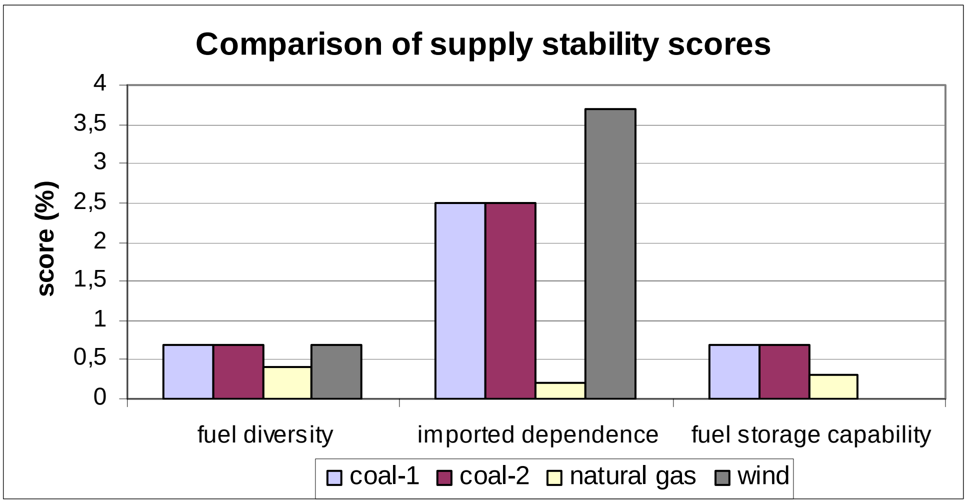


Figure 4.11. Comparison of generic power plants according to supply stability scores

Figure 4.12 presents the comparison of generic power plants according to their scores regarding contribution to national economy (the more the perceived contribution, the higher the related score for a power plant type). At the same generation capacity, the number of employees in coal power plant is more than that of in natural gas or wind power plants. So, generic coal power plants have the highest score for contribution to employment. It is also the same for value-added, which means coal power plants provide more business and economic activity to other local companies. Regarding know-how, generic wind power plants have the highest score. This is mainly because wind energy technology is a new sector for Turkey; therefore, the opportunity to gain new know-how and knowledge is higher when this new technology is deployed.

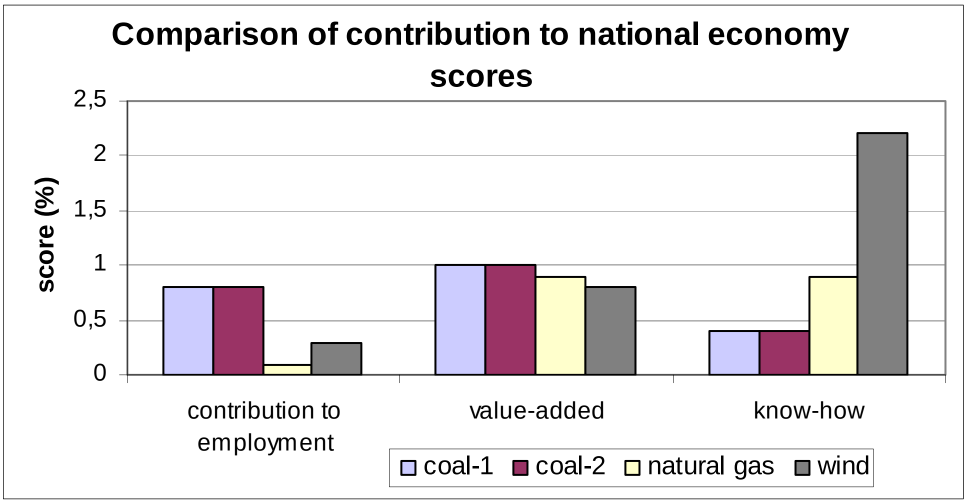


Figure 4.12. Comparison of generic power plants according to contribution to national economy scores

5. CONCLUSION

Electricity is a vital need for the economic, social and technological development of societies and its demand has been increasing rapidly. As of 2008, total electricity consumption in Turkey is 198,085 GWh with a 4,2% annual increase. According to electricity consumption forecasts for 2020, electricity demand will be at least 440,100 GWh and to meet this demand, current installed capacity (as of 2008, it is 41,817MW) should be doubled.

Meeting the electricity demand is a critical problem that should be solved by well-prepared energy policies. As a part of these policies, new power plants investments are required, but the related choices and decisions should be based on multi-dimensional assessment of all involved aspects (such as environmental, social, as well as financial).

In this study, coal, natural gas and wind power plants are compared according to their 'generalized costs' including economic, social and environmental aspects. Natural gas and coal power plants meet majority of the electricity demand in Turkey. As of 2008, natural gas has 32% share in total installed capacity and 48,4% in total electricity production, whereas coal accounts for 25% of the total capacity and 29% of total production. But local and worldwide depletion of fossil fuels, high dependence to imports for their availability and their negative effects on the environment have increased the role of renewable energy sources in future energy policies. There is also a fast growing interest in Turkey for wind energy based power plants. Installed capacity has increased from 18MW to 354,7 MW between 2004 and 2008. Additionally, ongoing wind power plant projects' capacity is approximately 1100 MW.

The AHP methodology is used in this study to accomplish a balanced consideration of the different social, environmental and economic aspects. For structuring the AHP model, literature survey is done about multi-criteria evaluation of power plants. Generalized electricity cost factors (including economic and social factors) are identified and classified. Experts' opinions are taken about the content of the model in order to determine if there is any missing or unnecessary criterion in the model. In the AHP structure, economic criteria include investment cost (land cost, design-planning cost, construction cost and equipment cost); investment duration (design-planning duration and construction duration); operating cost (fuel cost, labor cost, maintenance cost and capacity usage). Social criteria include environmental impacts (water and soil pollution, CO_2 emission, SO_2 and NO_x emissions, noise and radioactivity); direct impacts on human health (water and soil pollution, particulate matter, SO_2 and NO_x emissions, noise and radioactivity); supply stability (fuel diversity, import dependence and fuel storage capability); and contribution to national economy (contribution to employment, value added and know-how). When the AHP structure is completed, generic power plants are determined according to finalized criteria. Since it is not possible to get all related data for specific power plants, generic power plants are determined for coal, natural gas and wind energy sources.

After structuring the AHP model, interviews are done with 20 experts, where they are requested to respond to a questionnaire. In the questionnaire, each expert makes pairwise comparisons for each criterion within the hierarchic structure. The experts' subjective judgments obtained through their responses to the questionnaire provide the data for the AHP evaluation. This data set is processed with the Expert Choice (the AHP software).

The analysis results give the relative importance of each criterion for the generalized cost of electricity generation. According to the results, importance of economic criteria is equal to importance of social criteria. In economic criteria, the most important factor is investment cost; in social criteria, the most important factor is direct impacts on human health.

According to the end node criteria evaluation, fuel cost is the most important factor for the generalized cost of electricity generation. Equipment cost is the second important factor, radioactivity and water & soil pollutions are in the third and fourth position, respectively. Import dependence is in fifth place, whereas other supply stability factors are lower in order. Know-how, is the most important 'contribution national economy' factor, taking the sixth place in overall evaluation. Noise is the least important factor in overall evaluation.

As a second stage of this analysis, experts are divided into four groups according to their position in energy sector (Group Experts containing experts working in different companies for energy consultancy; Group University containing academicians from different universities; Group Private Sector containing people working in energy generation/distribution companies at different management levels; Group Environment containing members of various nongovernmental organizations focusing on environmental protection). The results show how each group perceive the relative importance of the generalized cost factors in their perspective.

Comparisons of the group judgments indicate some interesting points. Interviewees choose the factors that are related to their expertise as the more important generalized cost factors. For example, according to the Group Environment, social criteria are more important than economic criteria, whereas for the Experts Group, economic criteria are more important than social criteria. Another point is the existence of common judgments by all groups. For example, equipment cost is the most important factor in investment costs; fuel cost is the most important factor in operating costs; land cost is the least important factor in investment costs. In social criteria, human health is the most important factor. Radioactivity is the most important and noise is the least important factor in human health. Furthermore, it is also important that interviewees working in energy companies (responsible for power plant investments and operations), (i.e. Group Private Sector), give considerable priority to social criteria. Group results show that economic criteria are of equal importance with social criteria. Human health is the most important second-level factor. According to the end node criteria evaluations, there are four social factors (know-how, water&soil pollution, PM, SO_2 & NO_x emissions) in first ten factors.

After deriving the importance of each criterion from the analysis, generic power plants are evaluated according to their generalized cost of electricity generation. The overall score of each power plant is calculated according to their score for each criterion and criteria weights. Results indicate that wind power plant is in the first position with 38,9%; natural gas power plant is in the second position with 27% and coal power plants (differ in their emission control efficiencies and investment costs) rank in the last two positions with 18,6% (coal-2) and 15,5% (coal-1).

Wind power plant is at the top of the overall ranking mainly because of having a renewable energy source. It has higher scores for human health and environmental impacts criteria, import dependence, fuel cost and construction duration among all generic power plants. Furthermore, wind power energy is a new sector for Turkey and improves rapidly. This situation contributes to its highest know-how score. On the other hand, since wind power plant has the highest equipment cost and the lowest capacity usage, it has the lowest scores for these criteria. Additionally, it is not possible to store wind and wind power plants' score is zero for 'fuel storage capability' criterion.

Natural gas power plant is in the second position mainly because of their highest fuel cost which is the most important criterion in the AHP structure. Since national natural gas reserves are inadequate, it is imported for electricity generation. When compared to coal, diversity and storage of the fuel possibilities are also low for natural gas. Therefore, natural gas power plant has the lowest supply stability score. Contribution to employment is another criterion in which natural gas power plant has the lowest score. On the other hand, regarding human health and environmental impacts criteria, natural gas power plant has quite the same scores with wind power plant except water & soil pollution, CO_2 and particulate emission factors. Since natural gas power plant has the lowest investment cost, it has the highest scores for land, design-planning and especially for equipment costs.

There are two types of generic coal power plants (coal-1 and coal-2) in the evaluation which differ in their emission control efficiencies and investment costs. Although coal power plants-2 have higher scores for human health and environmental impacts criteria, both types of coal power plants rank in the last two positions, mainly because of these two criteria. They also have the lowest scores for investment costs (except equipment cost) and construction duration criteria. However, their high scores for fuel cost, capacity usage, supply stability and contribution to employment criteria contribute to the coal power plants' performance.

When generic power plants are compared, due to their lowest land, design-planning and equipment costs, natural gas power plant has the highest score regarding investment cost criterion. Although coal power plants (coal-1 and coal-2) have the highest investment cost, their equipment costs are less that of the wind power plants. This is because wind power plant investment cost almost totally depends on equipment cost. Design-planning durations of power plants are similar, however their construction durations show large variation. Since wind power plant has the shortest period for construction, it has the highest score in this criterion. Regarding operating costs, with zero fuel cost, wind power plant has dramatically higher score among the all generic power plants. Regarding labor cost, natural gas power plan has the highest score and for maintenance cost, both natural gas and wind power plants have the highest scores. On the other hand, due to their total reliance on the continuous availability of wind, wind power plants have the lowest score in the capacity usage criterion.

Regarding environmental and human health effects, wind power plant has the highest scores, whereas coal power plants (coal-1 and coal-2) have the lowest scores because of their higher emission values than other power plant types. Generic natural gas power plant emission values are very low and its score is close to that of the generic wind power plant.

Regarding supply stability, coal power plants (Coal-1 and Coal-2) have an advantage in supply stability due to large quantity of local reserves in different locations and high storage capacity. Therefore, generic coal plants have the highest scores for supply stability criteria except import dependence. Depending on the properties of wind energy (not possible to store and import wind), generic wind power plants have the highest score for import dependence criterion and the lowest score for fuel storage capability criterion. Additionally, wind and coal power plants have equal scores for fuel diversity criterion. In natural gas power plants imported fuel is used for electricity generation and there are not many choices to increase the fuel diversity. Compared to coal, storage capacity of natural gas is very low. Accordingly, generic natural gas power plants have the lowest scores for supply stability criteria except fuel storage capability criterion.

Regarding contribution to the national economy, generic coal power plants have the highest score for contribution to employment because at the same capacity, the number of employees in coal power plant is more than that of natural gas or wind power plants. Coal power plants also provide more business and economic activity to other local companies. Therefore, it has the highest score for value-added. Regarding know-how, generic wind power plant has the highest score. This is mainly because wind energy technology is a new sector for Turkey; therefore, the opportunity to gain new know-how and knowledge is higher when this new technology is deployed.

It is possible to add a new generic power plant to this study. If it is one of the selected types of generic power plant (coal, natural gas or wind power plant), then current criteria weights are valid for the evaluation, only data for new generic power plant is added to current data set. But, analysis result gives the priorities of alternatives as a percentage which adds up to 100. Accordingly, priorities of current generic power plants change by adding a new generic power plant to this model. Priorities should be calculated again. If it is a new type of generic power plant (such as hydro, geothermal), then current criteria weights are valid, but current data set changes. Because for some of the criteria (water and soil pollution, fuel diversity, import dependence, fuel storage capability, value-added, know-how) data is gathered from the questionnaire by the evaluation of power plants on a scale from 1 to 9. Accordingly, new type of generic power plant should be included to this evaluation which changes the current data set. Finally, priorities should be calculated again for all alternatives.

For a further study, different types of power plants (such as hydro, fuel-oil, geothermal) or different fuel types (such as hard coal, lignite, imported coal) can be compared.

Power plant is a high cost investment and selected technology mainly affects the investment cost and emission values of the power plant. There are different technologies both for power plants operation and emission control systems which are explained in detail in Chapter 2. If it is possible to gather all required data, power plants having different technologies can be evaluated in a further study.

As explained in details in this study, power plant investment decisions play a crucial role in national energy policies. Various economic, social and environmental factors should be considered in a balanced fashion for new power plant investment decisions. Evaluation of alternative power plants for a selected location can also be a subject of a further study.

APPENDIX A: QUESTIONNAIRE

Questionnaire is prepared in Turkish. The questionnaire below includes one of the interviewee's responses.

KÖMÜR – DOĞALGAZ – RÜZGAR SANTRALLERİNİN GENELLEŞTİRİLMİŞ ELEKTRİK ÜRETİM MALİYETLERİNE GÖRE KARŞILAŞTIRILMASI

Bu çalışmanın amacı kömür-doğalgaz-rüzgar santrallerinin 'genelleştirilmiş elektrik üretim maliyetleri' ne göre karşılaştırmaktır. 'Genelleştirilmiş Maliyet' tanımındaki kriterler 2 grupta toplanmıştır: Ekonomik kriterler ve Sosyal kriterler.

Ekonomik Kriterler:

Yatırım Maliyeti: Arazi maliyeti
Proje Maliyeti
İnşaat Maliyeti
Ekipman Maliyeti

Yatırım Süresi: Proje Süresi
İnşaat Süresi

İşletme Maliyeti: Yakıt Maliyeti
İşçilik Maliyeti
Bakım-Onarım Maliyeti
Kapasite Kullanımı

Sosyal Kriterler:

Çevre: Su &Toprak kirliliği etkisi
CO_2 çıkışı
SO_2 & NO_x çıkışı
Gürültü
Radyoaktivite

İnsan Sağlığı: Su &Toprak kirliliği etkisi
Partiküler Madde
SO_2 & NO_x çıkışı
Gürültü
Radyoaktivite

Arz Güvenliği:Çeşitlilik
İthal Bağımlılığın azaltılması
Kaynağın depolanabilir olması

Milli Ekonomiye Katkı: İşgücüne katkı
Katma Değer
Know-how

KRİTERLERİN TANIMLARI

1) EKONOMİK KRİTERLER:

1.1. Yatırım Maliyeti: projenin en başından santralin çalışmaya başlamasına kadar geçen süredeki maliyetleri kapsamaktadır.

1.1.1. Arazi Maliyeti: santral için kullanılacak arazinin maliyeti ($/KW)

1.1.2. Proje Maliyeti: proje hazırlığı kapmasında yapılan harcamaları içerir ($/KW)

1.1.3. İnşaat Maliyeti: santralin kurulumu için gerekli inşaat harcamaları ($/KW)

1.1.4. Ekipman Maliyeti:santral için gerekli ekipman, ekipmanın nakliye ve kurulum maliyetlerini içerir. ($/KW)

1.2. Yatırım Süresi: Proje başlangıcından santralin çalışmaya başlamasına kadar geçen süreyi kapsar.

1.2.1 Proje süresi:projenin hazırlanması, gerekli izinlerin alınmasını içerir.

1.2.2. İnşaat süresi:inşaat başlangıcından santralin faaliyete geçişine kadar olan süreyi içerir.

1.3. İşletme Maliyeti:santralin çalışması için gerekli harcamaları içerir.

1.3.1.Yakıt maliyeti: elektrik üretimi için santralde kullanılan hammadde maliyeti (cent/kWh)

1.3.2. İşçilik maliyeti:çalışanların maliyeti (maaş, sigorta,vb.) (cent/kWh)

1.3.3. Bakım-onarım maliyeti: santralin bakım-onarım harcamaları (cent/kWh)

1.3.4. Kapasite kullanımı: Kurulu santralin kapasite kullanım oranı (%).

2) SOSYAL KRİTERLER:

2.1. Çevre: Santrallerden çıkan gazların gerekli tedbirler alınmazsa çevre kirliliğine, iklim değişikliğine, canlıların sağlığına zarar vermeye sebep olacağı bilinmektedir. Santrallerin çevreye olan etkisini değerlendirmek için aşağıdaki kriterler seçilmiştir:

2.1.1. Su & toprak kirliliği etkisi: santralin kurulu alana ve çevresine verdiği zarar.

2.1.2. CO_2 çıkışı: Fosil yakıtların yanması sonucu oluşmaktadır. İklim değişikliğine, hortum, sel, kuraklık gibi felaketlerin olasılığının artmasına, tarımsal verimin düşmesine sebep olmaktadır. Kömür ile çalışan santrallerin çevreye olan etkisinde önemli bir göstergedir (gr/ kWh).

2.1.3. SO_2 and NOx çıkışı: Fosil yakıtların yanmasıyla ortaya çıkmakta ve asit yağmurlarına sebep olmaktadır.Kömür/ doğalgaz santrallerinin çevreye olan etkisinde önemli bir göstergedir (mg/ kWh).

2.1.4. Gürültü:santralin çalışması sırasında çıkan gürültü de çevre kirliliğini olumsuz etkilemektedir (dBA).

2.1.5.Radyoaktivite:kömür ve nükleer santrallerde radyoaktif madde çıkışı olmaktadır. Kömürde az miktarda bulunan uranyum,radyum ve toryum nedeniyle yanma sonucu oluşan küller radyoaktif madde içerir (person-rem/yıl 1000MWe santral).

2.2 İnsan Sağlığı: Santrallerin insan sağlığına olan etkisi aşağıdaki kriterlere göre değerlendirilecektir:

2.2.1. Su & toprak kirliliği etkisi: santralin kurulduğu alan ve çevresindeki toprak ve suya olan etkisi sonucu insan sağlığına verdiği zarar.

2.2.2.Partiküler madde:gözle görülmeyen küçük parçacıklar ve sıvı damlacıkların karışımından oluşur. Asitler,organik kimyasallar,metaller,toprak veya toz parçacıkları içerirler. İnsan sağlığı açısından ölüme veya kalıcı hastalıklara sebep olmaktadır. Özellikle kömür santrallerinin insan sağlığı açısından değerlendirilmesinde önemli bir kriterdir (mg/kWh).

2.2.3. SO_2 and NOx çıkışı: Fosil yakıtların yanmasıyla ortaya çıkmakta ve asit yağmurlarına sebep olmaktadır.Kömür/ doğalgaz santrallerinin insan sağlığına olan etkisinde önemli bir göstergedir (mg/ kWh)

2.2.4. Gürültü:santralin çalışması sırasında çıkan gürültü de insan sağlığını olumsuz etkilemektedir (dBA).

2.2.5.Radyoaktivite:kömür ve nükleer santrallerde radyoaktif madde çıkışı olmaktadır. Kömürde az miktarda bulunan uranyum,radyum ve toryum nedeniyle yanma sonucu oluşan küller radyoaktif madde içerir (person-rem/yıl 1000MWe santral).

2.3. Arz Güvenliği:Kaynakların, özellikle ithal edilenlerin tam zamanında ve önceden belirlenen miktarlarda kesintiye uğramadan sağlanması çok önemli.Bu kesintiler kısa vadede fiyat yükselmesi, fiziksel kısıtlar veya teknolojik sebeplerden gerçekleşebilir.Bu durum ekonomik kayıplara neden olmaktadır. Arz güvenliği aşağıdaki başlıklarla incelenecektir.

2.3.1. Çeşitlilik: Tek kaynağa bağlı kalmamak arz güvenliği açısından önemlidir. Santraller, kullanılan yakıtın farklı kaynaklardan temin edilebilmesi durumu açısından değerlendirilecektir.

2.3.2. İthal bağımlılığın azaltılması: ithal kaynaklar yerine mümkün olduğunca yerli kaynakların kullanılması.

2.3.3. Kaynağın depolanabilir olması: üretimin aksamaması için kullanılan kaynağın depolanabilir olması. Santraller, kullanılan kaynağın depolanabilir olma durumuna göre değerlendirilecektir

2.4. Milli Ekonomiye Katkı:Santrallarin kurulmasının milli ekonomiye olan katkısını aşağıdaki başlıklarla değerlendirilecektir:

2.4.1. İşgücüne katkı:Yapılan santrallerde çalışan sayısı (kişi/MW).

2.4.2. Katma değer: kurulan santralin ekonomiye kazandırdığı canlılık. Santralin çalışması için farklı yerli firmalara iş imkanı sağlaması

2.4.3. Know-how: Santralin kurulumunun kazandırdığı bilgi birikimi. Santralin kurulumundaki(proje,inşaat, ekipman) teknoloji transferi.

KRİTERLERİN DEĞERLENDİRİLMESİ ANKETİ

Seçilen kriterlerin ağırlıklarının belirlenmesi için kriterlerin bağlı oldukları üst kritere göre ikili kıyaslaması yapılacaktır. Bu değerlendirme için aşağıdaki tabloda verilen 1-9 arasındaki değerler kullanılacaktır.

Sayısal Değer	Tanım	Açıklama (A ile B karşılaştırıldığında)
1	eşit önemde	A ile B eşit önemde
3	biraz daha önemli	A, B'ye göre biraz daha önemli
5	fazla önemli	A, B'ye göre fazla önemli
7	çok fazla önemli	A, B'ye göre çok fazla önemli
9	aşırı derecede önemli	A,B'ye göre aşırı derecede önemli
2,4,6,8	ara değerler	

Karşılaştırılan 2 kriterden hangisi daha önemli ise sadece o kriterin altındaki kutuya tabloda açıklanan 1'den 9'a kadar olan değerlerden uygun olanının yazılması gerekiyor. İki kriter eşit önemde ise ikisinden birine '1' yazmanız yeterli.

Örnek:
'Ekonomik' açıdan değerlendirildiğinde 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

Yatirim Maliyeti – Yatirim Suresi : Yatirim Maliyeti 'nin, Yatirim Suresi'nden **cok fazla** önemli olarak degerlendirildigini gosterir.

Yatirim Maliyeti	Yatirim Suresi
7	

Yatirim Maliyeti – Isletme Maliyeti: Isletme Maliyeti'nin, Yatirim Maliyetinden **biraz daha** önemli olarak degerlendirildigini gosterir.

Yatirim Maliyeti	Isletme Maliyeti
	3

Yatirim Suresi – Isletme Maliyeti: Isletme Maliyeti'nin, Yatirim Süresinden **aşırı derecede** önemli olarak degerlendirildigini gosterir.

Yatirim Suresi	Isletme Maliyeti
	9

1) Santrallerin değerlendirilmesinde aşağıdaki kriterlerden hangisi daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz

Ekonomik kriterler - Sosyal kriterler

Ekonomik kriterler	Sosyal kriterler
3	

2) ‘Ekonomik’ açıdan değerlendirildiğinde 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1’den 9’a kadar belirleyiniz.

Yatırım Maliyeti – Yatırım Süresi

5	

Yatırım Maliyeti – İşletme Maliyeti

1	

Yatırım Süresi – İşletme Maliyeti

	5

3) ‘Yatırım Maliyeti’ açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1’den 9’a kadar belirleyiniz.

Arazi Maliyeti – Proje Maliyeti

	5

Arazi Maliyeti – İnşaat Maliyeti

	3

Arazi Maliyeti – Ekipman Maliyeti

	5

Proje Maliyeti – İnşaat Maliyeti

	7

Proje Maliyeti – Ekipman Maliyeti

	7

İnşaat Maliyeti – Ekipman Maliyeti

	3

4) ‘Yatırım Süresi’ açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1’den 9’a kadar belirleyiniz.

Proje Süresi – İnşaat Süresi

3	

5) ‘İşletme Maliyeti’ açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1’den 9’a kadar belirleyiniz.

Yakıt Maliyeti – İşçilik Maliyeti

5	

Yakıt Maliyeti – Bakım & Onarım Maliyeti

3	

Yakıt Maliyeti – Kapasite Kullanımı

3	

İşçilik Maliyeti - Bakım & Onarım Maliyeti

	3

İşçilik Maliyeti - Kapasite Kullanımı

	3

Bakım & Onarım Maliyeti - Kapasite Kullanımı

3	

6) 'Sosyal' açıdan değerlendirildiğinde 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

Çevre – İnsan Sağlığı

1	

Çevre – Arz Güvenliği

1	

Çevre – Milli Ekonomiye Katkı

3	

İnsan Sağlığı - Arz Güvenliği

3	

İnsan Sağlığı - Milli Ekonomiye Katkı

3	

Arz Güvenliği - Milli Ekonomiye Katkı

1	

7) 'Çevre' açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

Su & Toprak Kirliliği – CO_2 çıkışı

2	

Su & Toprak Kirliliği - SO_2 & NOx çıkışı

1	

Su & Toprak Kirliliği – Gürültü

3	

Su & Toprak Kirliliği – Radyoaktivite

	5

CO_2 çıkışı – SO_2 & NOx çıkışı

3	

CO_2 çıkışı – Gürültü

5	

CO_2 çıkışı – Radyoaktivite

	5

SO_2 & NOx çıkışı – Gürültü

5	

SO_2 & NOx çıkışı - Radyoaktivite

	5

Gürültü – Radyoaktivite

	5

8) 'İnsan Sağlığı' açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

Su & Toprak Kirliliği – Partiküler Madde

	3

Su & Toprak Kirliliği - SO_2 & NOx çıkışı

1	

Su & Toprak Kirliliği – Gürültü

5	

Su & Toprak Kirliliği – Radyoaktivite

	5

Partiküler Madde – SO_2 & NOx çıkışı

3	

Partiküler Madde – Gürültü

5	

Partiküler Madde – Radyoaktivite

	5

SO_2 & NOx çıkışı – Gürültü

5	

SO_2 & NOx çıkışı - Radyoaktivite

	5

Gürültü – Radyoaktivite

	5

9) 'Arz Güvenliği'açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

Çeşitlilik – İthal Bağımlılığın Azaltılması

3	

Çeşitlilik – Kaynağın Depolanabilir Olması

3	

İthal Bağımlılığın Azaltılması – Kaynağın Depolanabilir Olması

5	

10) 'Milli Ekonomiye Katkı'açısından karşılaştırıldığında 2 kriterden hangisi diğerine göre daha önemlidir? Önem derecesini yukarıdaki tabloya göre 1'den 9'a kadar belirleyiniz.

İşgücüne Katkı – Katma Değer

	5

İşgücüne Katkı – Know-How

	3

Katma Değer – Know-How

1	

SANTRALLERİN KRİTERLERE GÖRE DEĞERLENDİRİLMESİ

Santrallerin kriterlere göre değerlendirilmesinde sayısal olarak ölçülemeyecek olanlar için santrallerin ağırlıklı olarak değerlendirilmesi istenmektedir.

1) Aşağıdaki santrallerin Çevreye olan 'Su & Toprak kirliliği' etkisini 1'den 9'a kadar değerlendiriniz. (olumsuz etkisi fazla olan daha yüksek değer alıcak şekilde)

_9____ Kömür
_4____ Doğalgaz
_1____ Rüzgar

2) Aşağıdaki santrallerin İnsan Sağlığına olan 'Su & Toprak kirliliği' etkisini 1'den 9'a kadar değerlendiriniz. (olumsuz etkisi fazla olan daha yüksek değer alıcak şekilde)

__9___ Kömür
__4___ Doğalgaz
__1___ Rüzgar

3) Doğalgaz ve kömür santrallerini 'çeşitlilik' açısından değerlendiriniz. 1'den 9'a kadar (çeşitlilik açısından avantajlı olan da yüksek değer alıcak şekilde)

__3___ Doğalgaz
__6___ Kömür

4) Doğalgaz ve kömür santrallerini 'ithal bağımlılığın azaltılması' açısından değerlendiriniz. 1'den 9'a kadar (ithal bağımlılığı az olan yüksek değer alıcak şekilde)

__2___ Doğalgaz
__7___ Kömür

5) Doğalgaz ve kömür santrallerini 'kaynağın depolanabilir olması' açısından değerlendiriniz. 1'den 9'a kadar (kaynağın depolanabilmesi yüksek değer alıcak şekilde)

___2__ Doğalgaz
___6__ Kömür

6) Aşağıdaki santralleri 'katma değer' açısından değerlendiriniz. 1'den 9'a kadar (katma değeri fazla olan yüksek değer alıcak şekilde)

__4___ Kömür
__4___ Doğalgaz
__2___ Rüzgar

7) Aşağıdaki santralleri 'know-how' açısından değerlendiriniz. 1'den 9'a kadar (know-how açısından katkısı fazla olan daha yüksek değer alıcak şekilde)

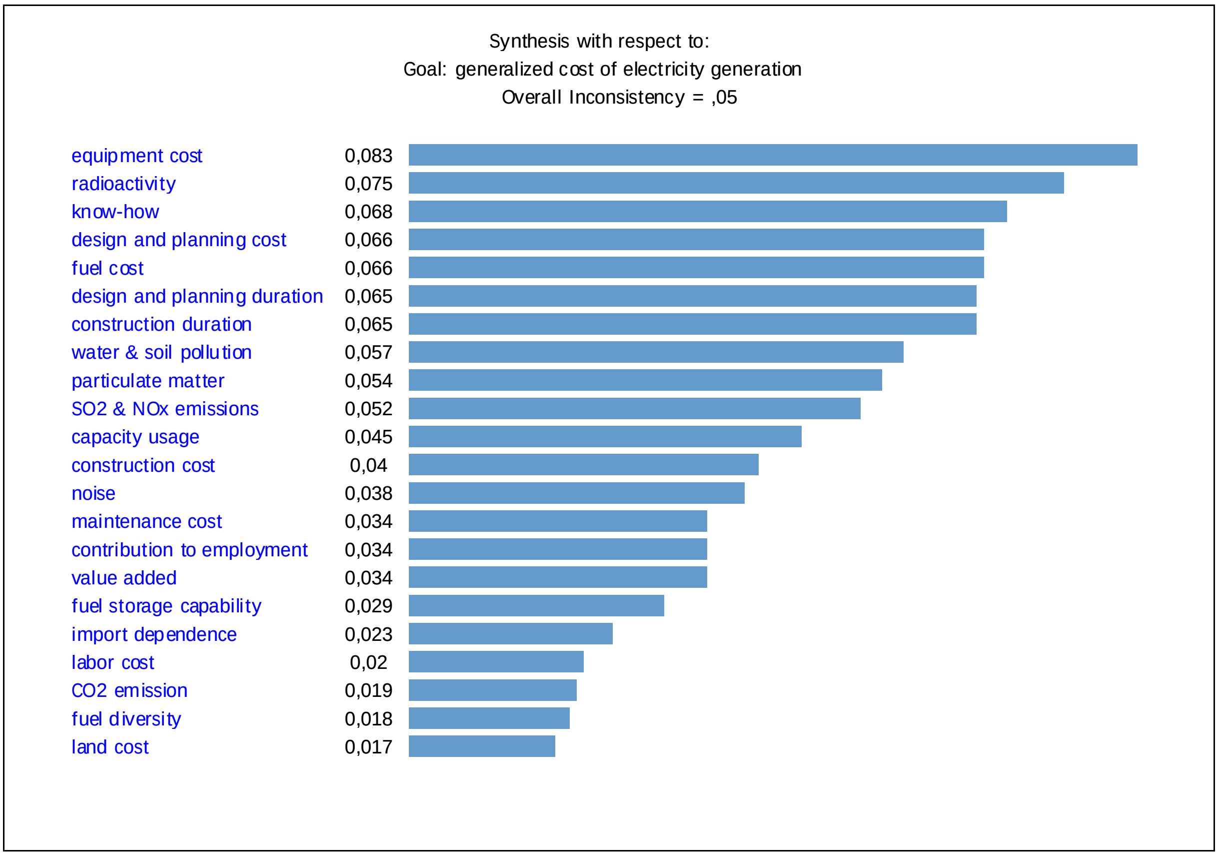
_2____ Kömür
_3____ Doğalgaz
_4____ Rüzgar

APPENDIX B : GROUP ANALYSIS RESULTS

- THE PS GROUP – Analysis Results

- **Goal: generalized cost of electricity generation**
  - **econimic criteria (L: ,500 G: ,500)**
    - **investment cost (L: ,413 G: ,206)**
      - **land cost (L: ,083 G: ,017)**
      - **design and planning cost (L: ,319 G: ,066)**
      - **construction cost (L: ,194 G: ,040)**
      - **equipment cost (L: ,404 G: ,083)**
    - **investment duration (L: ,260 G: ,130)**
      - **design and planning duration (L: ,500 G: ,065)**
      - **construction duration (L: ,500 G: ,065)**
    - **operating cost (L: ,327 G: ,164)**
      - **fuel cost (L: ,401 G: ,066)**
      - **labor cost (L: ,120 G: ,020)**
      - **maintenance cost (L: ,207 G: ,034)**
      - **capacity usage (L: ,272 G: ,045)**
  - **social criteria (L: ,500 G: ,500)**
    - **environmental impacts (L: ,163 G: ,082)**
      - **water & soil pollution (L: ,192 G: ,016)**
      - **CO2 emission (L: ,228 G: ,019)**
      - **SO2 & NOx emissions (L: ,194 G: ,016)**
      - **noise (L: ,126 G: ,010)**
      - **radioactivity (L: ,260 G: ,021)**
    - **direct impacts on human health (L: ,424 G: ,212)**
      - **water & soil pollution (L: ,195 G: ,041)**
      - **particulate matter (L: ,253 G: ,054)**
      - **SO2 & NOx emissions (L: ,171 G: ,036)**
      - **noise (L: ,129 G: ,027)**
      - **radioactivity (L: ,253 G: ,054)**
    - **supply stability (L: ,139 G: ,070)**
      - **fuel diversity (L: ,260 G: ,018)**
      - **import dependence (L: ,327 G: ,023)**
      - **fuel storage capability (L: ,413 G: ,029)**
    - **contribution to national economy (L: ,273 G: ,137)**
      - **contribution to employment (L: ,250 G: ,034)**
      - **value added (L: ,250 G: ,034)**
      - **know-how (L: ,500 G: ,068)**

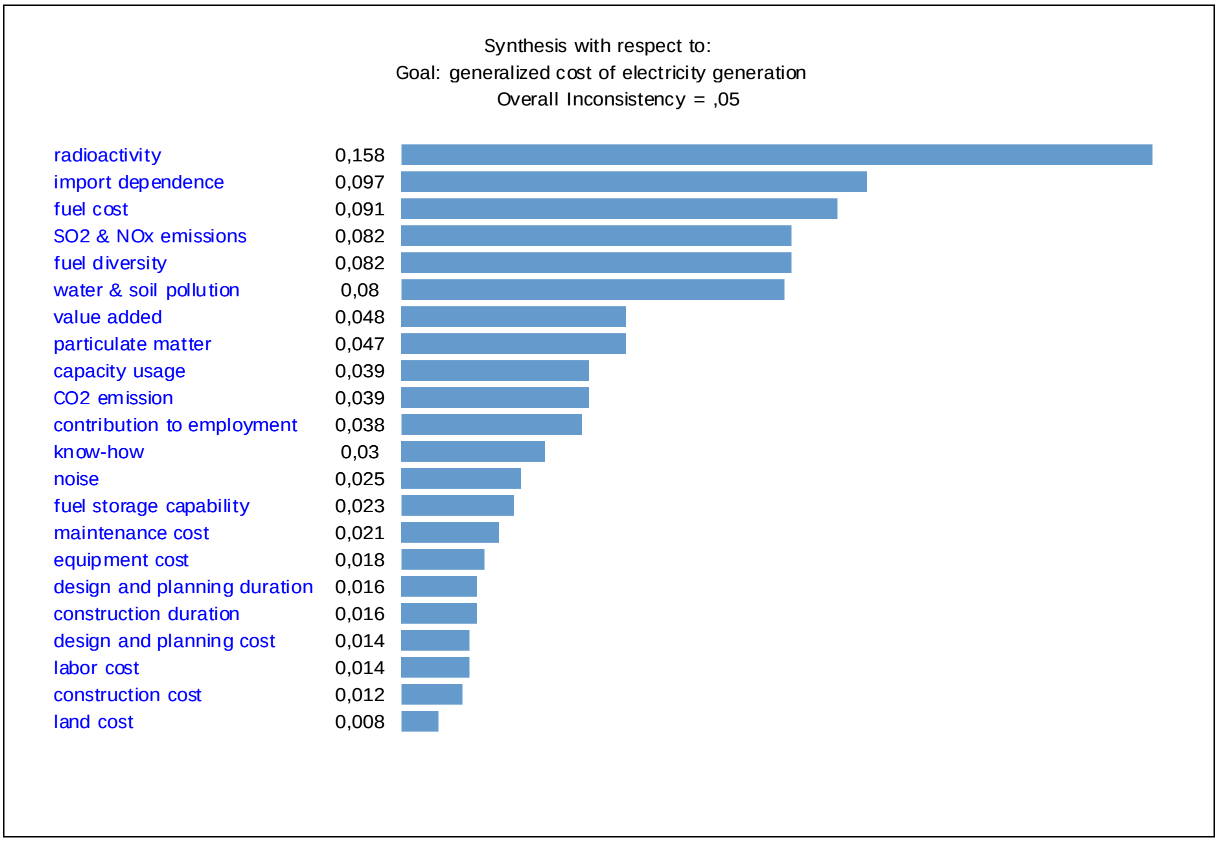
- THE PS GROUP– End Node Criteria Order According to Global Weightings



- THE ENVIRONMENT GROUP – Analysis Results

- **Goal: generalized cost of electricity generation**
  - **econimic criteria (L: ,250 G: ,250)**
    - **investment cost (L: ,208 G: ,052)**
      - **land cost (L: ,145 G: ,008)**
      - **design and planning cost (L: ,274 G: ,014)**
      - **construction cost (L: ,239 G: ,012)**
      - **equipment cost (L: ,343 G: ,018)**
    - **investment duration (L: ,131 G: ,033)**
      - **design and planning duration (L: ,500 G: ,016)**
      - **construction duration (L: ,500 G: ,016)**
    - **operating cost (L: ,661 G: ,165)**
      - **fuel cost (L: ,550 G: ,091)**
      - **labor cost (L: ,087 G: ,014)**
      - **maintenance cost (L: ,129 G: ,021)**
      - **capacity usage (L: ,234 G: ,039)**
  - **social criteria (L: ,750 G: ,750)**
    - **environmental impacts (L: ,237 G: ,178)**
      - **water & soil pollution (L: ,186 G: ,033)**
      - **CO2 emission (L: ,220 G: ,039)**
      - **SO2 & NOx emissions (L: ,197 G: ,035)**
      - **noise (L: ,057 G: ,010)**
      - **radioactivity (L: ,340 G: ,061)**
    - **direct impacts on human health (L: ,338 G: ,254)**
      - **water & soil pollution (L: ,186 G: ,047)**
      - **particulate matter (L: ,186 G: ,047)**
      - **SO2 & NOx emissions (L: ,186 G: ,047)**
      - **noise (L: ,060 G: ,015)**
      - **radioactivity (L: ,383 G: ,097)**
    - **supply stability (L: ,270 G: ,203)**
      - **fuel diversity (L: ,405 G: ,082)**
      - **import dependence (L: ,481 G: ,097)**
      - **fuel storage capability (L: ,114 G: ,023)**
    - **contribution to national economy (L: ,154 G: ,116)**
      - **contribution to employment (L: ,327 G: ,038)**
      - **value added (L: ,413 G: ,048)**
      - **know-how (L: ,260 G: ,030)**

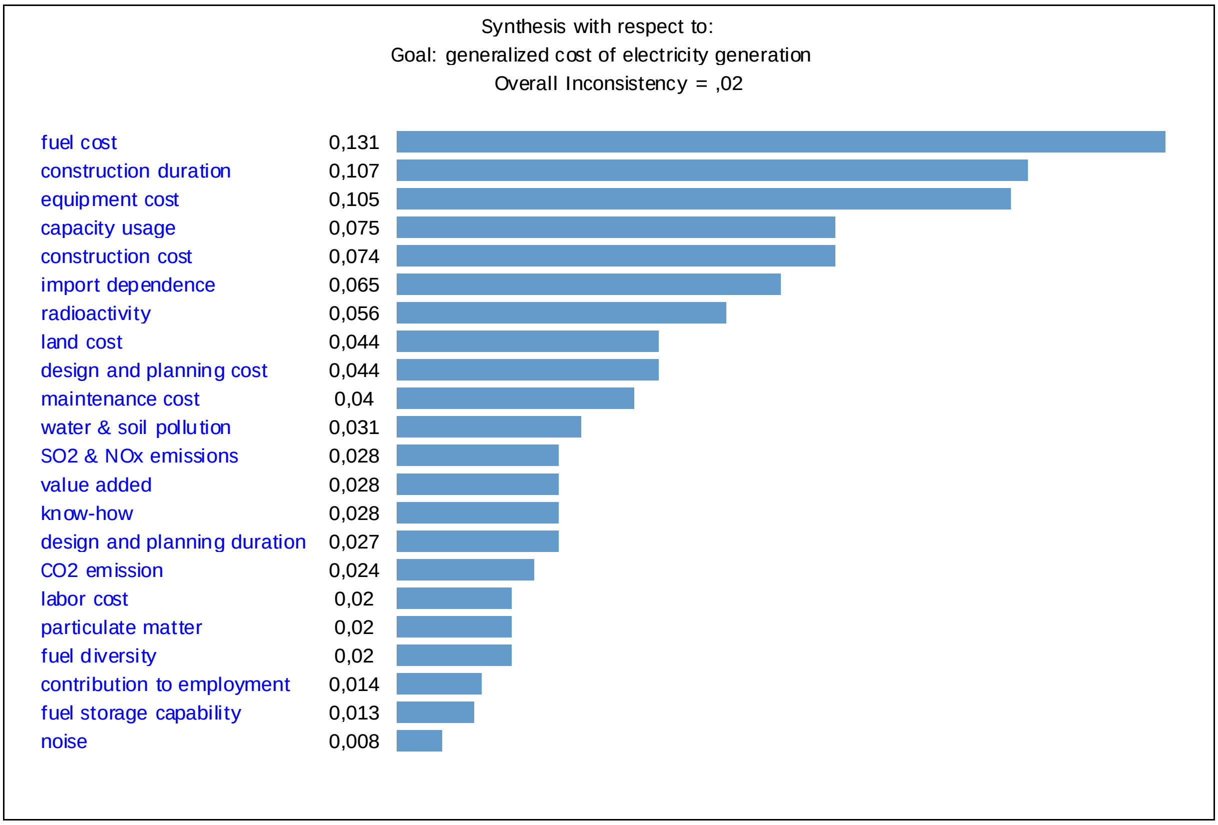
- THE ENVIRONMENT GROUP – End Node Criteria Order According to Global Weightings



- THE UNIVERSITY GROUP – Analysis Results

- **Goal: generalized cost of electricity generation**
  - **econimic criteria (L: ,667 G: ,667)**
    - **investment cost (L: ,400 G: ,267)**
      - **land cost (L: ,163 G: ,044)**
      - **design and planning cost (L: ,163 G: ,044)**
      - **construction cost (L: ,278 G: ,074)**
      - **equipment cost (L: ,395 G: ,105)**
    - **investment duration (L: ,200 G: ,133)**
      - **design and planning duration (L: ,200 G: ,027)**
      - **construction duration (L: ,800 G: ,107)**
    - **operating cost (L: ,400 G: ,267)**
      - **fuel cost (L: ,490 G: ,131)**
      - **labor cost (L: ,076 G: ,020)**
      - **maintenance cost (L: ,152 G: ,040)**
      - **capacity usage (L: ,283 G: ,075)**
  - **social criteria (L: ,333 G: ,333)**
    - **environmental impacts (L: ,207 G: ,069)**
      - **water & soil pollution (L: ,168 G: ,012)**
      - **CO2 emission (L: ,347 G: ,024)**
      - **SO2 & NOx emissions (L: ,122 G: ,008)**
      - **noise (L: ,048 G: ,003)**
      - **radioactivity (L: ,314 G: ,022)**
    - **direct impacts on human health (L: ,293 G: ,098)**
      - **water & soil pollution (L: ,200 G: ,020)**
      - **particulate matter (L: ,200 G: ,020)**
      - **SO2 & NOx emissions (L: ,200 G: ,020)**
      - **noise (L: ,047 G: ,005)**
      - **radioactivity (L: ,353 G: ,034)**
    - **supply stability (L: ,293 G: ,098)**
      - **fuel diversity (L: ,208 G: ,020)**
      - **import dependence (L: ,661 G: ,065)**
      - **fuel storage capability (L: ,131 G: ,013)**
    - **contribution to national economy (L: ,207 G: ,069)**
      - **contribution to employment (L: ,200 G: ,014)**
      - **value added (L: ,400 G: ,028)**
      - **know-how (L: ,400 G: ,028)**

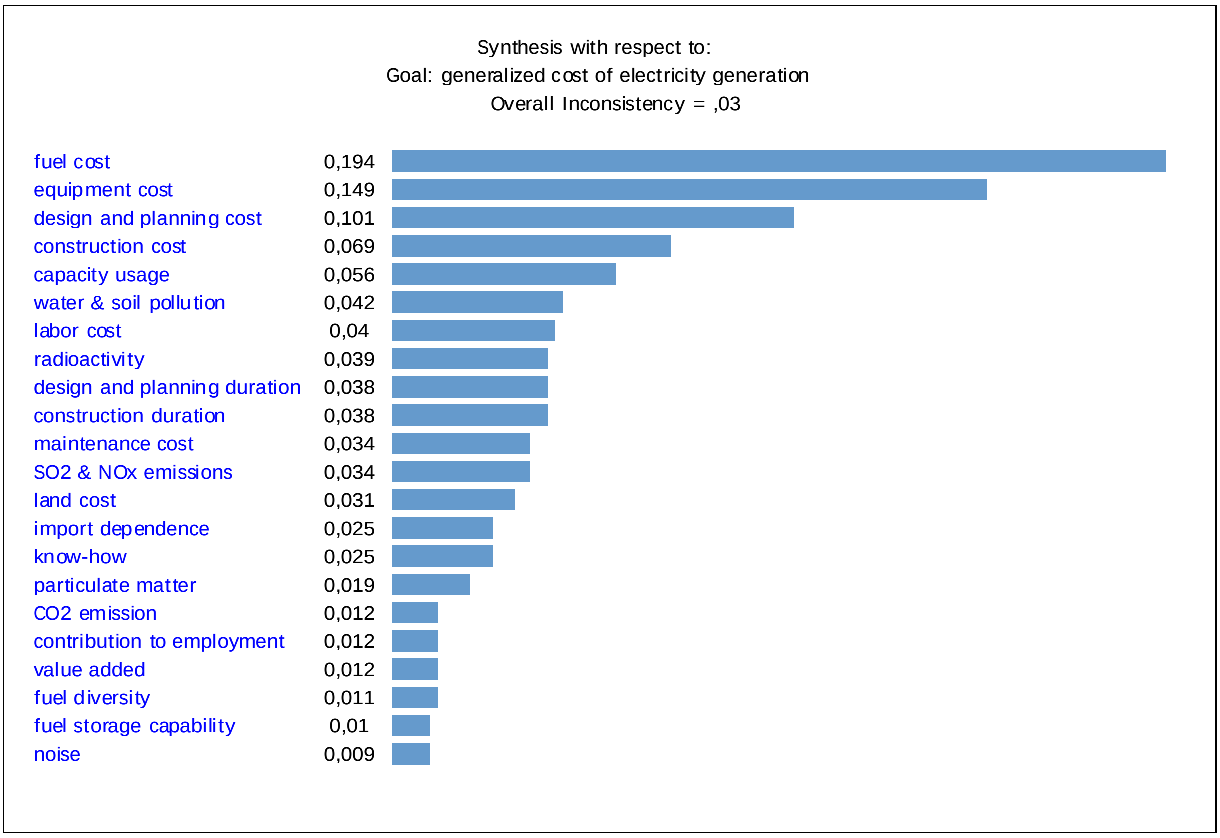
- THE UNIVERSITY GROUP – End Node Criteria Order According to Global Weightings



- THE EXPERT GROUP – Analysis Results

- **Goal: generalized cost of electricity generation**
  - **econimic criteria (L: ,750 G: ,750)**
    - **investment cost (L: ,466 G: ,350)**
      - **land cost (L: ,090 G: ,031)**
      - **design and planning cost (L: ,287 G: ,101)**
      - **construction cost (L: ,196 G: ,069)**
      - **equipment cost (L: ,427 G: ,149)**
    - **investment duration (L: ,100 G: ,075)**
      - **design and planning duration (L: ,500 G: ,038)**
      - **construction duration (L: ,500 G: ,038)**
    - **operating cost (L: ,433 G: ,325)**
      - **fuel cost (L: ,596 G: ,194)**
      - **labor cost (L: ,125 G: ,040)**
      - **maintenance cost (L: ,105 G: ,034)**
      - **capacity usage (L: ,174 G: ,056)**
  - **social criteria (L: ,250 G: ,250)**
    - **environmental impacts (L: ,243 G: ,061)**
      - **water & soil pollution (L: ,316 G: ,019)**
      - **CO2 emission (L: ,194 G: ,012)**
      - **SO2 & NOx emissions (L: ,194 G: ,012)**
      - **noise (L: ,070 G: ,004)**
      - **radioactivity (L: ,225 G: ,014)**
    - **direct impacts on human health (L: ,379 G: ,095)**
      - **water & soil pollution (L: ,239 G: ,023)**
      - **particulate matter (L: ,202 G: ,019)**
      - **SO2 & NOx emissions (L: ,239 G: ,023)**
      - **noise (L: ,052 G: ,005)**
      - **radioactivity (L: ,268 G: ,025)**
    - **supply stability (L: ,182 G: ,045)**
      - **fuel diversity (L: ,240 G: ,011)**
      - **import dependence (L: ,550 G: ,025)**
      - **fuel storage capability (L: ,210 G: ,010)**
    - **contribution to national economy (L: ,197 G: ,049)**
      - **contribution to employment (L: ,250 G: ,012)**
      - **value added (L: ,250 G: ,012)**
      - **know-how (L: ,500 G: ,025)**

- THE EXPERT GROUP – End Node Criteria Order According to Global Weightings



APPENDIX C : GENERIC POWER PLANTS ANALYSIS RESULTS

Synthesis: Details

Alts	Level 1	Level 2	Level 3	Prty
Percent c...				15,5
	Percent econimic criteria (L: ,500 G: ,500)			7,8
	econimic criteria (L: ,500 G: ,500)	Percent in...		2,6
		investmen...	land cost (...	,003
			design an...	,005
			constructi...	,004
			equipment...	,014
		Percent in...		1,0
		investmen...	design an...	,007
			constructi...	,003
		Percent o...		4,2
		operating ...	fuel cost (...	,029
			labor cost ...	,001
			maintenan...	,003
			capacity u...	,009
	Percent social criteria (L: ,500 G: ,500)			7,7
coal 1	social criteria (L: ,500 G: ,500)	Percent c...		2,2
		contributio...	contributio...	,008
			value add...	,010
			know-how...	,004
		Percent di...		1,0
		direct imp...	water & s...	,004
			particulate...	,000
			SO2 & N...	,004
			noise (L: ,...	,002
			radioactivi...	,000
		Percent e...		0,6
		environme...	water & s...	,003
			CO2 emis...	,000
			SO2 & N...	,002
			noise (L: ,...	,001
			radioactivi...	,000
		Percent s...		3,9
		supply sta...	fuel divers...	,007
			import dep...	,025
			fuel storag...	,007
Percent c...				18,6
	Percent econimic criteria (L: ,500 G: ,500)			7,7
coal 2	econimic criteria (L: ,500 G: ,500)	Percent in...		2,5
		investmen...	land cost (...	,003
			design an...	,005
			constructi...	,004
			equipment...	,013
		Percent in...		1,0
		investmen...	design an...	,007
			constructi...	,003
		Percent o...		4,2
		operating ...	fuel cost (...	,029
			labor cost ...	,001

Alts	Level 1	Level 2	Level 3	Prty
coal 2	econimic criteria (L: ,500 G: ,500)	operating ...	maintenan...	,003
			capacity u...	,009
	Percent social criteria (L: ,500 G: ,500)			10,9
	social criteria (L: ,500 G: ,500)	Percent c...		2,2
		contributio...	contributio...	,008
			value add...	,010
			know-how...	,004
		Percent di...		3,6
		direct imp...	water & s...	,004
			particulate...	,015
			SO2 & N...	,015
			noise (L: ,...	,002
			radioactivi...	,000
		Percent e...		1,2
		environme...	water & s...	,003
			CO2 emis...	,001
			SO2 & N...	,007
			noise (L: ,...	,001
			radioactivi...	,000
		Percent s...		3,9
		supply sta...	fuel divers...	,007
			import dep...	,025
			fuel storag...	,007
Percent ...				27,0
natural gas	Percent econimic criteria (L: ,500 G: ,500)			9,5
	econimic criteria (L: ,500 G: ,500)	Percent in...		5,5
		investmen...	land cost (...	,007
			design an...	,014
			constructi...	,010
			equipment...	,024
		Percent in...		1,1
		investmen...	design an...	,007
			constructi...	,004
		Percent o...		2,9
		operating ...	fuel cost (...	,004
			labor cost ...	,010
			maintenan...	,006
			capacity u...	,009
	Percent social criteria (L: ,500 G: ,500)			17,5
	social criteria (L: ,500 G: ,500)	Percent c...		1,9
		contributio...	contributio...	,001
			value add...	,009
			know-how...	,009
		Percent di...		9,8
		direct imp...	water & s...	,013
			particulate...	,021
			SO2 & N...	,022
			noise (L: ,...	,002
			radioactivi...	,040
		Percent e...		4,9
		environme...	water & s...	,009
			CO2 emis...	,010
			SO2 & N...	,011
			noise (L: ,...	,001
			radioactivi...	,018
		Percent s...		0,9
		supply sta...	fuel divers...	,004

Alts	Level 1	Level 2	Level 3	Prty
natural gas	social criteria (L: ,500 G: ,500)	supply sta...	import dep...	,002
			fuel storag...	,003
Percent ...				38,8
	Percent econimic criteria (L: ,500 G: ,500)			14,0
		Percent in...		4,0
	econimic criteria (L: ,500 G: ,500)	investmen...	land cost (...	,004
			design an...	,010
			constructi...	,015
			equipment...	,011
		Percent in...		2,5
		investmen...	design an...	,007
			constructi...	,018
		Percent o...		7,5
		operating ...	fuel cost (...	,065
			labor cost ...	,001
			maintenan...	,006
			capacity u...	,003
	Percent social criteria (L: ,500 G: ,500)			24,8
		Percent c...		3,3
wind	social criteria (L: ,500 G: ,500)	contributio...	contributio...	,003
			value add...	,008
			know-how...	,022
		Percent di...		10,8
		direct imp...	water & s...	,022
			particulate...	,022
			SO2 & N...	,022
			noise (L: ,...	,002
			radioactivi...	,040
		Percent e...		6,3
		environme...	water & s...	,015
			CO2 emis...	,018
			SO2 & N...	,011
			noise (L: ,...	,001
			radioactivi...	,018
		Percent s...		4,4
		supply sta...	fuel divers...	,007
			import dep...	,037
			fuel storag...	,000

REFERENCES

1. Hepbasli, A., "Development and Restructuring of Turkey's Electricity Sector: A Review", *Renewable and Sustainable Energy Reviews*, Vol. 9, pp. 311-343, 2005.

2. Özkivrak, Ö., "Electricity Restructuring in Turkey", *Energy Policy*, Vol. 33, pp. 1339-1350, 2005.

3. Cetin, T. and F. Oguz, "The Politics of Regulation in the Turkish Electricity Market", *Energy Policy*, Vol. 35, pp. 1761-1770, 2007.

4. Erdogdu, E., "Some Thoughts on the Turkish Electricity Distribution Industry", *Renewable and Sustainable Energy Reviews*, Vol. 13, pp. 1485-1494, 2009.

5. Atiyas, I., *Elektrik Sektöründe Serbestleşme ve Düzenleyici Reform*, TESEV Publications, 2006.

6. Atiyas, I. And M. Dutz, "Competition and Regulatory Reform in Turkish Electricity Industry", *Conference Paper on EU Accession*, Turkey, 2003.

7. *Türkiye Elektrik Enerjisi 10 Yıllık Üretim Kapasite Projeksiyonu (2009-2018)*, http://www.teias.gov.tr, 2009.

8. *EUAS Annual Report 2008*, http://www.euas.gov.tr,2009.

9. *EUAS Elektrik Üretim Sektör Rapor 2008*, http://www.euas.gov.tr, 2009.

10. *TETAS Sektör Raporu 2009*, http://www.tetas.gov.tr, 2009.

11. *TEDAS Annual Report 2008*, http://www.tedas.gov.tr,2009.

12. *Republic of Turkey Ministry of Energy and Natural Resources Webpage* http://www.enerji.gov.tr, 2009.

13. *Control and Minimisation of Coal-fired Power Plant Emissions*, International Energy Agency, http://www.iea.org/textbase/papers/2003/Coal_Fired_Fossil_Fuels.pdf, 2009.

14. Kutz, M., *Environmentally Conscious Alternative Energy Production*, John Wiley&Sons, New Jersey, 2007.

15. *Electric Generation Using Natural Gas*, http://www.naturalgas.org/ overview/ uses_eletrical.asp, 2009.

16. *Global Wind Energy Outlook 2008*, Global Wind Energy Council, http://www.gwec.net, 2009.

17. *Global Wind 2008 Report*, Global Wind Energy Council, http://www.gwec.net, 2009.

18. Erdoğdu, E. "On the Wind Energy in Turkey", *Renewable and Sustainable Energy Reviews*, Vol. 13, pp.1361-1371, 2009.

19. Kocaman, B., *Elektrik Enerjisi Üretim Santralleri,* Birsen Yayınevi, İstanbul, 2003.

20. *Wind Energy- The Facts: Environment*, Vol. 4, http://www.ewea.org, 2009.

21. Chatzimouratidis, A. I. and P. A. Pilavachi, "Technological, Economic and Sustainability Evaluation of Power Plants Using the Analytic Hierarchy Process", *Energy Policy*, Vol. 37, pp. 778-787, 2009.

22. Chatzimouratidis, A. I. and P. A. Pilavachi, "Objective and Subjective Evaluation of Power Plants and Their Non-radioactive Emissions Using the Analytic Hierarchy Process", *Energy Policy*, Vol. 35, pp. 4027-4038, 2007.

23. Chatzimouratidis, A. I. and P. A. Pilavachi, “Multicriteria Evaluation of Power Plants Impact on the Living Standard Using the Analytic Hierarchy Process”, *Energy Policy*, Vol. 36, pp.1074-1089, 2008.

24. Afgan, N. H. and M. G. Carvalho, “Multi-criteria Assessment of New and Renewable Energy Power Plants”, *Energy*, Vol. 27, pp. 739-755, 2002.

25. Tzeng, G. H., T. A. Shiau and C. Y. Lin, “Application of Multicriteria Decision Making to the Evaluation of New Energy System Development in Taiwan”, *Energy*, Vol.17, No. 10, pp. 983-992, 1992.

26. Pilavachi P. A., S. D. Stephanidis, V. A. Pappas and N. H. Afgan, “Multi-criteria Evaluation of Hydrogen and Natural Gas Fuelled Power Plant Technologies”, *Applied Thermal Engineering*, Vol.29, pp. 2228-2234, 2009.

27. Afgan, N. H., P. A. Pilavachi and M. G. Carvalho, “Multi-criteria Evaluation of Natural Gas Resources”, *Energy Policy*, Vol. 35, pp. 704-713, 2007.

28. Georgopoulou, E., D. Lalas and L. Papagiannakis, “A Multicriteria Decision Aid Approach for Energy Planning Problems: The Case of Renewable Energy Option”, *European Journal of Operational Research,* Vol. 103, pp. 38-54 , 1997.

29. Saaty, T.L., “How to Make A Decision: The Analytic Hierarcy Process”, *Interfaces*, Vol. 24:6, pp.19-43, November- December 1994.

30. Saaty, T.L. and L. G. Vargas, *Models, Methods, Concept & Application of The Analytic Hierarchy Process*, Kluwer Academic Publishers, USA, 2001.

31. Forman, E.H. and S: I. Gass “The Analytic Hierarchy Process- An Exposition”, *Operation Research*, Vol. 49 (4), pp. 469-486, July-August 2001.

32. Siskos, J. and P. Hubert, “Multi-criteria Analysis of the Impacts of Energy Alternatives: A Survey and A New Comparative Approach”, *European Journal of Operational Research,* Vol. 13, pp. 278-299, 1983.

33. Georgopoulou, E., Y. Sarafidis, D. Diakoulaki, “Design and Implementation of A Group DSS for Sustaining Renewable Energies Exploitation”, *European Journal of Operational Research,* Vol. 109, pp. 483-500 , 1998.

34. Brans,J.P, P. Vincke and B. Mareschal, “How to Select and How to Rank Projects: The PROMETHEE Method”, *European Journal of Operational Research,* Vol. 24, pp. 228-238 , 1986.

35. Polatidis, H., D. A. Haralambopoulos, G. Mund and R. Vreeker, “Selecting An Appropriate Multi-Criteria Decision Analysis Technique for Renewable Energy Planning”, *Energy Sources*, Part B, Vol. 1, pp. 181-193, July 2006.

36. *International Energy Agency (IEA), Projected Costs of Generating Electricity 2005 Update*, http://www.iea.org, 2009.

37. *The Economics of Wind Energy*, The European Wind Energy Association (EWEA), http://www.eaew.org, 2009.

38. *Enerji Dünyası*, http://www.enerji-dunyasi.com/ vol 58_59, 2009.

39. Vaidya,S. and S. Kumar, “Analytic Hierarchy Process: An Overview of Applications”, *European Journal of Operational Research,* Vol. 169, pp.1-29 , 2006.

40. Cevik,U., N. Damla, S. Nezir, “Radiological Characterization of Cayırhan Coal-fired Power Plant in Turkey”, *Fuel*, Vol. 86, pp. 2509-2513, 2007.

41. *International Atomic Energy Agency (IAEA) Reference Technology Database*, http://www.iaea.org/OurWork/ST/NE/Pess/RTDB, 2009.

REFERENCES NOT CITED

Bagdadioglu, N. And N. Odyakmaz , “Turkish Electricity Reform”, *Utilities Policy*, Vol. 17, pp.144-152, 2009.

Republic of Turkey Prime Ministry Privatization Administration Webpage, http://www.oib.gov.tr, 2009.

Turkish Wind Energy Association, http://www.ruzgarenerjisibirligi.org.tr, 2009.