

Article

Turkey's present hydraulic energy and hydropower potential

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Abstract: Energy is a prime agency for economic liberty and sustainability. It can be supplied from fossil or renewable sources. Hydropower is a renewable energy source that generates electricity without emitting greenhouse gases. So, it possesses significant potential for replacing fossil fuel power plants and providing energy by reducing carbon-based energy sources. In that sense, Turkey has several promising initiatives, such as the Southeastern Project (GAP), which generates 27 billion kWh of hydroelectric energy. On the other hand, Turkey has significant installed capacity. The Atatürk Dam is the sixth largest volume dam in the world, and the average electricity energy production is 8.5 billion kWh/year. Based on the geographic distribution of these sources, a significant portion of the water potential is located in the southeast (28%) and the Black Sea region (8%). Considering these advantages of hydropower, this article shows the hydraulic energy potential in our country. Energy necessities and the balance between supply and demand and their effects are also comprehensively discussed. Finally, the presented study emphasized that Turkey has high hydraulic potential due to its varied topology and numerous rivers. That source also displays economically feasible, environmentally available, and unique domestic characteristics.

Keywords: water resources; rivers; lakes; water management systems; ecosystems

1. Introduction

The importance of energy for the development and welfare of nations cannot be underestimated. The energy demand has skyrocketed every day due to the population rise in human beings. Its consumption per capita is the prime determinant of that nation's development [1].

Energy can be supplied from fossil sources, renewable ones, or waste materials [2]. Fossil-type sources have the activator of undesired toxic streams that contribute to various interactions among them. Global warming is a widespread threat all over the world [3]. The greenhouse gases are also responsible for ozone depletion and climatic irregularities. As a result, climatic changes have harsh effects all over the world [4]. Today, fossil fuels can be used easily everywhere but also cause many ecological destructions [5]. On the contrary, renewable energy sources have superior advantages because of the depletion risk of fossils.

Amongst the renewable energy alternatives, water is an indispensable element both for sustaining life and potential energy in dams. Hydropower is a renewable energy source and also plays a pivotal role in the irrigation of agriculture [6]. Hydraulic energy is a cheap and domestic one for Turkey [7]. It sustains high energy conversion without fouling the environment. It cannot be comparable to thermal plants from the point of view of the environment [8].

Considering the mentioned negative effects of fossil-based sources and the necessity of national energy policies for sustainable development, several incentives

and regulations were introduced. Following the economic crisis of 2001, Turkey embarked on significant economic reforms to enhance the economy's competitiveness and restructure the government. Electricity Market Law marked the inception of a competitive electricity market to enhance operational efficiency. As a result of these new legislations, state-owned power facilities underwent the process of privatization [9]. After the implementation of radical liberalization for shifting from the state-controlled market in 2001, Turkey established the Energy Market Regulatory Authority ("EMRA") and developed critical state institutions, such as the Energy Exchange Market ("EXIST") and the Turkish Electricity Transmission Corporation ("TEİAŞ") in 2009 and 2015, respectively. Ultimately, these regulations and processes have contributed to the rapid growth of the country's energy system [10]. More than 25.0% or 57.5 TWh of the country's electricity demand is supplied from hydropower. According to official projections, this would increase to approximately 116.0 TWh in the upcoming years [11].

Based on the mentioned importance of energy regulations and Turkey's renewable energy potentials, this paper aimed to comprehensively demonstrate Turkey's recent regulations for energy liberalization, hydropower potentials, main regions, rivers, and dams.

2. Energy demand and water resources

There is a big gap between energy production and consumption in Turkey. The production capacity is nearly 48% of the demand. This trend is expected to diminish to 26% in 2025. Turkey's indigenous present and future energy demand in 2030 is shown in **Table 1**. The sources are not enough. Energy production is low, so the import of necessities is inevitable [12,13].

Table 1. Amount of primary energy sources of Turkey [14–18].

Energy sources	Total	2030 Potential
Hard coal (million tons)	1126	1126
Lignite (million tons)	8075	8075
Asphaltite (million tons)	82	82
Bituminous schist (million tons)	1641	1641
Hydropower (MW)	34,592	38,600
Oil (million tons)	36	28.8
Natural gas (million m ³)	8	26
Nuclear (GW)	-	7.2
Uranium (ton)	9129	9129
Thorium (ton)	380,000	380,000
Geothermal (MW)	1063.7	16,355
Solar (GW)	3420.7	52.9
Wind (GW)	6516.2	29.6

Fossil resources such as coal, lignite, asphaltite, schist, and oil potentials are given as million bases. Renewable resources such as hydro, geo, solar, and wind potentials are given on a watt basis.

The demand and consumption of Turkey's energy are given in **Table 2**. The columns show energy sources and time periods (years). The lines are concerned with the demand and supply potential of related energy sources. To compensate for the difference between supply and demand, imports take a significant share of necessities. Fossil source imports have been increasing year by year [8]. Hydropower energy is an indigenous one due to the various threats of importing entities [19].

Turkey has Marmara, Aegean, Mediterranean, Inner Anatolian, Black Sea, Eastern Anatolian and Southeastern Anatolian regions. They consist of 26 river districts. The Black Sea region has the Sakarya, Kızılırmak, Yeşilirmak, Çoruh, İkizdere, Hurşit and Fırtına rivers. The Marmara region has Kocaçay, Biga and Gönen. Küçük Menderes, Büyük Menderes and Gediz are Aegean rivers. The Mediterranean regions have Aksu, Köprü, Manavgat, Göksu, Seyhan and Ceyhan. Two main rivers, the Aras and the Kura flow to the Caspian Sea. Euphrates and Tigris are directed to Basra Gulf. They carry about 186 km³ the runoff surface water annually [20].

Table 2. The demand and supply (in parentheses) targets of Turkey (ktoe) [21].

Energy sources	2000	2005	2010	2015	2020	2025
Coal (H.coal + lign.)	17,202 (20,256)	21,259 (30,474)	28,522 (50,311)	31,820 (83,258)	39,385 (129,106)	45,944 (296,997)
Oil and natural gas	3408 (59,250)	2127 (73,256)	1735 (92,637)	1516 (112,993)	1604 (136,365)	1455 (179,765)
Central heating	253 (253)	495 (495)	884 (884)	1336 (1336)	2018 (2018)	2748 (2748)
Hydraulic power	3763 (3763)	5845 (5845)	7520 (7520)	8873 (8873)	9454 (9454)	10,445 (10,445)
Wood and waste	6963 (6963)	6760 (6760)	6446 (6446)	6029 (6029)	5681 (5681)	5393 (5393)
Geothermal	432 (432)	1380 (1380)	3760 (3760)	4860 (4860)	4860 (4860)	5400 (5400)
Nuclear	0.0 (0.0)	0.0 (0.0)	3657 (3657)	9143 (9143)	18,286 (18,286)	29,200 (29,200)
Solar	204 (204)	459 (459)	907 (907)	1508 (1508)	2294 (2294)	3248 (3248)
Wind	55 (55)	250 (250)	620 (620)	980 (980)	1440 (1440)	2134 (2134)

3. Hydropower and hydroelectric plants

Fossil or renewable sources can be used for electricity production. Nuclear is the alternative one also. The shares are nearly 64% for thermal, 19% for hydroelectric, and 17% for nuclear [22,23]. **Table 3** shows the installed electricity needs and supplying energy from various sources.

Table 3. Electricity production from some sources in Turkey [24,25].

Installed capacity (MW)			Energy (GWh)				% of hydro power
Year	Thermal	Hydro power	Total	Thermal	Hydro power	Total	
1950	390	18	408	759	30	789	3.80
1960	861	412	1272	1814	1001	2815	35.55
1970	1510	725	2235	5590	3033	8623	35.17
1980	2988	2131	5119	11,927	11,348	23,275	48.75
1990	9551	6764	16,315	34,395	23,148	57,543	40.22
1995	11,074	9865	20,939	50,621	35,541	86,162	41.25
1999	15,555.9	10,537	26,092.9	81,661	34,678	116,339	29.81

Table 3. (Continued).

Year	Installed capacity (MW)			Energy (GWh)			% of hydro power
	Thermal	Hydro power	Total	Thermal	Hydro power	Total	
2000	16,052.5	11,175.2	27,227.7	93,934	30,879	124,813	24.74
2001	16,623.1	11,672.9	28,296	98,563	24,010	122,573	19.60
2002	19,569.4	12,177	31,746.4	71,796	44,034	116,000	38.00
2010	14,035	15,831	29,866	73,043	65,387	128,000	51.08
2020	20,433	28,503	48,946	90,359	97,456	306,100	31.84

Dam constructions are important for sustaining power and water, either domestic or irrigation needs. DSI constructed various sizes of 550 dams, of which 140 km³ of water is being stored and 2 km³ of domestic water is supplied to citizens [26].

Table 4. DSI's hydroelectric power plants [28].

Hydroelectric power plant	Province	Installed capacity (MW)	Annual generation (GWh)	Completion date
Akköprü	Muğla	115	343	2007
AlpaslanI	Muş	160	488	2007
Atasu	Trabzon	5	27	2009
Boğaz village	Bursa	10	20	2008
Borçka	Artvin	300	1039	2006
Cindere	Denizli	29	88	2007
Çine	Aydın	40	118	2007
Deriner	Artvin	670	2118	2009
Dim	Antalya	38	123	2007
Ermenek	Karaman	309	1187	2007
Kılavuzlu	Kahramanmaraş	57	100	2007
Kığı	Bingöl	140	423	2009
Kirazlı bridge	Kastamonu	12	41	2008
Köprübaşı	Zonguldak	74	203	2008
Kum village	Samsun	10	65	2006
Manyas	Balıkesir	20	59	2007
Muratlı	Artvin	115	444	2005
Obruk	Çorum	200	473	2007
Süreyya bey (Çekerek)	Yozgat	14	50	2008
Şanlıurfa tunnel	Şanlıurfa	50	124	2005
Topçam	Ordu	60	200	2007
Torul	Gümüşhane	103	322	2006
Ulubat-Çınarcık	Bursa	120	548	2009
Uzun çayır	Tunceli	71	317	2007
Total		2722	8920	

The three biggest river basins for dams are the Fırat 31.58 km³/year (127,000 km²); the Dicle, 25.24 km³/year (57,000 km²); and the Black Sea, 14.9 km³/year,

respectively [27]. Turkey has an average of 643 mm of rainfall in a year, approximately equivalent to 186 billion m³ flows to rivers and seas. **Table 4** gives the capacity of the plants.

Hydropower is obtained from a turbine while producing electricity at the same time. **Table 5** shows larger hydropower stations than 100 MW.

Table 5. Dams and Hydropower stations in Turkey capacities larger than 100 MW [28].

Dams	River	Province	Embankment vol. (1000 m ³)	Crest level (m)	From found (m)	From river Bed (m)	Water level (m)	Vol. (m ³)	Lake area (km ²)
Atatürk	Fırat	Ş.urfa	84,500	549	169	166	542	48,700	817
Karakaya	Fırat	D.bakır	2000	698	173	158	693	9580	268
Keban	Fırat	Elazığ	15,585	848	207	845	845	31,000	675
Altinkaya	Kızılırmak	Samsun	16,000	195	195	190	190	5763	118.31
Birecik	Fırat	Ş.Urfa	9209	389	63.50	385	385	1220	56.25
Oymapınar	Manavgat	Antalya	676	185	185	184	184	300	4.70
Berke2	Ceyhan	K.Maraş	735	346	201	345	345	427	7.80
Hasan Uğurlu	Yeşilirmak	Samsun	9223	195	175	190	190	1074	22.66
Sır2	Ceyhan	K.Maraş	494	443	116	440	440	1120	47.5
Gökçe kaya	Sakarya	E.şehir	650	392	158	388	388	910	20
Batman	Batman	Batman	5400	668.5	85.5	655	665	1175	49.25
Karkamış	Fırat	Maraş	1537	346	40	340	340	157	28
Özlüce	Peri	Bingöl	14,000	1144	144	1140	1140	1075	25.80
Çatalan	Seyhan	Adana	17,000	130	82	125	125	2116	81.86
Sarıyar2	Sakarya	Ankara	568	480	108	475	475	1900	83.83
Gezende	Ermanek	İçel	83	335	75	333	333	92	3.97
Aslantaş	Ceyhan	Adana	8493	160	95	145	146	1150	49
Hirfanlı	Kızılırmak	K.şehir	2000	860	83	851	851	5980	263
Menzelet	Ceyhan	K.Maraş	8700	614.5	156.5	609.4	609.4	1950	42
Kılıçkaya	Kelkit	Sivas	6900	855	134	850	850	1400	64.42
Dicle	Dicle	D.bakır	2180	718	87.5	715.5	715.5	595	24

4. Small hydroelectric power (SHP)

The huge dam constructions contributed to hydraulic electricity production in the 20th century. Those dams are beneficial for large farming areas, but there may be rapid silting up [29]. Therefore, small plants (SHP) are prominent for rural electrification necessities. Small plants can produce electricity on demand with no need for storage systems. They are rather cheaper than fossil ones [30].

Turkey's SHP development was begun in 1900. Since then, municipalities have constructed many decentralized plants. Temelsu is a well-known company in Turkey [31]. The major projects driven by Temelsu are shown in **Table 6**.

Table 6. Major hydroelectric plant projects undertaken by Temelsu in Turkey.

Basin name	Rated head (m)	Installed capacity (MW)	No/Turbin type
Esen-I	695	60	2/Pelton
Kokluce	440	90	2/Francis
Çamlıca-I	390	84	3/Francis
Duzkesme	285	150	3/Francis
Deriner	210	670	4/Francis
Özlüce	113	170	4/Francis
Beşkonak	112	152	3/Francis
Sir	110	284	3/Francis
Karacaören-II	95	46	2/Francis
Yedigöze	94	311	2/Francis
Gürsöğüt	91	56	2/Francis
Karacaören-I	82	32	2/Francis
Borçka	80	301	2/Francis
Muratlı	37	115	2/Kaplan
Çatalan	61	169	3/Francis
Birecik	44	672	6/Francis
Manavgat	23	48	2/Francis
Karkamış	12	189	6/Bulb
Hasanlar	50	9	2/Francis
Kepez-II	13	6	6/Bulb

The capacity of between 101 kW and 10 MW potentials is accepted as SHP [32]. The share of SHP to total electricity generation is approximately 10% [33]. However, although having that portion, some problems are seen while producing electricity by SHP. Those can be listed as (i) deficiency of the related topographical data; (ii) some equipment problems; (iii) sediment accumulation in route; (iv) problems in finding experts for SHPs; and (v) the gap among connections.

A profitable application related to small hydroelectric plants in Giresun (Turkey) is given in the following table (**Table 7**) [33].

Table 7. Technical data and capacity factor calculation of SHP in Giresun.

Name of SHP	Installed capacity (MW)	Total power (MWh)	Power Plant Cost (€)	Annual Profit (€)	Payback period (years)	Energy Cost (€/KWh)	Capacity Factor (%)
Moran	5.75	11,110	7,187,500	499,950	14.38	0.65	22.06
Akköy II	7.33	15,100	9,162,250	679,500	13.48	0.60	23.52
Güce	10.57	25,270	14,212,500	1,137,150	11.62	0.52	27.29
Yiğit	7.54	19,114	9,425,000	860,130	10.96	0.49	28.94
Serhat	9.10	24,840	11,375,000	1,117,800	10.18	0.46	31.16
Çalıkobası	8.28	22,920	10,350,000	1,031,400	10.04	0.45	31.60
Tokmadin	3.57	10,160	4,462,500	457,200	9.76	0.44	32.49
Delisava	4.88	14,110	6,100,000	634,950	9.61	0.43	33.01
Merek	9.18	26,650	11,475,000	1,199,250	9.57	0.43	33.14

Table 7. (Continued).

Name of SHP	Installed capacity (MW)	Total power (MWh)	Power Plant Cost (€)	Annual Profit (€)	Payback period (years)	Energy Cost (€/KWh)	Capacity Factor (%)
Yüce	10.57	30,750	13,212,500	1,383,750	9.55	0.43	33.22
Gelen	6.56	19,300	8,200,000	868,500	9.44	0.42	33.59
Soğukpınar	8.90	28,100	11,125,000	1,264,500	8.80	0.40	36.04
Gecür	3.23	10,200	4,037,500	459,000	8.79	0.40	36.08
Yumruktepe	13.68	43,720	17,100,000	1,967,400	8.69	0.39	36.49
Ekere	4.18	13,620	5,225,000	612,900	8.53	0.38	37.23
Kızılev	11.49	37,950	14,362,500	1,707,750	8.41	0.38	37.70
Üçgen 2	10.22	33,815	12,775,000	1,521,675	8.40	0.38	37.79
Arpacık	3.77	12,520	4,712,500	563,400	8.36	0.38	37.91
Telli I	9.10	30,270	11,375,000	1,362,150	8.35	0.38	37.97
İlimsu	4.57	15,300	57,125,000	688,500	8.30	0.37	38.22
Vanazit	2.66	9120	3,325,000	410,400	8.10	0.36	39.14
Kanat	13.30	46,000	16,625,000	2,070,000	8.03	0.36	39.48
Köprübaşı	5.70	20,200	712,5000	909,000	7.84	0.35	40.46
Karaca	3.01	19,978	3,762,500	494,010	7.62	0.34	41.61
Çanakçı I	6.00	22,720	7,500,000	1,022,400	7.34	0.33	43.23
Adadağı	4.70	18,198	5,875,000	818,910	7.17	0.32	44.20
Çay Reg.	10.05	39,980	12,562,500	1,799,100	6.98	0.31	45.41
Akköy	14.07	57,510	17,587,500	2,587,950	6.80	0.31	46.66
Kıran	9.74	40,690	12,175,000	1,831,050	6.65	0.30	47.69
Kahraman	1.52	6650	1,900,000	299,250	6.35	0.29	49.91
				Average	8.94	40.17	37.77

5. Southeastern project (GAP)

GAP is comprised of projects on the Euphrates and Tigris Rivers, incorporating 22 dams and 19 power plants. It will generate 27 billion kWh of energy and irrigate 1.7 billion hectares [34]. The installed Euphrates capacity is 5304 MW and will generate 20 billion kWh of energy and irrigate 1 million ha. It involves fourteen dams and 11 power plants. The Tigris installed capacity is 2172 MW and will generate 7 billion kWh of energy and irrigate 700,000 ha. There are eight dams and power plants [35].

Other dams are Karakaya (1000 MW), Atatürk (2400 MW), and Keban (1360 MW) capacities. Some thermal powers are Çağçağ III 14.5 MW and Kırıl Kızı 90 MW on this river. The project's installed capacity is 5960 MW, and the production is 28,000 GWh annually [36].

Apart from the energy advantages, GAP projects have increased the fishing and agricultural potential of the southeastern region of Turkey. The total area of agricultural land in the GAP region was estimated to be 3 million ha, or 42% of the area in the GAP Master Plan. More specifically, 85% of this area is dryland farming, 4% is irrigated farmland, and 11% is for horticultural and special crops.

Approximately 91% of farmers practice mixed farming, and 9% are engaged in crop production alone [37,38].

6. The environmental effects of hydropower

Environmental issues are governed by the regulations of the environmental ministry during the plant establishment stage. The other regulations are related to the discharged limit values of thermal wastewater streams, noise limits of plants, and discharge of some residues such as polychlorinated biphenyls (PCBs). It was widely used in old thermal plants, which had a construction year before 1995. Thermal fly ash and desulfurization gypsum agents are also monitored [34].

Although this study focused on Turkey's hydropower potential and the positive aspects of hydropower energy, there are still important environmental and socio-economic impacts of hydropower that cannot be overlooked [39,40]. International tension over fresh water sources, delays and contingencies in construction, high debts, and population displacements could be considered socioeconomic problems of the discussed topic [41,42]. In addition to these problems, some environmental issues should be noted. It is worth mentioning that, based on the environmental impact analysis through life-cycle assessment (LCA), hydropower projects are also responsible for some emissions and resource usage due to construction-related operations, including yard improvement, construction, maintenance, and operations, and lastly plant decommissioning after dam lifetime. Additionally, reservoir net emissions during pre-impoundment and post-impoundment are also another environmental impact [43].

It was also noted that freshwater eutrophication and water salinity or microalgae are other environmental concerns about the hydropower plants [44]. However, several studies focused on the utilization of these algae for biodiesel production, which could be an auxiliary fuel for the plants [45]. Overall, like other renewable energy sources, hydropower has some negative issues but still can be accepted as a more environmentally friendly alternative among others [46–48]. Annual total greenhouse gas (GHG) emissions arising from the global energy supply sector continue to increase. So, it will be decreased by utilizing renewable sources [49].

7. Conclusions

In conclusion, with the goal of environmentally friendly and economically feasible energy sources, it is critical to evaluate energy sources meticulously. Some embargoes and price fluctuations are encountered for sustaining energy demand, and the recent COVID-19 pandemic has displayed some detrimental effects. So, the renewable energy production must be mounted. Among them, biomass is abundant, and geothermal energy is useful, but high sulfur and carbonates are the main disadvantages. On the other hand, fossil-based fuels are not sufficient all over the world and are not accepted as clean sources. Therefore, hydraulic energy must be used based on the economic and technical situation. The hydroelectric plant service period is feasible, so it is rather economical from this point of view.

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