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Reevaluation of Turkey's hydropower potential and electric energy demand

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ABSTRACT

This paper deals with Turkey's hydropower potential and its long-term electric energy demand predictions. In the paper, at first, Turkey's energy sources are briefly reviewed. Then, hydropower potential is analyzed and it has been concluded that Turkey's annual economically feasible hydropower potential is about 188 TWh, nearly 47% greater than the previous estimation figures of 128 TWh. A review on previous prediction models for Turkey's long-term electric energy demand is presented. In order to predict the future demand, new increment ratio scenarios, which depend on both observed data and future predictions of population, energy consumption per capita and total energy consumption, are developed. The results of 11 prediction models are compared and analyzed. It is concluded that Turkey's annual electric energy demand predictions in 2010, 2015 and 2020 vary between 222 and 242 (average 233) TWh; 302 and 356 (average 334) TWh; and 440 and 514 (average 476) TWh, respectively. A discussion on the role of hydropower in meeting long-term demand is also included in the paper and it has been predicted that hydropower can meet 25–35% of Turkey's electric energy demand in 2020.

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1. Introduction

Energy is considered to be a key player in the generation of wealth and also a significant component in economic development. This makes energy resources extremely significant in the world. There is an ongoing action for energy market reform in International Energy Agency (IEA) countries. So, energy market reform focused primarily on the electricity sector and to a lesser extent on gas. Reform in both sectors offers strong potential gains in efficiency through the unbundling of production, transmission and distribution (Dincer, 1999, 2002).

Turkey is situated at the meeting point of three continents (Asia, Europe and Africa) and stands as a bridge between Asia and Europe. The country is located in southeastern Europe and southwestern Asia. Its size is 779,452 km^2. Turkey's population is nearly 73 million and 60% of the inhabitants of the country live in cities. Economic growth in recent years has been associated with the privatization of public enterprises. The macroeconomic performance was boosted by a growth in the energy sector (Yüksek et al., 2006). Because of its geopolitical position, Turkey can be considered as a bridge for energy to connect Europe to Asia and the Middle East. Turkey has improved its economic situation in recent years, and this has caused more energy needs, which means more consumption and more imports. The economic growth rate is the 16th largest in the world and the energy needs of the country are also increasing gradually (Kiliç and Kaya, 2007).

Various studies were performed on Turkey's energy status and hydropower (HP) capacity (Hepbasli et al., 2001; Kaygusuz, 2002a; Bakır, 2007; Yüksek and Kaygusuz, 2006). In these and similar studies, the total HP capacity was generally dealt with and no study was carried out to predict the long-term energy demand and the role of HP in meeting this demand. Yüksek et al. (2006) have studied Turkey's long-term energy demand by Model for Assessment of Energy Demand (MAED) Model, reviewed its hydropower potential (HP) and discussed the role of HP in meeting long-term energy demand. They have resulted in that Turkey's HP can meet nearly 40% of demand.

Turkey's annual total gross and technically feasible HPs are 435 and 215 TWh, respectively. Economically feasible HP has been calculated by General Directorate of State Hydraulics Works (DSİ) as 128 TWh, nearly 60% of technically feasible potential. If the usage of all of the hydropower resources were economically feasible, then the technically and economically feasible potential values would be equal. However, since the use of some part of the resources is not economical for various reasons, these figures are more or less different.

The estimation of the economically feasible electric energy potential (EFEP) has of vital importance in the future planning of economical development and investment policies on energy sources, as well as in various energy policy decisions. Some feasibility criteria have been used to estimate the EFEP. Here, the key concept is to determine the criteria used for deciding what is

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feasible and what is not. Therefore, an analysis about this item is very important in planning of energy sources.

In this study, Turkey's hydroelectric energy potential is reevaluated by using the findings of Bakır's study (2007), in which a new criterion was developed related to key concept of "the economical feasibility", by taking into consideration some undervalued and even ignored benefits of hydro plants and some overvalued benefits of thermal power plants (TPPs); economically feasible hydropower potential goes up to 188 TWh/year, with an increase ratio of nearly 47% compared to DSİ (DSİ, 2008) figure. An analysis also is made on Turkey's hydropower and especially small hydropower potential.

Similar to the estimation of economically feasible potential, the prediction of the future electric energy demand and the potential of capacity to meet this demand are also very important issues; because the energy shortage (difference between capacity and demand) must be met by some other energy sources (either by discovering new indigenous resources or by importing). Therefore, elaborated analysis on this issue must be made to overcome the shortage.

There have been some new studies to predict Turkey's long-term electric energy demand (Yumurtacı and Asmaz, 2004; Tunç et al., 2006; Hamzaçebi, 2007). In these studies, electric energy consumption between 2005 and 2020 is predicted by using previous consumption data. However, the results of these studies exhibit much scattering, resulting in uncertainties in demand predictions. A discussion about these long-term electric energy demand prediction models is given and new prediction scenarios are introduced. Then, by taking into consideration the increase ratios of population, electric energy consumption per capita and total electric energy consumption values, both observed in the past and predicted by DPT (State Planning Organization), new six predictions are introduced. Various statistical properties, including mean, standard deviation, coefficient of variation and confidence intervals for two confidence levels, are calculated for all of the scenarios.

Depending on the applied scenario and used model, Turkey's annual electric energy demands in 2010, 2015 and 2020 are predicted to vary between 222 and 242 (on average 233) TWh; 302 and 356 (on average 334) TWh; and 440 and 514 (on average 476) TWh, respectively.

A discussion on the role of hydropower in meeting demand is also included in the paper. It has been concluded that hydropower can meet 25–35% of Turkey's electric energy demand in 2020 and new energy plants should be made as soon as possible.

2. A review on Turkey's energy sources

Because of social and economic development of the country, the demand for energy and particularly for electricity is growing rapidly in Turkey. Turkey's natural energy resources are quite miscellaneous; for example, hard coal, lignite, asphalt, oil, natural gas, hydro, geothermal, wood, animal and plant wastes, solar and secondary energy resources, coke, and briquettes. These resources are produced and consumed in the country. Turkey does not own large fossil-fuel reserves. In the future, it seems that it will be very difficult to meet the anticipated demand for oil, natural gas, and even coal. On the other hand, Turkey has huge reserves of renewable energy sources (Kiliç and Kaya, 2007). In Turkey, where there is no nuclear power, electricity is produced by TPPs, consuming coal, lignite, natural gas, fuel oil and geothermal energy; and by hydropower plants (HPPs) (Yüksek et al., 2006).

Turkey's geographic location has several advantages for extensive use of most of the renewable energy sources. It is on the humid and warm climatic belt, which includes most of Europe, the near east and western Asia. Demographic projections as well as the growing gap between national energy demand and production raised concerns on the economical and environmental impacts of power generation based on Turkey's national energy sources.

Clean, domestic and renewable energy is commonly accepted as the key for future life, not only for Turkey but also for the entire world. This is primarily because renewable energy resources have some advantages when compared to fossil fuels. Turkey has to adopt new long-term energy strategies to reduce the share of fossil fuels in the energy consumption (Hepbasli et al., 2001).

Meeting energy demand is of high importance in Turkey. But exploiting the country's large energy efficiency potential is also vital. Air pollution is a significant problem and, as the government's projections show, carbon emissions could rise sharply if current trends continue (Kaygusuz, 2002a). Turkey is striving to make good use of its geographic location as a transit country linking the oil- and gas-rich Caspian area to the Mediterranean and to the demand centers of the West. Several pipeline projects are under way. They could have a positive effect on the diversity and security of supply in many consuming countries. They could also help avoid further environmental strain on the maritime routes through the Bosporus (Kaygusuz, 2001).

Hydropower energy and the surrounding seas are Turkey's main potential sources of renewable energies. In addition, geothermal energy beneath the surface of the western Anatolia; wind and solar energy available at western, eastern, and middle Anatolia; and nuclear energy by abundant thorium and uranium ores lying throughout Anatolia and hydrogen potential accumulated at the submarine of Black Sea are the other potential renewable energy sources in Turkey. In this regard, the major areas of renewable energy research in Turkey are hydropower, solar thermal, wind, geothermal, photovoltaic energy, and new programs such as hydrogen energy, fuel cells, etc. (Kaygusuz, 2002b).

Turkey's renewable energy sources are plentiful and extensive. Renewable energy production makes up approximately 14.4% of the total primary energy supply and renewable sources represent the second-largest domestic energy source after coal (Kiliç and Kaya, 2007).

Turkey's main fossil energy resource is coal, which has been produced for years domestically, and its share of the country's total energy consumption is about 24%. It is used mainly for power generation, cement production, and steel manufacturing. Turkey is one of the biggest producers of lignite in the world. This comes predominantly from deposits of the Southwest and the Southeastern Afsin-Elbistan Basin, where 7339 million tons lignite is economically usable. The government plans to increase the coal supply from 20.1 Mtoe in 1999 to 118.4 Mtoe in 2020 (Kiliç and Kaya, 2007).

3. Reevaluation of Turkey's hydroelectric potential

3.1. Hydroelectric power

Hydropower provides unique benefits, rarely found in other sources of energy. These benefits can be attributed to the electricity itself, or to side-benefits, often associated with reservoir development. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and water discharge. As the most important of the clean, renewable energy options, hydropower is often one of a number of benefits of a multipurpose water resources development project. Hydropower is the largest

renewable resource used for electricity (Frey and Linke, 2002; IHA, 2000). It plays an essential role in many regions of the world with more than 150 countries generating hydroelectric power.

There is vast unexploited potential worldwide for new hydro plants, particularly in the developing countries of Asia, Latin America and Africa, while most of the best sites have already been developed in Europe and North America. There is also upgrading potential at existing schemes though any future hydro projects will, in general, have to satisfy stricter requirements both environmentally and economically than they have in the past (Bartle, 2002).

It is expected that the world energy demand, and especially that for electricity, will increase greatly during the 21st century, not only because of demographic pressures, but also through an improvement in living standards in the less developed countries, which will represent 7 billion inhabitants in 2050 (78% of the total) (IEA (International Energy Agency), 2001).

General characteristics of HPPs can be summarized as follows (IHA, 2000):

- Its resources are widely spread around the world. Potential exists in about 150 countries, and about 70% of the economically feasible potential remains to be developed.
- It is a proven and well advanced technology with modern power plants providing the most efficient energy conversion process (>90%), which is also an important environmental benefit.
- The production of peak load energy from hydropower allows for the best use to be made of base-load power from other less flexible electricity sources, notably wind and solar power. Its fast response time enables it to meet sudden fluctuations in demand.
- It has the lowest operating costs and longest plant life, compared with other large scale generating options. Typically a hydro plant in service for 40–50 years can have its operating life doubled.
- The "fuel" (water) is renewable, and is not subject to fluctuations in market. Countries with ample reserves of fossil fuels, such as Iran and Venezuela, have opted for a large scale program of hydro development, recognizing environmental benefits. Hydro also represents energy independence for many countries.

3.2. Turkey's hydroelectric potential

3.2.1. Current status

The annual average precipitation in Turkey is nearly 643 mm, corresponding to a volume of 500 km^3. The average runoff coefficient is 0.37, and the annual runoff is 186 km^3 (2400 m^3/ha). The annual depth of precipitation is as high as 250 cm in the Eastern Black Sea Region and as low as 30 cm in some parts of central Anatolia. Most of the country's water potential lies in the southeast (28%) and the Black Sea region (8%). Some 22% of the boundaries between Turkey and the neighboring countries are along international rivers (Yüksek and Üçüncü, 1999).

Owing to Turkey's regions, most of which are hilly, it can be possible to develop relatively higher heads without expensive civil engineering works, so that relatively smaller flows are required to develop for the desired power. In these cases, it may be possible to construct a relatively simple diversion structure and to obtain the highest drop by diverting flows at the top of a waterfall. There are intensive investigations to improve the small and large hydropower development in Turkey. For putting this aim into practice, some of small HPPs are still under construction.

Turkey has rigorous plans for the development of its substantial hydropower potential. Schemes built on the concept of build-own-transfer (BOT) are being encouraged strongly, and bilateral agreements have been signed with a number of countries to further international cooperation in hydropower development (Yüksek and Kaygusuz, 2006).

3.2.2. Hydroelectric potential according to existing economical feasibility criteria

Turkey's annual total gross and technically feasible HPs are 435 and 215 TWh, respectively. Economically feasible HP has been calculated by DSİ as 128 TWh, nearly 60% of technically feasible potential. The key concept in calculating the economically feasible potential is to determine the criteria used for deciding what is feasible and what is not. A brief discussion about this concept is given below. More detail can be found in Bakır (2007).

The feasibility criteria has been calculated by taking into account only internal costs of TPPs, which are considered as the alternative energy sources to HPPs; and external costs are disregarded. It is well known that, however, external costs (greenhouse gas, acid rains, environmental pollution, etc.) are nearly 30% of internal costs. DSİ is using the following criteria for the feasibility studies of hydroelectric power plants (DSİ, 2008):

- Firm energy benefit: 6.0 cents/KWh,
- Secondary energy benefit: 3.3 cents/KWh,
- Peak power benefit: 85 $/KW.

In comparing the feasibility of hydro and thermo plants, there have been two issues to be discussed. The first issue is concerning Turkey's hydropower in general, and it has been proposed that hydro plants must be evaluated as part of whole system of Turkey, instead of being evaluated individually. Because, Turkey has huge storage capacity in dams and it can function as the storage and buffer for smaller units without storage. Thus, all electricity produced by hydro plants, small or large and with or without storage, should be classified as firm energy. The whole load temporal variations throughout the country during the day can be balanced by hydro plants with storage. All these must have an additional economical value, which is estimated 1.25 cents/KWh, using weighted average of electricity prices at peak loads.

The second issue to be considered is the external costs of TPPs, which is estimated to be at least 1.5 cents/KWh. Taking these two issues into consideration, the following criteria are proposed instead of the existing ones in the feasibility studies of HPPs:

- For HEPP with dams (storage):
  - Firm energy benefit: 6.0+1.5 = 7.5 cents/KWh,
  - Secondary energy benefit: 6.0–1.25 = 4.75 cents/KWh,
  - Peak power benefit: 250 $/KW.
- For HEPP without dams (run of river plants):
  - Firm energy benefit: 6.0+1.5 = 7.5 cents/KWh,
  - Secondary energy benefit: 6.0–1.25 = 4.75 cents/KWh.

If these criteria are taken into consideration instead of the ones used by DSİ, even those hydro plants are 40–45% more expensive than currently feasible ones will become feasible themselves. Even if the external costs of thermal plants are excluded, these ratios are 20–25%. Turkey's HP according to DSİ and the new developed criteria by Bakır (2007), together with installed power values, are given in Table 1.

Table 1
Turkey's annual HP according to DSİ (2008) and Bakır (2007)

Basin	Gross potential (GWh)	According to DSİ		According to Bakýr	
		Econ. feas. pot. (GWh)	Inst. power (MW)	Econ. feas. pot. (GWh)	Inst. power (MW)
Fırat (Euphrates)	84,122	39,375	10,345	46,267	12,176
Dicle (Tigris)	48,706	17,375	5416	24,353	7610
Eastern Black Sea	48,478	11,474	3257	24,239	6925
Eastern Meditt.	27,445	5216	1490	10,978	3137
Antalya	23,079	5355	1537	9232	2638
Çoruh	22,601	10,933	3361	12,431	3825
Ceyhan	22,163	4825	1515	8865	2860
Seyhan	20,875	7853	2146	9394	2609
Kızılırmak	19,552	6555	2245	7821	2697
Yeşilırmak	18,685	5494	1350	8408	2213
West. Black Sea	17,914	2257	669	7166	2108
Western Meditt.	13,595	2628	723	5438	1511
Aras	13,114	2372	631	5246	1418
Sakarya	11,335	2461	1175	3967	1984
Susurluk	10,573	1662	544	2643	881
Others (total)	30,744	1788	546	1721	507
Total	432,981	127,623	36,950	188,169	55,099

3.2.3. Small hydropower (SHP)

The development of hydro-electricity in the 20th century was usually associated with the building of large dams. Hundreds of massive barriers of concrete, rock and earth were placed across river valleys worldwide to create huge artificial lakes. While they created a major, reliable power supply, plus irrigation and flood control benefits, the dams necessarily flooded large areas of fertile land and displaced many thousands of local inhabitants. In many cases, rapid silting up of the dam has since reduced its productivity and lifetime. There are also numerous environmental problems that can result from such major interference with river flows (Paish, 2002).

Small hydro technology is extremely robust (systems can last for 50 years or more with little maintenance), also has the capacity to make a more immediate impact on the replacement of fossil fuels since, unlike other sources of renewable energy, it can generally produce some electricity on demand (at least at times of the year when an adequate flow of water is available) with no need for storage or backup systems. It is also in many cases cost competitive with fossil-fuel power stations, or for remote rural areas, diesel generated power (Kaygusuz, 2004).

Micro hydropower schemes are more suitable for rural dispersed communities. In particular, the power generated from micro hydropower schemes can be used for agro-processing, local lighting, water pumps, small business and industries, farms, and household in rural communities. Small HPPs combine the advantages of hydropower with those of decentralized power generation, without the disadvantages of large-scale installations (Yüksel, 2007).

Small hydro currently contributes over 40 GW of world capacity. With positive environmental policies now being backed by favorable tariffs for "green" electricity, the industry believes that small hydro will have a strong resurgence in Europe in the next 10 years, after 20 years of decline (Paish, 2002). Small hydropower can provide base-load capacity, and its potential in Europe is not yet fully exploited (Kaygusuz et al., 2007).

The development of small hydropower began in the year 1902 in Turkey. Since then, many small HPPs have been installed by government organizations, the private sector, and local municipalities in many parts of the country. However, until now, as a result of a rapid increase in the field of energy consumption, priority has been given to the development of large-scale hydropower projects to recover increasing energy demand and to provide maximum energy to Turkey's economy. During last three decades, the average annual increase of SHP capacity was 5–10% (Bakış and Demirbaş, 2004; Balat, 2007).

If existing rivers, lakes, and their tributaries are evaluated again according to their head potential points, there might be many available sides to install SHP plants along them, especially in the Eastern Black Sea Region of Turkey, which is the rainiest region of the country and has more geographic and topographic advantage. Owing to Turkey's regions, most of which are hilly, it can be possible to develop relatively higher heads without expensive civil engineering works so that relatively smaller flows are required to develop for the desired power. In these cases, it may be possible to construct a relatively simple diversion structure and obtain the highest drop by diverting flows at the top of a waterfall.

There are intensive investigations to improve the small and large hydropower development in Turkey. For putting this aim into practice, some small HPPs are still under construction in Turkey. There is a proposal of the project called "HYDROPOT" submitted for FP6 (the 6th Framework Program) funding in order to reevaluate hydropower potential.

There is more hydropower potential to be studied in Turkey, including small hydro plants and run of river (without storage) plants. According to tables prepared by DSİ (DSİ, 2008), there have been developed 1100 local hydropower projects (by April 16, 2008), which will be made by corporate bodies (private sector) by the concept of BOT. The total capacities and annual energy potentials are predicted 7000 MW and 25,000 GWh, respectively. The situation of hydropower energy according to design level (by April 16, 2008) is presented in Table 2 (DSİ, 2008). As can be seen, total hydropower is predicted as 117,564 GWh. Since there have been intensive and feverish studies about developing these kinds of projects, this figure is continuously going up.

4. Reevaluation of Turkey's electric energy demand

4.1. A review on the existent demand predictions

4.1.1. Previous consumption data

Turkey's population (PO), energy consumption per capita (CC, KWh/person) and total electric energy consumptions (total consumption—TC, TWh), for 5-yearly intervals, are given in Table 3

Table 2
The situation of hydropower energy according to design level (DSİ, 2008)

Level	Power (MW)	Cumulative power (MW)	Energy (GWh)	Cumulative energy (GWh)
In operation	13,614	13,614	46,763	46,763
Under construction	2371	15,985	9685	56,448
Report ready for				
Final design	231	16,216	1105	57,553
Planning	3513	19,729	12,814	70,367
Master plan	3276	23,005	12,484	82,851
Preliminary	1343	24,348	5001	87,852
Prelim. report under preparation	1215	25,563	4712	92,564
Corporate bodies (roughly)	7000	32,563	25,000	117,564

(TEİAŞ, 2005). The development of Turkey's electric energy demand between 1997 and 2007 is presented by Alış (2008). The demand values for 2005, 2006 and 2007 are given in Table 4 and have been used to determine the reliability of the prediction methods to be explained in the following sections.

There are various models to predict Turkey's long-term electric energy demand. Most of these models predict Turkey's electric energy demand for each year between 2005 and 2020. In this section, brief analyses of some of them are given for 2010, 2015 and 2020 years. Since the figures are only prediction values, it is believed that predictions for each year are not necessary.

4.1.2. MAED model

A demand prediction model, called "MAED" has been used to predict Turkey's long-term electric energy demand. This model is a simulation model which evaluate mid and long-term energy demands. MAED evaluates future energy needs based on medium to long-term scenarios of socioeconomic, technological and demographic development in a country or region. MAED models how energy demands are influenced, or driven, by a variety of social, economic and technological factors.

The electric energy demand varies according to various parameters. The main parameters to affect the energy demand are: Gross National Product; PO and demographic variations; development in housing, industry, agriculture and transportation sectors; income per capita; climatic conditions; employment, technological development, etc. MAED Model was executed for various development scenarios and Turkey's annual electric energy demand values were predicted from 2004 to 2020. The details and the results of the model may be found in (Yüksek et al., 2006; RTLED, 2004). The results of demand projection studies for various scenarios and sensitivity analysis are also presented in TEİAŞ (2007) as "Annex-4: Results of Demand Projection Studies". According to the results of totally nine predictions, the values for 2005, 2006 and 2007 years are presented in Table 4 and compared with those that observed values given by Alış (2008). It has been determined that some scenarios have predicted the observed values very well. These are "Demand June 2004" (J04), "Sensitivity I-A" (IA) and "Sensitivity III" (III) prediction values. The prediction results of these three scenarios are given in Table 5 as M1, M2 and M3, respectively. Although some of the other six prediction values have resulted in similar values, the best prediction vales are those of JO4, 1A and III and they have been used in the predictions of the future demand values.

4.1.3. Yumurtacı and Asmaz's model

Yumurtacı and Asmaz (2004) have developed a prediction model for 2050. In this study, projected values were calculated with a statistical technique based on the data from the period of 1970–2000. These data were the population of the country and the amount of energy consumption per capita. They predicted both population and energy consumption per capita by a model and by using these predictions, they also predicted TC. Prediction results for 2005, 2006 and 2007 are presented in Table 4 as YM and compared with the observed values. As can be seen, the predicted values are much less than those observed values (with average 11.3% relative error) and therefore they have not been considered in the following analyses.

Table 3
Turkey's electric consumption statistics (TEİAŞ, 2005)

Year	PO	CC (KWh/p)	TC (GWh)
1975	40,348	390	15,719.0
1980	44,737	550	24,616.6
1985	50,664	718	36,361.3
1990	56,473	1006	56,811.7
1995	60,614	1411	85,551.5
2000	67,845	1891	128,275.6
2005	72,065	2231	160,794.0

Table 4
Comparison of observed and predicted demand values (TWh)

Year	Obs. val.	Predicted values											
		MAED demand projections									Other methods		
		J04	IA	IB	II	III	IVA	IVB	V	O03	YM	TM	HM
2005	161	163	163	163	162	163	162	164	159	168	150	170	134
2006	175	176	176	176	173	175	174	178	170	186	157	181	146
2007	189	191	189	191	186	188	186	193	180	204	164	192	159

Table 5
Predicted annual electric energy demand according to previous scenarios (TWh)

Year	Name of the scenario				
	M1	M2	M3	HS	LS
2005	163	163	163	–	–
2010	242	236	230	239	222
2015	356	344	325	352	302
2020	499	479	440	–	–

4.1.4. Tunç, Çamdali and Parmaksizoğlu's model

Tunç et al. (2006) have developed a regression analysis model to predict Turkey's electric energy consumption. They have used

TC values between 1980 and 2001 and predicted the values between 2004 and 2020. Their predicted values for 2005, 2006 and 2007 are presented in Table 4 as TM and compared with the observed values. As can be seen, the predicted values are more than those observed values with average 3.5% relative error. This error figure may be evaluated as an unimportant value; however, their method has predicted very small values as the prediction duration increase, in other words for the years of 2015 and 2020, and therefore this method has not been considered in the following analyses.

4.1.5. Hamzaçebi's model

Hamzaçebi (2007) has forecasted Turkey's net electricity energy consumption on sectoral basis by artificial neural networks (ANN) model. He has used consumption values between 1970 and 2004 and predicted the values between 2005 and 2020. Prediction results for 2005, 2006 and 2007 are presented in Table 4 as HM and compared with the observed values. As can be seen, the predicted values are much less than those observed values (with average 19.6% relative error) and therefore they are not taken into account for following analyses.

4.1.6. TEIAŞ model

TEİAŞ (Turkish Electricity Transmission Company) has predicted Turkey's electric energy demand between 2007 and 20016 by using two scenarios as Case I (High Scenario, HS) and Case II (Low Scenario, LS), depending on the growth scenarios. The details of the methods can be found in TEİAŞ (2007). The results are presented in Table 5.

4.1.7. A brief analysis of these models

By using the prediction values of the above five models, which are presented in Table 5, the increment ratios between predicted years are calculated by geometric mean as follows

$$G_m = \left(\frac{N_v}{P_v}\right)^{1/N}, \quad I_r = 100(G_m - 1) \tag{1}$$

where G_m is geometric mean, N_v and P_v are predicted values for new and previous years, respectively, N is the time between years and I_r is increment ratio. The calculated increment ratios are presented in Table 6 for the each prediction methods. M1 method has yielded the most increase ratios. Average increment ratios are generally going down by the time, which means that, the increase speed of electric energy demand values are expected to decrease.

4.2. New prediction scenarios

4.2.1. Applied scenarios

As can be seen in Table 5, all of the above models have yielded different predictions. In this section, new prediction scenarios are introduced to predict Turkey's electric energy demand. In the analysis, the data of Turkey's population (PO), total electric energy consumptions (TC) and energy CC for 5-yearly intervals, which are presented in Table 3, are employed. Annual average increment ratios of all of the three variables are calculated and presented in Table 7. As is seen, although there are some fluctuations, a general decrease trend is obvious in the increment ratios of all of the variables. The increment ratios of PO, CC and TC values have annual average values of 1.95, 6.0 and 8.1%, respectively.

The increase ratios for development ratio (DR) and PO are predicted by DPT (State Planning Organization) in 2004 and presented in Table 7 (TEİAŞ, 2007). By assuming that the increase in energy CC is equal to the increase in DR, increase ratio in TC is calculated as multiplying increases of PO and CC and are also included in Table 7. In the following, various kinds of increase scenarios for each of the variable (PO, CC and TC) are employed for 5 yearly time intervals and according to these increment ratios, the values are predicted. The applied increment ratio values to predict the future demand are presented in Table 8.

Scenario 1 is as predicted by DPT; the other five scenarios are applied for various increment ratios either in PO and CC or in TC values. The increment ratios are selected by taking into account the observed (1975–2005) and predicted values of PO, CC and TC. The predicted and observed values for 2006 and 2007 are presented in Table 9. As is seen, the applied scenarios predicted the observed values in 2006 and 2007 with small errors. The predicted annual electric energy demand values of all of the applied 11 scenarios are summarized in Table 10. The maximum values are predicted for M1, HS and S6 scenarios, while minimum values are for M3 and LS scenarios.

4.2.2. Analysis of the predicted values

The mean, standard deviation and coefficient of variation values for all of the employed scenarios are calculated. Confidence intervals for 2010, 2015 and 2020 demand predictions are calculated by t (student) distribution for 90% and 50% confidence levels. All of the statistical properties are presented in Table 11.

Table 6
Increment ratios for the predicted demand values (%)

Time intervals	Name of the scenario					Average
	M1	M2	M3	HS	LS	
2005–2010	8.2	7.7	7.1	–	–	7.7
2010–2015	8.0	7.8	7.2	8.1	6.3	7.5
2015–2020	7.0	6.8	6.2	–	–	6.7
2005–2020 (average)	7.7	7.5	6.8	–	–	7.3

Table 7
Increment ratios of PO, CC and TC values (%)

Time interval	PO	CC	TC
Measured values (TEİAŞ, 2005)			
1975–1980	2.09	7.1	9.0
1980–1985	2.52	5.5	8.1
1985–1990	2.19	7.0	9.3
1990–1995	1.42	7.0	8.5
1995–2000	2.27	6.0	8.4
2000–2005	1.21	3.4	4.6
1975–2005 (average)	1.95	6.0	8.1
Predicted values (TEİAŞ, 2007)			
2005–2010	1.4	5.5	7.0
2010–2015	1.2	6.4	7.7
2015–2020	1.0	6.4	7.5
2005–2020 (average)	1.2	6.1	7.4

Table 8
Applied increment ratio scenarios (%)

Scenario	Time interval	PO	CC	TC
S1	2005–2010	1.4	5.5	
	2010–2015	1.2	6.4	–
	2015–2020	1.0	6.4	
S2	2005–2020	1.2	6.0	–
S3	2005–2020	1.2	6.5	–
S4	2005–2020	1.4	6.0	–
S5	2005–2020	–	–	7.0
S6	2005–2020	–	–	8.0

As is seen, the standard deviation and coefficient of variation values are rather small, resulting in narrow confidence intervals and increasing the reliability of the demand values. As the years elapse, by getting new consumption data, the reliability of the predictions will, of course, be increase.

5. The role of hydropower in meeting demand

The electric energy demand may be met by various resources, including thermal, hydro, wind and other renewable sources. TEİAŞ (2007) has planned two scenarios both for demand and resource projections between 2007 and 2016, of which demand predictions have previously been cited as HS (high scenario) and LS (low scenario). TEİAŞ has classified the power plants as existing, under construction, licensed power plants and new additional capacity. The results of hydropower generation capacities and energy demand balance analyses for HS and LS are presented in Tables 12 and 13, respectively, where D is demand and H is hydropower capacity. As can be seen, hydropower can meet 14% and 16% of total demand for the existing and under construction plants in 2016 for HS and LS alternatives, respectively. These figures go up to 18% and 20% for existing, under construction and licensed plants and to 26% if the planned additional capacity plants are made.

The situation of hydropower energy according to design level is presented in Table 2 (DSİ, 2008). As is seen, the capacity of plants in operation is 47 TWh, which meet the 25% of 2007 demand (189 TWh). If all of the plants which are under construction can be ready until 2010, they can provide 24% of the demand according to the average value of predictions (Table 11). Similar projections may be carried out by comparing Tables 2 and 11.

In order to make reliable predictions, it should be known that on which level HPPs can be in operation in which year. Especially, there are intensive and feverish studies on the projects by corporate bodies and therefore, it has been hoped that considerable parts of these projects will be in operation within a few years. If this expectation become fact, the ratio of hydropower meet the demand will increase. If all of the plants given in Table 2 are established by the time 2015 and 2020, then hydropower will provide 35 and 25 of the average demand in these years, respectively. As a last scenario it is hoped that, if all of the hydropower capacity estimated by DSİ (128 TWh) is utilized until 2020 (which seems a reasonable scenario), then hydropower can provide 27% of total demand for the average demand prediction value.

According to prediction values of reevaluated economically feasible HP, (Bakır, 2007), Turkey's total HP (188 TWh) can meet 81%, 56% and 39% of the expected average demands in 2010, 2015 and 2020, respectively. By taking into consideration of official investment plans proposed both by DSİ and TEİAŞ, the probability that this new potential will be available by 2020, let alone by 2010 or 2015, seems to be small. However, corporate bodies are very

Table 9
Predicted and observed demands of the applied scenarios (TWh)

Year		Name of the scenario					
		S1	S2	S3	S4	S5	S6
2006	Predicted	172	172	173	173	175	175
	Observed	175	175	175	175	175	175
2007	Predicted	184	185	187	186	189	189
	Observed	189	189	189	189	189	189

Table 10
Predicted annual electric energy demand according to applied scenarios (TWh)

Year	Name of the scenario										
	M1	M2	M3	HS	LS	S1	S2	S3	S4	S5	S6
2005	163	163	163	–	–	161	161	161	161	161	161
2010	242	236	230	239	222	225	230	235	231	232	238
2015	356	344	325	352	302	326	324	340	331	325	350
2020	499	479	440	–	–	467	461	495	475	455	514

Table 11
Statistical properties of predicted demand values (TWh)

Year	Mean	Standard deviation	Coefficient of variation	Confidence intervals	
				Conf. lev. 90%	Conf. lev. 50%
2010	233	6.0	0.026	220–246	229–237
2015	334	16.0	0.048	305–363	323–345
2020	476	23.4	0.049	432–520	459–493

Table 12
Hydropower generation and demand balance for high scenario (TEİAŞ, 2007)

Year	D (TWh)	Existing+under const.		Exsiting+under constr.+licensed		Exsiting+under constr. licensed +addit. capac.	
		H (TWh)	H/D	H (TWh)	H/D	H (TWh)	H/D
2008	204	48	0.24	49	0.24	49	0.24
2009	221	51	0.23	52	0.24	52	0.24
2010	239	53	0.22	59	0.25	61	0.26
2011	259	53	0.20	64	0.25	70	0.27
2012	280	54	0.19	67	0.24	78	0.28
2013	302	54	0.18	67	0.22	84	0.28
2014	326	53	0.16	67	0.21	90	0.28
2015	352	53	0.15	67	0.19	94	0.27
2016	378	52	0.14	67	0.18	98	0.26

Table 13
Hydropower generation and demand balance for low scenario TEİAŞ (2007)

Year	*D* (TWh)	Existing+under const.		Exsiting+under constr.+licensed		Exsiting+under constr. licensed+addit. capac.	
		H (TWh)	*H*/*D*	*H* (TWh)	*H*/*D*	*H* (TWh)	*H*/*D*
2008	197	48	0.24	49	0.25	49	0.25
2009	209	51	0.24	52	0.25	52	0.25
2010	222	53	0.24	59	0.27	59	0.27
2011	236	53	0.22	64	0.27	64	0.27
2012	251	54	0.22	67	0.27	70	0.28
2013	267	54	0.20	67	0.25	74	0.28
2014	284	53	0.19	67	0.24	75	0.26
2015	302	53	0.18	66	0.22	78	0.26
2016	322	52	0.16	66	0.20	83	0.26

eager for investing especially in small HPPs and this seems to be a gleam of hope for future energy projections.

6. Conclusions

From the viewpoint of energy sources such as petroleum and natural gas reserves, Turkey is not a rich country, but has an abundant hydropower potential to be used for generation of electricity and must base its energy strategy on developing the whole hydroelectric potential as soon as possible. Turkey's main indigenous energy resources are hydro and almost all oil natural gas and high-quality coal are imported and, in order to avoid foreign dependency both in sources and funds, Turkey must discover new and renewable energy resources. Renewable sources of power other than hydro (solar, wind, tide, geothermal, etc.) are also valuable options. But, even if major efforts were made to develop them, they will not be able to produce large amounts of energy in the coming decades. In assessing life cycle costs, hydropower consistently compares favorably with virtually all other forms of energy generation.

In this paper, Turkey's hydroelectric potential and long-term electric energy demand is reevaluated. Firstly, Turkey's hydro capacity is reevaluated according to DSİ and new criteria by Bakır. Turkey's annual economically feasible HP values calculated by DSİ are 128 TWh. However, according to findings of Bakır's study, in which a new criterion is developed related to key concept of the economical feasibility, annual economically feasible HP goes up to 188 TWh, with an increase ratio of 47% compared to DSİ value.

Secondly, the results of eight methods, which have been carried out to predict the Turkey's long-term electric energy demand, are reviewed. By comparing the predicted values with those observed in 2005, 2006 and 2007, three of these methods are eliminated, as a result of incorrect predictions. Then, by taking into consideration the increase ratios of population, electric energy consumption per capita and total electric energy consumptions values, both observed in the past and predicted by DPT (State Planning Organization), new six prediction methods are introduced. Various statistical properties, including mean, standard deviation, coefficient of variation and confidence intervals for two confidence levels, are calculated for all of the scenarios.

Because of social and economic development of the country, the demand for energy and electricity is growing rapidly in Turkey. Depending on the applied scenario and used model, Turkey's annual electric energy demand in 2010, 2015 and 2020 varies between 222 and 242 TWh; 302 and 356 TWh; and 440 and 514 TWh; with average values of 233, 334 and 476 TWh, respectively. There are some uncertainties in demand predictions. Much study should be carried out to reach more reliable predictions. As new data are obtained, these predictions should be updated.

A discussion on the role of hydropower in meeting demand is also included in the paper. Because of the knowledge shortage on when the power plants will be in operation, it is impossible to certainly predict this role. It is obvious that, however, hydropower can meet 25–35% of Turkey's electric energy demand in 2020 and new energy plants should be made as soon as possible.

Small hydropower (SHP) plants are one of key concepts in Turkey's energy projection. By evaluating small hydro potential, Turkey will provide important part of its electric energy demand from its own hydropower resources. By enlarging hydropower potential, the economical status of the rural people, most of whom are unemployed and poor, will be improved by constructing various kinds of structures and thus by diminishing unemployment and by providing cheaper electricity for domestic usage. Therefore, the Turkish Government should encourage utilizing hydropower.

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