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Investigation of hydropower energy potential and policy shift from natural gas to hydropower energy in Turkey

Türkiye'de hidroelektrik enerji potansiyeli araştırması ve doğal gazdan hidroelektriğe geçiş politikası

Mutlu YAŞAR[1*]

[1]Department of Civil Engineering, Faculty of Engineering, Pamukkale University, Denizli, Turkey.
mutluyasar@pau.edu.tr

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Abstract

This study investigates the possible hydropower potential of Turkey, using literature and the General Directorate of State Hydraulic Works plans. Based on the obtained hydraulic potential, two scenarios are proposed. The first scenario is an electricity investment and share of electricity production continuing as a historical trend, while the second scenario is the increase in the share of hydropower plants in total electricity production as 35%, including a newly calculated potential of 156 TWh. The results show that the hydropower potential of Turkey increased from 140 to 156 TWh with a level of 12%. Scenario I shows that the total share of electricity production from hydropower changed from 25% to 26% but natural gas did not change. Scenario II shows that natural gas power production will decrease from 42% to 30% and hydropower production increase from 26% to 35% in 2023. The results also show that if Scenario II is applied, the cumulative present value of gain will be approximately 32% in 2043 with a savings of about $25 billion.

Keywords: Energy policy, Renewable energy sources, Hydropower

Öz

Bu çalışmada Türkiye'nin hidroelektrik potansiyeli literatür ve Devlet Su İşleri planları çerçevesinde araştırılmıştır. Elde edilen hidrolik potansiyele dayanarak iki senaryo oluşturulmuştur. İlk senaryoda, mevcut eğilimin sürdürülmesi durumunda elektrik üretimi için gerekli yatırımlar değerlendirilirken, ikinci senaryoda yeni hesaplanan 156 TWh'lik potansiyele sahip olan hidroelektrik santrallerin elektrik üretimindeki payının %35 olması durumu incelenmiştir. Türkiye'nin hidroelektrik potansiyelinin literatürde belirtilen 140 TWh değerinden %12 fazla yani 156 TWh olduğu ortaya konulmuştur. Senaryo 1'e göre elektrik üretiminde hidrolik kaynakların payı %25'ten %26'ya çıkarken doğal gazın payı değişmemiştir. Senaryo 2'ye göre doğal gazdan üretilen elektriğin payı %42'den %30'a düşerken, hidroelektriğin payı %26'dan %35'e yükselmiştir. Sonuçlar, Senaryo 2'nin Senaryo 1'e göre 2043 yılı için %32 daha karlı olacağını ve kazancın bugünkü değerinin yaklaşık 25 milyar dolar mertebesinde olacağını göstermiştir.

Anahtar kelimeler: Enerji politikası, Yenilenebilir enerji kaynakları, Hidroelektrik

1 Introduction

Renewable energy sources have become more and more attractive, given that non-renewable energy sources are decreasing and they cause environmental pollution. Hydropower, is one of the most important renewable energy sources. It is also considered as a possible primary energy source for the world, including Turkey [1]. Abundant hydroelectric energy sources, the second most abundant energy source in the country after coal, may be integrated into the overall energy production in Turkey [1],[2]. Nearly a third of the renewable energy production in Turkey comes from hydro energy, while the rest comes from biomass [3].

Kinetic energy is harnessed through the action of water falling onto a turbine, thereby turning a shaft to produce electricity through hydroelectric generation. Rivers and streams can also be harnessed to obtain hydroelectric energy. It is highly economical and causes no detrimental environmental effects such as air pollution, in contrast to various other non-renewable energy sources [4].

Many sources calculate the Economically Feasible hydraulic energy Potential (EFP) and Total Feasible Potential (TFP) in Turkey at various levels, as seen in the literature and the General Directorate of State Hydraulic Works (DSİ). The calculated theoretical, economic and feasible hydropower energy potential is given in Table 1. As can be seen in Table 1, the Gross Hydropower Potential (GHP) of Turkey is approximately the same for all studies, but the EFP ranges from 125 to 188 TWh. Most of the studies [5]-[14] indicate that the EFP is approximately 140 TWh. Bakir [7] ascertained that the EFP is 188 TWh by introducing so-called "new criteria" for calculation of the EFP, but this would be unrealistic with the lack of available data.

As previously indicated that the EFP of hydropower in Turkey ranges in terms of estimated values, investigation needs to be conducted in order to find the realistic values of the EFP. As shown in Table 1, the realistic EFP in Turkey would rise to 156 TWh by taking into account the installed and planned hydropower power plants. According to the new values of EFP, there should also be a policy shift from natural-gas power production to hydroelectric power plants within the vision of the 2023 strategy. Similarly, Yüksek [15] also predicted that hydropower can meet 25-35% of Turkey's electric energy demand in 2020.

To fill the gap in the literature, this study proposes to re-investigate the EFP in Turkey and a policy shift from natural gas to hydroelectric power production. This study also makes an economic appraisal of the shift from natural gas investments to hydroelectric power investments in terms of the present value of costs.

Table 1: Calculated hydropower potential in Turkey by source.

Sources	Gross hydropower potential (TWh)	Installed capacity (MW)	TFP (TWh)	EFP (TWh)
Toklu et al. [5]	-	45,000	-	140
Capik et al. [6]	433	-	216	140
Bakir [7]	433	55,099	-	188
Yuksek and Kaygusuz [8]	433	35,540	-	125
Kaygusuz [9]	-	35,309	-	-
Yuksek et al. [10]	435	12,600	215	128
DSİ[11]	433	36,950	-	128
Berkun [12]	433	-	-	125
Dursun and Gokcol [13]	433	38,006	216	130
Yüksel [14]	-	-	-	140
This Study (explained in Section 4)	433	45,314	-	156

This paper has the following form: Section 2 looks at the brief overview of electricity demand of Turkey. Section 3 presents the future energy demand, Section 4 is an investigation of hydropower potential and Section 5 is a scenario analysis. Financial calculations are given in Section 6, and the last section provides conclusions.

2 An overview of electricity demand in Turkey

Energy is of vital importance for humankind. It is well known that electrical energy must be produced when it is to be consumed. Therefore, the essential determinant in electrical energy production is the demand size. Because the part of the installed capacity that can be transformed into energy will only be produced in proportion to the size of the demand, a part of the capacity must be ready for production as reserve without being constantly produced constantly. The power plants in the system are operated based on their disposability, and electricity is generated to meet the demand. Disposability may be easily achieved in the accumulation of hydroelectric power plants and thermal power plants, and it is determined based on the availability of operating conditions.

Turkey occupies a significant land area and has a population in excess of 76 million. With a total domestic income of $772 billion and domestic income per capita of $10,000, the country has an annual average energy consumption of 3,099 kWh per capita. In comparison, the world average is 2,500 kWh, the average of developed countries is 8,900 kWh and the US. average is 12,322 kWh. Over the past 20 years, when Turkey's peak time demand is higher than the world average, it is also far lower than that of developed countries and the US [16],[17].

Energy needs in Turkey are supplied by various sources. A total of 73% of the overall energy supply in 2010 was met from imports. For example, 93% of petroleum, 98% of natural gas and 90% of hard coal [18] were imported, making Turkey a net importer of energy. While the majority of the electricity supply was met by hydroelectric power plants and lignite-fired power plants in the early 1980s, most of today's supply is met by natural gas and hydroelectric power plants. This is not an acceptable situation for the country, which lacks a proven natural gas reserve, in terms of the cost and security of the energy supply.

Energy demand in Turkey increased rapidly from 1990 to 2014 by a factor of 4.5, as can be seen in Table 2. The installed peak-time power demand increased from approximately 9,000 to 41.000 MW. At the same time, the energy demand increased from 56 to 257 TWh/yr during the years from 1990 to 2014 [15]. The negative increase in 2001 and 2009 shows economic crisis in Turkey that hit two times within the past 15 years.

The demand given in Table 2 is supplied by various sources, as shown in Figure 1 [16]. As can be seen in Figure 1, natural gas reached about 25,600 MW by 2014 and still demonstrates increasing trend. Production based on hydraulic resources has also substantially increased, reaching approximately 23,600 MW. By the year 2014, energy production trends from natural gas and hydroelectric power plants are roughly similar. Additionally, after 2008 energy production from geothermal and wind increased by approximately 3,600 MW.

Table 2: Peak-time power and energy demand in Turkey (TEİAŞ).

Years	Peak-time power demand (MW)	Increase (%)	Energy demand (GWh)	Increase (%)
1990	9,180	7.3	56,812	8.0
1991	9,965	8.5	60,499	6.5
1992	11,113	11.5	67,217	11.1
1993	11,921	7.3	73,432	9.2
1994	12,760	7.0	77,783	5.0
1995	14,165	11.0	85,552	10.0
1996	15,231	7.5	94,789	10.8
1997	16,926	11.1	105,517	11.3
1998	17,799	5.2	114,023	8.1
1999	18,938	6.4	118,485	3.9
2000	19,390	2.4	128,276	8.2
2001	19,612	1.1	126,871	-1.1
2002	21,006	7.1	132,500	4.4
2003	21,729	3.4	141,151	6.5
2004	23,485	8.1	150,018	6.3
2005	25,174	7.2	160,794	7.2
2006	27,594	9.6	174,637	8.6
2007	29,249	6.0	190,000	8.8
2008	30,517	4.3	198,085	4.3
2009	29,870	-2.1	194,079	-2.0
2010	33,392	11.8	210,434	8.4
2011	36,122	8.2	230,603	9.4
2012	39,045	8.1	242,370	5.2
2013	38,274	-2.0	248,324	2.5
2014	41,003	7.1	257,220	3.6

As can be seen in Figure 2, by the year 2014 Turkey met approximately 35% of its energy need from hydraulic resources, 37% from natural gas, 22% from lignite and coal, and 6% from other resources. In a country that meets a total of 60% of its need from thermal resources, an increased number of

hydroelectric power plants will provide environmental and economic benefits.

Figs. 1 and 2 indicate that the energy production from natural and hydroelectric power plants is in increasing trend, but there is a question of how it would be shifted from natural gas to hydropower energy if there is enough potential for hydro. This is discussed in Section 4.

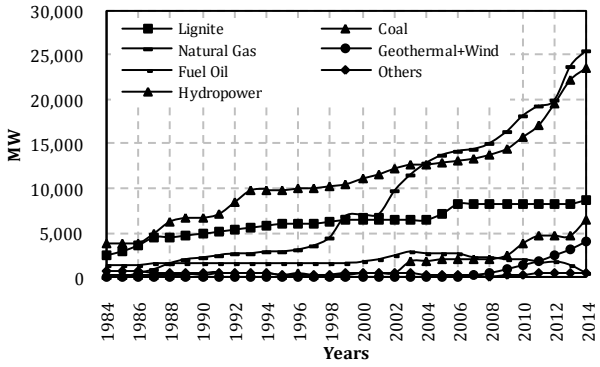

Figure 1: Distribution of energy production in Turkey by source and year (TEİAŞ).

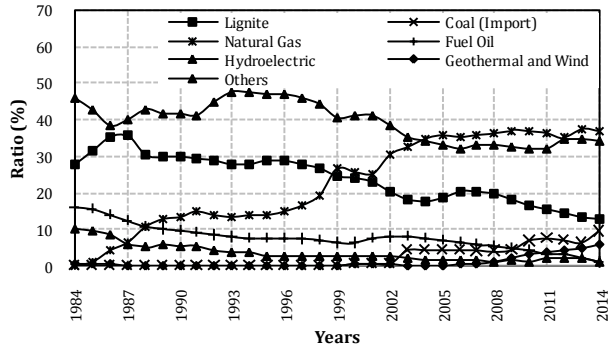

Figure 2: Electrical production in Turkey by source and year (TEİAŞ).

3 Energy demand projection for Turkey

Several national and international organizations strive to forecast possible increases in energy demand based on certain assumptions for the coming years. Such forecasts corroborate each other with admissible deviations. In view of the report published by the Turkish Electricity Transmission Company (TEİAŞ), Turkey's peak demand of 42,375 MW for 2015 will increase to approximately 69,200 MW in high-demand projection or to around 63,759 MW in low-demand projection, as given in Table 3 [16].

TEİAŞ projects Turkey's electricity demand according to two economic scenarios. The first case is "high demand," for which the average growth rate of the Turkish economy is approximately 7.5%. The second case is "low-demand," for which the average growth rate of the Turkish economy is approximately 6.5%. According to those assumptions, the two cases are given in Table 3. As can be seen in that table, the energy demand in 2023 will rise to about 414 TWh/yr in the low-demand scenario, which is roughly equivalent to the theoretical capacity of the GHP of Turkey in the low-demand scenario.

Table 3: Projection of energy demand (TEİAŞ).

Years		Peak-Time Demand		Energy Demand	
		MW	Increase (%)	GWh	Increase (%)
2015	High demand	42,375	3.3	275,140	7.0
2016		45,744	7.9	297,010	7.9
2017		49,357	7.9	320,470	7.9
2018		52,454	6.3	340,580	6.3
2019		55,724	6.2	361,810	6.2
2020		59,175	6.2	384,220	6.2
2021		62,363	5.4	404,920	5.4
2022		65,704	5.4	426,610	5.4
2023		69,202	5.3	449,320	5.3
2015	Low demand	41,402	1.0	268,820	4.5
2016		43,826	5.9	284,560	5.9
2017		46,383	5.8	301,160	5.8
2018		49,043	5.7	318,430	5.7
2019		51,861	5.7	336,730	5.7
2020		54,811	5.7	355,880	5.7
2021		57,689	5.3	374,570	5.3
2022		60,668	5.2	393,910	5.2
2023		63,759	5.1	413,980	5.1

4 Hydropower potential in Turkey

Turkey has important, valuable hydropower potential, particularly in the introduction of small hydropower plants. Hydropower is the most important renewable, sustainable energy source. There have been several studies on the country's technical and economic hydroelectric potential. The literature given in Table 1 indicates that the theoretical hydroelectric potential is approximately 433 TWh, the technically usable potential is 216 TWh and the economic hydroelectric energy potential is 140 TWh/year. However, these studies have proposed that the hydroelectric potential will exceed the calculation because the contributions of Small Hydroelectric power Plants (SHPs) are generally disregarded.

The full utilization of hydropower potential in Turkey is the most important vision in 2023, given that it would be used to decrease the share of imported energy. For that purpose, the private sector has also expressed support for the creation of SHPs in a short term of one to three years. According to a study by Melikoglu [19], Turkey's fresh water reserves have been divided into 25 river basin sand more than 95% of the country's potential has been distributed into 14 river basins. According to that study, the EFP reached level of 123,040 GWh/yr in 2012. The reason for this increase is the introduction of private-sector construction of SHPs on a build-operate-transfer basis.

In this study, the EFP of hydropower in 2015 is investigated by using the DSİ data to calculate the new hydroelectric potential. The hydropower plants, their installed capacity and energy production are given in Table 4.

Table 4 shows that 20,800 MW installed capacity and 73,639 GWh/yr have been under operation. Among this, 55% is owned by the public and 33% is owned by the private sector. A summary of the power plants that have been under construction and/or planned by both the state and the private industry is presented in Table 4 according to 2015 values.

Table 4: Hydropower plants in Turkey (DSİ).

		Owning	Quantity	Installed capacity (MW)	Annual production (GWh)	Ratio in production (%)
Project phases	Under operation	DSİ	62	11,625	41,001	26.3
		Private sector	271	6,851	24,201	15.5
		Other	76	2,324	8,437	5.4
		Sum	409	20,800	73,639	47.2
	Under construction	DSİ	7	2,669	8,456	5.4
		Private sector	186	6,866	21,908	14.0
		Sum	193	9,535	30,364	19.4
	Under planning	DSİ	1	290	768	0.5
		Private sector	812	14,689	51,229	32.9
		Sum	813	14,979	51,997	33.4
	Total	DSİ	70	14,584	50,225	32.2
		Private sector	1,269	28,406	97,338	62.4
		Other	76	2,324	8,437	5.4
	Overall Sum		1.415	45,314	156,000	100.0

The table shows that the private sector share has increased to a level of 6,866 MW installed capacity and 21,908 GWh, thus increasing its share from 33% to 72% as can be seen in Figure 3. Moreover, the planned hydropower by the private sector will be approximately 98% in the near future [11]. The planning conducted by the TEİAŞ, which formulates and implements the country's energy policies, is presented in Table 4 [16]. Based on the introduction of the private sector along with public, it is projected that, by using the values in Table 4, Turkey's EFP will increase from 140 to 156 TWh within the next 10 years (by 2025). Overall, the country's potential technically and economically viable hydroelectric installed capacity is projected to be 45,314 MW with an annual average production of 156 TWh/yr. The potential is observed to increase by (156-140)/140 TWh=12%. Therefore, the present situation indicates that an additional potential of 24,514 (9,535+14,979) MW has yet to be realized.

The reason for the rapid growth of hydropower energy production is that the introduction of privatization came into the agenda with the enforcement of Law No. 3096 dated 04.12.1984. A share of the public and private sectors in total energy production is given Figure 3.

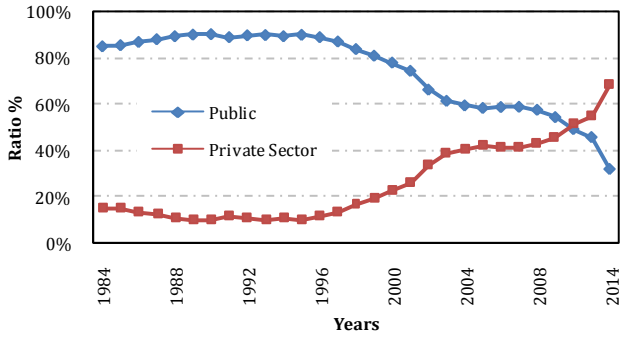

Figure 3: Shares of the public and private sectors in total energy production (EPDK).

Figure 3 shows that the energy production remained stable until 1998. Meanwhile, a quantitative development of the installed capacity and electricity production from 1984 to the end of 2014. The public share of total electricity production in Turkey decreased from 85% in 1984 to 32% in 2014. On the other hand, the private sector's share of the production total increased. Additionally, Figure 4 shows the total shares of natural gas and hydropower electricity production. The share of natural gas was approximately 48% in 2014 and that of hydropower was approximately 16%. There is still a huge gap in these two sources in terms of electricity production.

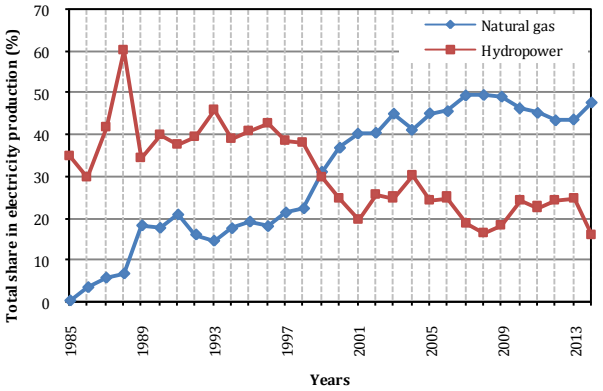

Figure 4: Total share in natural gas and hydropower in total electricity generation (TEİAŞ).

Given this reserve of the hydropower energy production and general trend of private sector investments in energy production, there is a need to re-justify the electrical energy production policy from different sources. Although the TEİAŞ intends to decrease the total share of natural-gas power production to the level of 35%, this would be investigated since the EFP is higher than the estimated current value. In that regard two scenarios are proposed using historical data and estimated new values of the EFP.

As can be seen in Table 5, that hydroelectric power plants with a total installed capacity of 7,458 MW will be commissioned within the next five years. The TEİAŞ plans to increase hydraulic resources to approximately 37% of total production and other resources by approximately 2% of total production while decreasing shares of natural-gas power plants to approximately 35% and lignite-fired power plants to approximately 11% but keeping imported coal resources stable at approximately 8%.

Table 5: Projection of installed capacities of the public and private sectors under construction based on different power sources.

	Sources	Unit	Years					Sum of decided
			2015	2016	2017	2018	2019	
Private sector	Hydroelectric	MW	2,543	612	2,026	869	0	6,050
		GWh	7,824	2,127	6,037	2,503	0	18,491
	Lignite	MW	68	0	0	1200		1,268
		GWh	420	0	0	7820,9		8,241
	Local coal	MW	1,010	0	0	135		1,145
		GWh	7,500	0	0	855,5		8,356
	Natural gas	MW	1,413	154,2	965	890,4		3,422
		GWh	11,247	1228	4,197	7,249	16,894	40,815
	Geothermal + wind	MW	538,6	243,4	1727,8	100	0	2,610
		GWh	2,629	1016,4	6,324	300	0	10,269
	Solar	MW	600	600	600	600	600	3,000
		GWh	1,500	1500	1,500	1,500	1,500	7,500
	Others	MW	307,5	91	29,2	0	0	428
		GWh	3,129	616,4	183,1	0	0	3928,7
Public	Hydroelectric	MW	64,8	1341,9	0	0	0	1,407
		GWh	200	4543	0	0	0	4,743
	Sum	MW	64,8	1341,9	0	0	0	1,407
		GWh	200	4543	0	0	0	4743
TOTAL	Thermal	MW	2,892	232,7	976	2225,4	2080	8,406
		GWh	22,082	1789	4,284	15,925	16,894	60,973
	Hydroelectric	MW	2,608	1954,4	2,027	869	0	7,458
		GWh	8,024	6,671	6,038	2,503	0	23,236
	Wind + renewables	MW	1165,2	855,9	2346	700	600	5,667
		GWh	4,281	2,572	7,920	1,800	1,500	18,073
	Overall sum	MW	6,665	3,043	5,349	3,795	2,680	21,531
		GWh	34,387	11,032	18,242	20,228	18,394	102,282

5 Analyses

The analyses are carried out with two proposed scenarios. The Scenario 1 shows the variation of the cost of energy production in the case of current energy policies of the TEİAŞ are proceeded while the Scenario 2 emphasizes an economic appraisal of the shift from natural gas investments to hydroelectric power investments in terms of the present value of costs.

5.1 Scenario-I

If the current trend of energy production continues based on historical data, the electricity production figures for 2023 result.

In order to calculate the current trend in this scenario, the data is as given in Table 6 [17]. It shows the electrical energy production and consumption as a GWh between 1985 and 2014. The average yearly increase rate of electrical energy production is approximately 6%. In 2013, total share of natural gas is approximately 48%, and hydropower is about 16%.

Table 7 shows the projected electrical energy production from thermal, natural gas, hydropower and renewable energy sources until 2019. There is no investment in fuel oil. The planned electricity production will be made by these sources, which are either under construction or planned.

The projected electricity demand according to the "low demand" and production for various sources according to the TEİAŞ [16] is given in the second column of Table 8. By using the average yearly growth rate in electricity production between 1985 and 2014, the calculated values in this scenario are also given in Table 8. The last column shows the gross production of electricity demand since the loss of approximately 8% in production and transmission.

If this scenario (base case) continues to meet Turkey's demand for electrical energy, natural gas will reach a level of approximately 188,000 GWh with a share of 42% and hydropower will reach 118,000 GWh with a share of 26% (see Table 9). Similarly, renewables will reach a level of 25,000 GWh and a share of 6%.

5.2 Scenario-II

If the projected values of the electricity production from different "energy sources" are completed until 2019 as in the TEİAŞ, keeping the natural gas electricity production fixed at that date and shifting the natural gas to hydropower through use of the new value of about 156 TWh in 2023, we achieve the electricity production figures for 2023.

The analysis in this scenario shows that after cumulatively adding the projected electricity production (see Table 7) until 2019 for each source and keeping the natural-gas power production (i.e., keeping it fixed at a value of approximately 135,000 GWh), while the need for electricity production is supplied by hydropower using the estimated potential of 156,000 GWh until 2023 in Section 4, the share of hydropower is obtained in Table 10.

The second and last columns of Table 10 show the projected electrical energy demand and gross electricity demand, respectively. As can be seen in Table 11, the total share of hydraulic will increase to a level of 35% and the natural gas share will reach a level of 30%. The result for the 9-year period is a realistic scenario that policy makers may apply.

Table 6: Data for scenario analysis (TUİK).

Years	Total consumption (GWh)	Total production (GWh)	Thermal (lignite + coal, %)	Liquid fuels (%)	Natural gas (%)	Hydropower (%)	Renewable energy and wastes (%)
1985	29,709	34,219	43.9	20.7	0.2	35.2	0.0
1986	32,210	39,695	49.0	17.6	3.4	29.9	0.1
1987	36,697	44,353	39.8	12.4	5.7	42.0	0.1
1988	39,722	48,049	26.0	6.9	6.7	60.3	0.1
1989	43,120	52,043	38.9	8.2	18.3	34.5	0.1
1990	46,820	57,543	35.1	6.9	17.7	40.2	0.1
1991	49,283	60,246	35.8	5.5	20.9	37.7	0.2
1992	53,985	67,342	36.5	7.8	16.1	39.5	0.2
1993	59,237	73,808	32.2	7.0	14.6	46.0	0.2
1994	61,401	78,322	36.0	7.1	17.6	39.1	0.2
1995	67,394	86,247	32.5	6.7	19.2	41.2	0.4
1996	74,157	94,862	32.1	6.9	18.1	42.7	0.3
1997	81,885	103,296	32.8	6.9	21.4	38.5	0.4
1998	87,705	111,022	32.1	7.1	22.4	38.0	0.3
1999	91,202	116,440	31.8	6.9	31.2	29.8	0.3
2000	98,296	124,922	30.6	7.5	37.0	24.7	0.3
2001	97,070	122,725	31.3	8.4	40.4	19.6	0.3
2002	102,948	129,400	24.8	8.3	40.6	26.0	0.3
2003	111,766	140,581	22.9	6.5	45.2	25.1	0.2
2004	121,142	150,698	22.9	5.1	41.3	30.6	0.2
2005	130,263	161,956	26.7	3.4	45.3	24.4	0.2
2006	143,070	176,300	26.5	2.5	45.8	25.1	0.2
2007	155,135	191,558	27.9	3.4	49.6	18.7	0.4
2008	161,948	198,418	29.1	3.8	49.7	16.8	0.6
2009	156,894	194,813	28.6	2.5	49.3	18.5	1.2
2010	172,051	211,208	26.1	1.0	46.5	24.5	1.9
2011	186,100	229,395	28.9	0.4	45.4	22.8	2.6
2012	194,923	239,497	28.4	0.7	43.6	24.2	3.1
2013	198,045	240,154	26.6	0.7	43.8	24.7	4.2
2014	207,375	251,963	30.3	0.9	47.9	16.1	4.9

Table 7: Projected electric energy production from various sources until 2019 (TEİAŞ).

Years	Thermal (Lignite + Coal, GWh)	Fuel Oil (GWh)	Natural Gas (GWh)	Hydropower (GWh)	Renewables (Wind+ Geothermal + Solar, GWh)
2015	7,920	884.1	11,247	7,824	4,129
2016	0	474.1	1,228	2,127	2,516
2017	0	0	4,197	6,037	7,824
2018	8,676	0	7,249	2,503	1,800
2019	0	0	16,894	0	1,500

Table 8: Current trend scenario and average growth rate of electricity production.

Years	TEİAŞ projection for "low demand" (GWh)	Thermal (lignite + coal) (GWh)	Natural gas (GWh)	Hydropower (GWh)	Renewable (wind+geothermal+ etc.) (GWh)	Gross production (GWh)
2015	271,450	81,648	120,743	72,556	13,376	288,324
2016	287,310	84,648	131,020	81,332	16,347	313,348
2017	302,750	85,298	135,217	84,642	17,905	323,063
2018	319,980	90,160	142,925	89,467	18,926	341,478
2019	338,270	95,299	151,072	94,566	20,005	360,942
2020	357,430	100,731	159,683	99,957	21,145	381,515
2021	376,150	106,473	168,785	105,654	22,350	403,262
2022	395,540	112,542	178,405	111,676	23,624	426,248
2023	415,680	118,957	188,574	118,042	24,971	450,544

Table 9: Total share of electricity production in Scenario I.

Years	Thermal (lignite + coal) (%)	Natural gas (%)	Hydropower (%)	Renewable (wind+geothermal+etc.) (%)
2015	28	42	25	5
2016	27	42	26	5
2017	26	42	26	6
2018	26	41	26	5
2019	26	41	26	5
2020	26	41	26	5
2021	26	42	26	6
2022	26	42	26	6
2023	26	42	26	6

Table 10: Application of Scenario II.

Years	TEİAŞ projection for "low demand" (GWh)	Thermal (lignite + coal) (GWh)	Natural gas (GWh)	Hydropower (GWh)	Renewable (wind+geothermal+ etc.) (GWh)	Gross production (GWh)
2015	271,450	81,648	120,743	72,556	13,376	288,324
2016	287,310	84,648	131,020	81,332	16,347	313,348
2017	302,750	85,298	135,217	84,642	17,905	323,063
2018	319,980	93,865	135,217	96,442	20,054	345,578
2019	338,270	99,411	135,217	108,242	22,461	365,332
2020	357,430	105,609	135,217	120,042	25,156	386,024
2021	376,150	111,008	135,217	131,842	28,175	406,242
2022	395,540	116,768	135,217	143,642	31,556	427,183
2023	415,680	122,933	135,217	**155,442**	35,342	448,934

Table 11: Total share of electricity production in Scenario II.

Years	Thermal (lignite + coal) (%)	Natural gas (%)	Hydropower (%)	Renewable (wind+geothermal+etc.) (%)
2015	28	42	25	5
2016	27	42	26	5
2017	26	42	26	6
2018	27	39	28	6
2019	27	37	30	6
2020	27	35	31	7
2021	27	33	32	7
2022	27	32	34	7
2023	27	30	35	8

Figure 5 compares the total share of electricity production from natural gas and hydropower plants. It includes the possible application of a scenario that would change the total share of electricity production from 26% to 35% until 2023. Similarly, the natural-gas power production will decrease from a share of 42% to 30% by 2023. Next section compares the economic analysis of two scenarios in terms of Net Present value (NPD) in a 30-year time span.

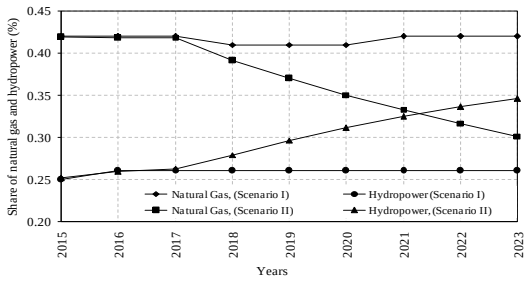

Figure 5: Comparison of scenarios.

6 Financial calculations for proposed scenario

6.1 Initial investment cost

The initial investment costs of power plants for energy production vary according to the performance of the machinery, topography, geology, manpower, land prices, etc. Thus the initial investment costs of energy plants can be calculated as per the local conditions of the country. The management and control duties of energy market in Turkey belong to the Energy Market Regulatory Authority (EPDK). This institution has calculated the unit investment costs as given in Table 12, based on the average values of several power plants [20].

As can be seen in Table 12, one of the cheapest initial costs in Turkey is the natural gas cycle power plant and the most expensive is the wind power plant. Similarly, operation costs vary in terms of manpower wages, fuel prices and other parity factors in the country. A significant number of energy power plants are operated by corporations for the Electricity Generation Company (EÜAŞ). According to data in consideration of the end of 2013 reproduced by the EÜAŞ, operation costs of natural gas, thermal, renewable energy power plants and hydroelectric power plants have been calculated, providing the results shown in Table 13.

Table 12: Investment costs of power plants (EPDK).

Sources	Investment cost (USD/MW_e)
Coal	705,000
Natural gas	470,000
Fuel oil	470,000
Hydroelectric	950,000
Wind	1,175,000
Geothermal	1,000,000
Biomass	900,000
Solar	1,400,000

Table 13: Operation and maintenance costs of power plants [21].

	Hydropower ($/kWh)	Natural gas ($/kWh)	Thermal ($/kWh)	Renewable ($/kWh)
Resource	0	0.1092	0.0419	0
Material	0.0001	0.0003	0.0016	0.0001
Industrial payment	0.0012	0.0008	0.006	0.0012
Employment payment	0.0006	0.0003	0.0008	0.0006
Outsourced service fee	0.0041	0.002	0.0076	0.0041
Other expenses	0.0003	0.0002	0.001	0.0003
Taxes	0	0	0.0004	0
Amortization	0.0019	0.0008	0.0114	0.0019
Sum	0.0082	0.1137	0.0707	0.0082

As can be seen in Table 13, the operation cost of a hydroelectric power plant is 0.0082 ($.082) for each kWh of energy, while this expenditure is 0.1137 ($11.37) in a natural-gas burning facility. The thermal power plant operating cost is $0.07 and the renewable is approximately $.082, which is similar to hydropower.

6.2 Economic evaluations by present value

The definition of "Net Present Value (NPV)" is that the difference between the present value of cash inflow and the

present value of cash outflow. NPV is used in capital budgeting to analyze the profitability of an investment or project. Equation 1 is used to calculate the NPV:

$$NPV = \sum_{j=1}^{n} \frac{c_j}{(1+i)^j} - c_0 \quad (1)$$

Where, c_j represents net cash inflow during the period, c_o is the initial investment; i is the discount rate, while n is the number of time periods. Within the scope of this study, the Present Value (PV) has been used instead of the NPV. The relevant formula for calculation of the present value is given below:

$$PV = \frac{c}{(1+i)^n} \quad (2)$$

where c is the future amount of money that must be discounted, n is the number of the compounding period between the present date and the date where the sum is worth c, and i is the interest rate for one compounding period (the end of a compounding period is when interest is applied). The initial investment and operation costs which will be used for calculating PVs of scenarios are given in Table 14.

Table 14: Capacity factor and unit costs of power plants (EPDK).

Plant Type	Capacity factor (%)	Investment Cost (10^6 $)	Unit Cost ($)
Natural gas	87	0.470	0.1137
Hydropower	53	0.950	0.0082
Thermal	87	0.705	0.0707
Renewable	60	1.100	0.0082

Table 15 shows the PV calculation of Scenario I until 2023. The cumulative present value of Scenario I is approximately $35 billion in 2023. The PV of Scenario II is given in Table 16 until 2023. With this scenario, the PV is approximately $30.5 billion in 2023 with a savings of approximately 13%.

Figure 6 shows the total cumulative present values of scenarios until 2043 with a social discount rate of 9%. The reason for using the 28-year time span from now on is that the initial investment cost will compensate within about 10 years, after which only the costs of operation and maintenance will be available.

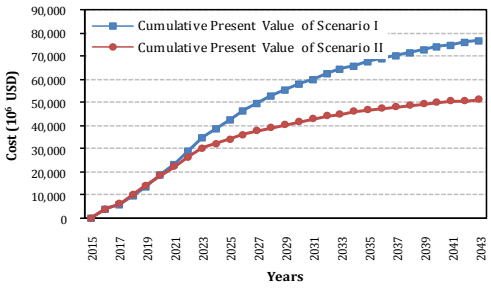

Figure 6: Cumulative present value comparison.

Within a 28-year time span, the cumulative present value of Scenario I is approximately $77 billion and the Scenario II is approximately $52 billion with a saving of $25 billion or a saving of approximately 32% when compared with Scenario I.

7 Conclusions

This study investigates the possible hydropower potential of Turkey and proposes two scenarios. The electrical energy demand in Turkey is also utilized. The economically feasible hydropower potential is investigated in the literature and the DSİ plans. Two scenarios are developed using the historical data and the new value of hydroelectric potential. The following findings may be drawn from this study:

Table 15: PV analysis of Scenario I.

Source		Unit	Years 2015	2016	2017	2018	2019	2020	2021	2022	2023
Natural gas	Capacity	MW	30	1,220	545	1,011	1,069	1,130	1,194	1,262	1,334
	Investment cost	10^6 USD	14	573	256	475	502	531	561	593	627
	Electricity production	GWh	26	10,277	4,197	7,708	8,147	8,611	9,102	9,620	10,169
	Cumulative production	GWh	26	10,303	14,500	22,208	30,355	38,966	48,068	57,688	67,857
	Cumulative operational and maintenance cost	$, 10^6	3	1,171	1,649	2,525	3,451	4,430	5,465	6,559	7,715
	Total cost	$, 10^6	17	1,745	1,905	3,000	3,954	4,961	6,027	7,152	8,342
Hydropower	Capacity	MW	305	1,890	713	1,039	1,098	1,161	1,227	1,297	1.371
	Installation cost	10^6 USD	289	1,796	677	987	1,043	1,103	1,166	1,232	1.303
	Electricity production	GWh	1,414	8,776	3,310	4,825	5,099	5,391	5,697	6,022	6.366
	Cumulative Production	GWh	1,414	10,190	13,500	18,325	23,424	28,815	34,512	40,534	46.900
	Cumulative operational and maintenance cost	$, 10^6	12	84	111	150	192	236	283	332	385
	Total cost	$, 10^6	301	1,879	788	1,138	1,235	1,339	1,449	1,565	1.687
Thermal power	Capacity	MW	0	394	85	638	674	713	753	796	842
	Installation cost	10^6 USD	0	278	60	450	475	502	531	561	593
	Electricity production	GWh	0	3,000	650	4,862	5,139	5,432	5,742	6,069	6.415
	Cumulative production	GWh	0	3,000	3,650	8,512	13,651	19,083	24,825	30,894	37.309
	Cumulative operational and maintenance cost	$, 10^6	0	212	258	602	965	1,349	1,755	2,184	2.638
	Total cost	$, 10^6	0	490	318	1,052	1,441	1,852	2,286	2,746	3.231
Renewable	Capacity	MW	130	565	296	194	205	217	229	242	256
	Installation cost	$, 10^6	143	622	326	214	226	239	252	267	282
	Electricity production	GWh	683	2,971	1,558	1,021	1,079	1,140	1,205	1,274	1.347
	Cumulative production	GWh	683	3,654	5,212	6,233	7,312	8,452	9,657	10,931	12.278
	Cumulative operational and maintenance cost	$, 10^6	6	30	43	51	60	69	79	90	101
	Total cost	$, 10^6	149	652	369	265	286	308	331	356	383
	Total cost of all sources	$, 10^6	467	4,765	3,380	5,454	6,915	8,460	10,093	11,819	13,643
	Present value of Scenario I	$, 10^6	393	3,680	2,394	3,545	4,123	4,628	5,065	5,442	5,763
	Cumulative present value of Scenario I	$, 10^6	393	4,073	6,467	10,012	14,135	18,763	23,829	29,270	35,034

Table 16: PV analysis of Scenario II.

Source		Unit	Years								
			2015	2016	2017	2018	2019	2020	2021	2022	2023
Natural gas	Capacity	MW	30	1,220	545	0	0	0	0	0	0
	Investment cost	10^6 USD	14	573	256	0	0	0	0	0	0
	Electricity production	GWh	26	10,277	4,197	0	0	0	0	0	0
	Cumulative production	GWh	26	10,303	14,500	14,500	14,500	14,500	14,500	14,500	14.500
	Cumulative operational and maintenance cost	$, 10^6	3	1,171	1,649	1,649	1,649	1,649	1,649	1,649	1.649
	Total cost	$, 10^6	17	1,745	1,905	1,649	1,649	1,649	1,649	1,649	1.649
Hydropower	Capacity	MW	305	1,890	713	2,542	2,542	2,542	2,542	2,542	2.542
	Installation cost	10^6 USD	289	1,796	677	2,415	2,415	2,415	2,415	2,415	2.415
	Electricity production	GWh	1,414	8,776	3,310	11,800	11,800	11,800	11,800	11,800	11.800
	Cumulative Production	GWh	1,414	10,190	13,500	25,300	37,100	48,900	60,700	72,500	84.300
	Cumulative operational and maintenance cost	$, 10^6	12	84	111	207	304	401	498	595	691
	Total cost	$. 10^6	301	1,879	788	2,622	2,719	2,816	2,913	3,009	3.106
Thermal power	Capacity	MW	0	394	85	1,124	728	813	708	756	809
	Installation cost	10^6 USD	0	278	60	792	513	573	499	533	570
	Electricity production	GWh	0	3,000	650	8,567	5,546	6,198	5,399	5,760	6.165
	Cumulative production	GWh	0	3,000	3,650	12,217	17,763	23,961	29,360	35,120	41.285
	Cumulative operational and maintenance cost	$, 10^6	0	212	258	864	1,256	1,694	2,076	2,483	2.919
	Total cost	$, 10^6	0	490	318	1,656	1,769	2,267	2,575	3,016	3.489
Renewable	Capacity	MW	130	565	296	409	458	513	574	643	720
	Installation cost	10^6 USD	143	622	326	450	504	564	632	708	792
	Electricity production	GWh	683	2,971	1,558	2,149	2,407	2,695	3,019	3,381	3.786
	Cumulative production	GWh	683	3,654	5,212	7,361	9,768	12,463	15,482	18,863	22.649
	Cumulative operational and maintenance cost	$, 10^6	6	30	43	60	80	102	127	155	186
	Total cost	$, 10^6	149	652	369	510	584	666	759	862	978
	Total cost of all sources	$, 10^6	467	4,765	3,380	6,437	6,720	7,398	7,895	8,536	9,222
	Present value of Scenario II	$, 10^6	393	3,680	2,394	4,184	4,007	4,047	3,962	3,930	3,895
	Cumulative present value of Scenario II	$, 10^6	393	4,073	6,467	10,651	14,658	18,705	22,667	26,598	30,493

A review of the literature showed that the economically feasible hydroelectric potential ranges from 125 to 140 TWh. This study found that the value will reach a level of 156 TWh, taking into account the hydropower planned and under construction, including Small Hydroelectric Power Plants (SHPs).

The total share of electricity production from hydropower will increase from 26% to 35% when compared with Scenario I. Similarly, natural-gas power production will decrease from 42% to 30% in 2023.

Economic analysis showed that if Scenario II is applied, the cumulative present value of gain is approximately 32% in 2043. In other words, the Scenario 2 will save approximately 28,000*10^6 USD in comparison to Scenario 1 in 2043.

Nuclear energy has not been investigated in this study since the first nuclear power started to construct nowadays and it is expected that the production of energy will start in 2023 as a full capacity [22]. Thus the policies and scenario in this study has not been affected until 2023. Subsequently, the nuclear energy needs to be taken into account for energy balance.

Future studies should focus on investigating the potential roles of other renewables and should concentrate on increasing the share of renewables in the overall production of electrical energy.

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