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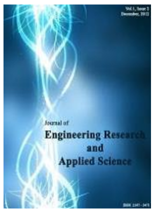

Small hydropower potential and utilization in Turkey

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Abstract
Although the amount of energy produced by this means has steadily increased, the amount produced by other types of power plants has increased at a faster rate and hydroelectric power presently supplies about 14% of the electrical generating capacity of Turkey. Turkey has a total gross hydropower potential of 433 GWh/year, but only 125 GWh/year of the total hydroelectric potential of Turkey can be economically used. Hydropower plants with an installed capacity of below 10 MW are widely considered small hydropower (SHP) in Turkey. Installed capacity at the end of 2015 was approximately 3686 MW with a total economically feasible potential capacity estimated at 6,500 MW indicating approximately 17.8% has been developed. This paper discusses the small hydropower situation in Turkey.

Keywords: Hydropower; small hydropower; electricity generation; Turkey.

1. Introduction

Hydropower is an internationally recognized source of clean and green energy, which has played an important role for the global energy supply. Driven by the increasing demand for energy and global climate change, many countries have given priority to hydropower development in the expansion of their energy sectors. Small hydropower has unique benefits – it is a mature technology which is economically feasible and has minimal impact on the environment. Small hydropower has greatly contributed to solving the problem of rural electrification, improving living standards and production conditions, promoting rural economic development, alleviating poverty as well as reducing emissions. Moreover, small hydropower is an economically efficient technology, and as such, has been highly favored by the international community, especially by developing countries [1-3].

Humans have used the power of flowing water for thousands of years. Early civilizations used wooden paddle wheels to grind corn and wheat to flour. The word Hydro comes from the Greek word for water. Hydropower traditionally represents the energy generated by damming a river and using turbine systems to generate electrical power. However, there are several other ways we can generate energy using the power of water. Ocean waves, tidal currents and ocean water temperature differences can all be harnessed to generate energy. More than 70% of the earth is covered by water. The United States is one of the worlds top producers of hydropower (see Figure 1). As much as 12% of the electrical energy generated in the U.S. is currently derived from hydropower systems. Parts of the Pacific Northwest generate as much as 70% of their electricity using hydroelectric sources. More than half the renewable energy generated in the United States comes from hydroelectric dams. Hydroelectric power is currently the least expensive source of electrical power and is much cleaner than power generated using fossil fuels [2].

China is the largest developing country in the world as well as the country endowed with the richest hydropower resources. The Government has promoted hydropower to a significant position. By the end of 2015, the total hydropower capacity of China reached 320 GW with an annual output of 1,100 TWh. Hydropower plays an essential role in the energy sector of China, contributing to the adjustment of the energy mix, emission reductions, as well as the economic development of the country, which has also promoted and led hydropower development worldwide. During the 12th Five-year Plan, the Government of China paid particular attention to the small hydropower sector, promoting the people's "well-being, and safe, green, and harmonious" small hydropower development. To date, 4,400 SHP plants (up to 50 MW) have been

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upgraded and refurbished; as a result, installed capacity and annual output have increased by more than 20 per cent and 40 per cent respectively.

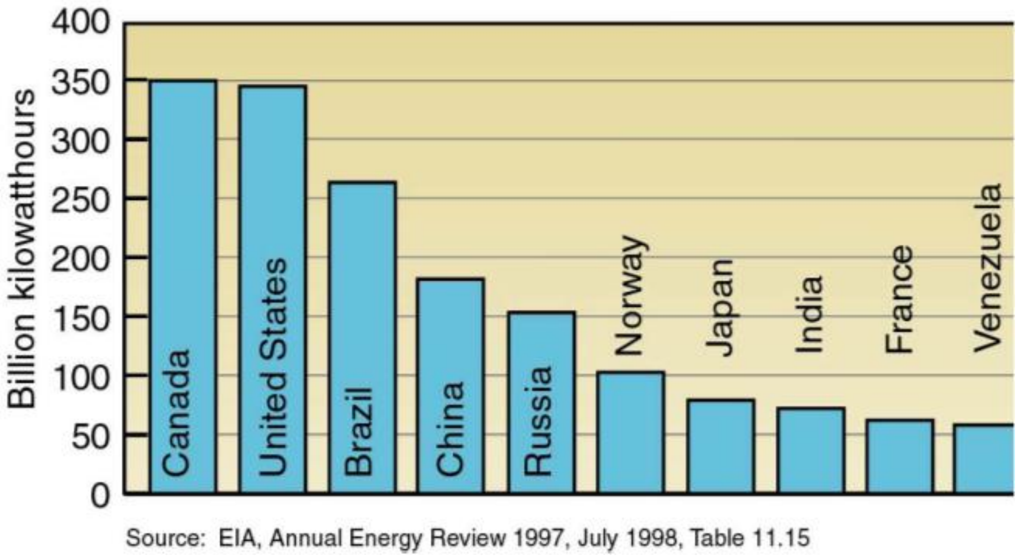

Figure 1. The amount of annual hydro electric energy of different countries [2].

Furthermore, 300 counties completed the objectives of the New Hydropower Rural Electrification County Program by developing 5,150 MW of newly installed SHP capacity, which accounted for 50 per cent of the total increase in SHP capacity. Additionally, through the national program Replacing Firewood with SHP, 592,000 households, totalling 2.24 million people, have been provided with access to electricity and 733,333 hectares of forest have been saved. The total installed SHP capacity of China has exceeded 75 GW, with an annual output of 230 TWh, thus, meeting the target set by the Medium and Long-term Renewable Energy Development Plan five years ahead of schedule [1, 3].

2. General climatic overview of Turkey

Turkey is semi-arid with some extremes in temperature. Its coastal areas have a Mediterranean climate with hot, dry summers between June and August with temperatures reaching 35°C. In the higher interior Anatolian Plateau, the winter months between December and February can be very cold, with temperatures going down to –7°C. The average temperature in 2014 was 14.9°C [4].

Dominated by the central Anatolian Plateau that covers much of the country apart from narrow coastal plains on the Aegean and Black Seas, the highest point is Mount Agrı at 5,166 m. There are also more than a hundred peaks higher than 3,000 m. Turkey lies within a seismically active area. The average annual precipitation is 643 mm, ranging from 250 mm in Central Anatolia to over 2,500 mm in the coastal area of the north-eastern Black Sea. Approximately 70% of the total precipitation falls during between October and April [4].

The Euphrates and the Tigris rise in the high mountains of north-eastern Anatolia and flow through Turkey before entering Syria. Together, they account for approximately one-third of Turkey's water potential. Many rivers rise and discharge into seas within Turkey's borders. The rivers discharging into the Black Sea are the Sakarya, Filyos, Kızılırmak, Yesilırmak and Çoruh; discharging into Mediterranean Sea are the Asi, Seyhan, Ceyhan, Tarsus and Dalaman; discharging into the Aegean Sea are the Büyük Menderes, Küçük Menderes, Gediz and Meriç; and discharging into the Sea of Marmara are the Susurluk/Simav, Biga and Gönen [4].

3. Definition and cost of small hydropower

The definition of a small hydro project (SHP) varies significantly from one country to another, but the consensus is to use the total installed generating capacity of a plant as the criterion. The following is a collection of international definitions of SHP [1-3]:

- Germany ≤ 1 MW
- Italy ≤ 3 MW
- UK (NFFO) ≤ 5 MW
- France ≤ 8 MW
- Colombia ≤ 20 MW
- Australia ≤ 20 MW
- India ≤ 25 MW
- China ≤ 50 MW
- Brazil ≤ 30 MW
- Philippines ≤ 50 MW
- New Zealand ≤ 50 MW
- Canada < 50 MW

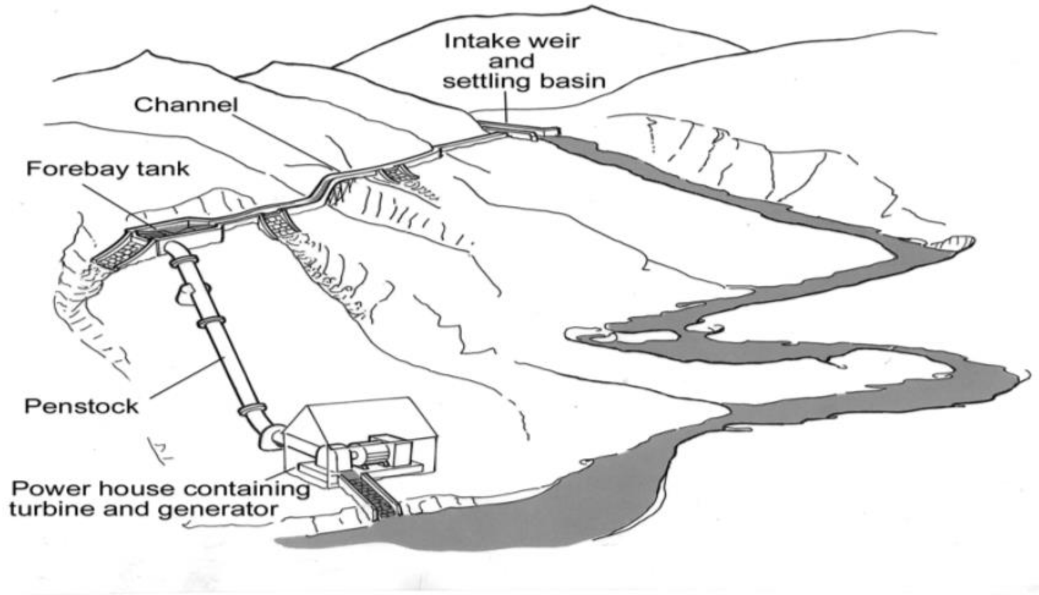

Figure 2. Small hydropower (run-of-river) plant components [2].

According to the European Small Hydro Association (ESHA), the European Commission, the International Union of Producers and Distributors of Electricity, and the United Nations Industrial Development Organization, a generating capacity of up to 10 MW is now generally accepted as the upper limit of small hydro. The US Department of Energy (DOE) defines SHPs as facilities that have a capacity less than 30 megawatts, but proposed legislation defines SHPs as having a capacity of less than 5 MW. Additional definitions used for varying degrees of SHPs within the hydropower industry include [3].

- pico-hydro: <10 kW
- micro-hydro: 10–100 kW (and/or design flow < 15 cfs)
- mini-hydro: 100–1000 kW (and/or design flow between 15-450 cfs)
- small hydro: >1000 kW (and/or design flow > 450 cfs)

Because of increasing concern regarding greenhouse gas emissions and global warming phenomena in recent years, there is worldwide renewed interest in hydropower generation, especially in small hydro development. Small hydro offers significant benefits in terms of faster deployment, distributed generation, small business opportunities, and significantly reduced concerns about regional environmental/ecological system disturbances, although the levelized cost of energy (LCOE) from small hydro generation is usually higher than from large hydro [1, 3].

4. Energy and electricity consumption in Turkey

As a fast developing country with increasing energy demand due to industrialization and increase in population, Turkey's future energy supply should be supplied by domestic sources. At present, 75% of total energy demand of Turkey supplied by imported energy sources as shown in Table 1. Turkey has enough coal and renewable energy sources, but in case of oil and gas, the country is very poor. Table 2 shows Turkey’s total installed power by energy sources.

Table 1. Turkey’s energy production and consumption in 2015 (Mtoe)

Energy source	Production	Consumption
Hard coal	990	17 692
Lignite	13 973	13 182
Asphaltite	488	416
Oil	2 485	33 896
Natural gas	443	37 628
Hydropower	5 110	5 110
Geothermal (electric)	1 173	1 173
Geothermal (heat)	1 463	1 463
Animal & plant wastes	1 666	1 666
Wood	2 707	2 707
Wind	650	650
Solar	795	795
Total	31 944	120 290

Source: Ref. [13]

Table 2.Turkey’s total installed power in 2014 (MW)

Energy source	Amount	Percent (%)
Natural gas	20 854	% 31.7
Coal	12 828	% 19.5
Other thermal	5 711	% 9.1
Hydropower	22 898	% 34.8
Wind	2 930	% 4.4
Geothermal	317	% 0.5

Source: Ref. [13]

Turkey’s electrification rate in 2010 was 100%. Its electricity consumption in 2015 was 260.21 TWh (see Figs. 3-5). Between 2020 and 2030, electricity demand is predicted to go up to 610 TWh and 871 TWh, respectively. The Turkish Electricity Market Law no. 4628 was published in March 2001 and has led to the establishment of the Electricity Market Regulatory Authority. Thus, the private sector has been able to obtain a licence granted from this authority to own, build and operate power plants [5-14].

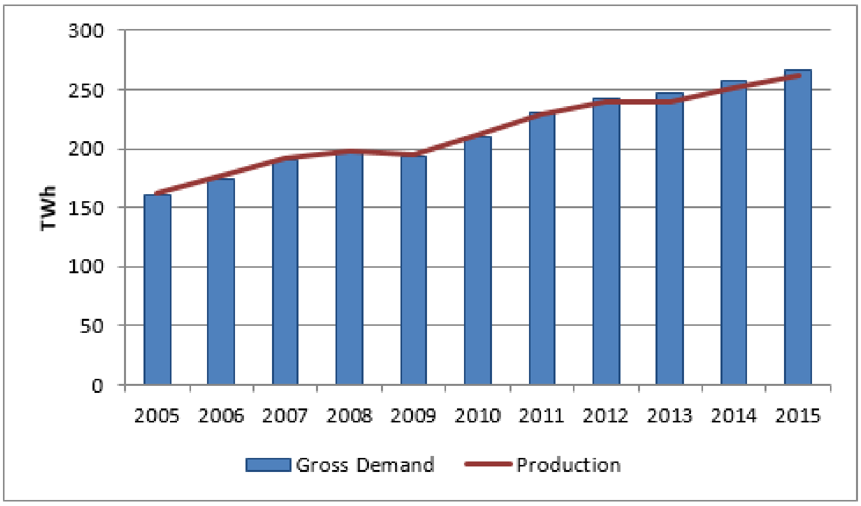

Figure 3. Annual development of gross electricity generation and demand in Turkey [5].

Hydropower development in Turkey has been carried out for about a century for different purposes, namely electricity generation, land irrigation, water supply for domestic and industrial utilization and flood control in the surrounding area. Hydropower accounts for more than 26% of electricity generation. In view of the considerable variation in seasonal, annual and regional runoff, it is absolutely necessary for the major rivers in Turkey to have water storage facilities and to allow the use of the water when it is necessary. Consequently, priority has always been given to the construction of water-storage facilities. Significant progress has taken place in the construction of dams throughout the 55 years that have elapsed since the establishment of the State Hydraulic Works [15-20].

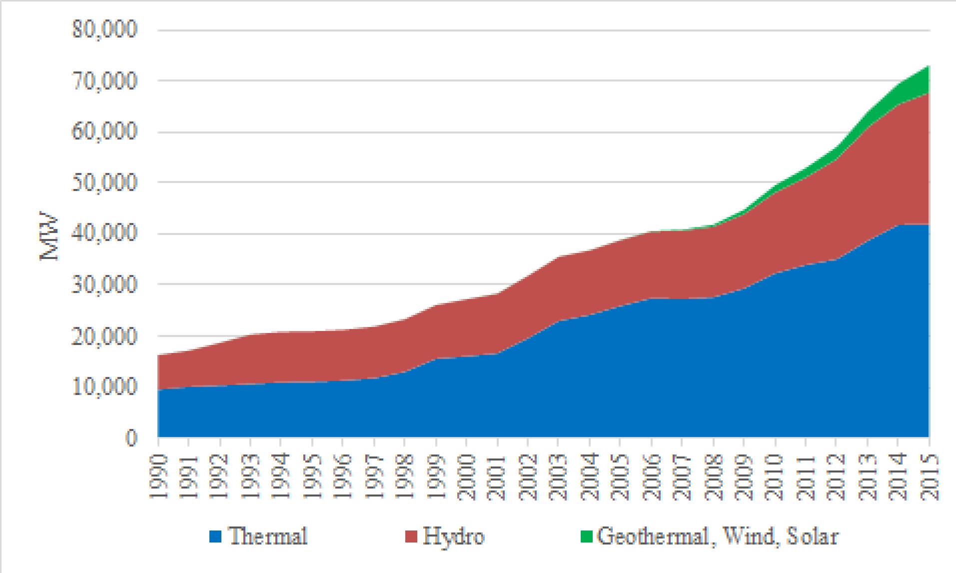

Figure 4. Turkey's annual development of installed capacity by sources [5].

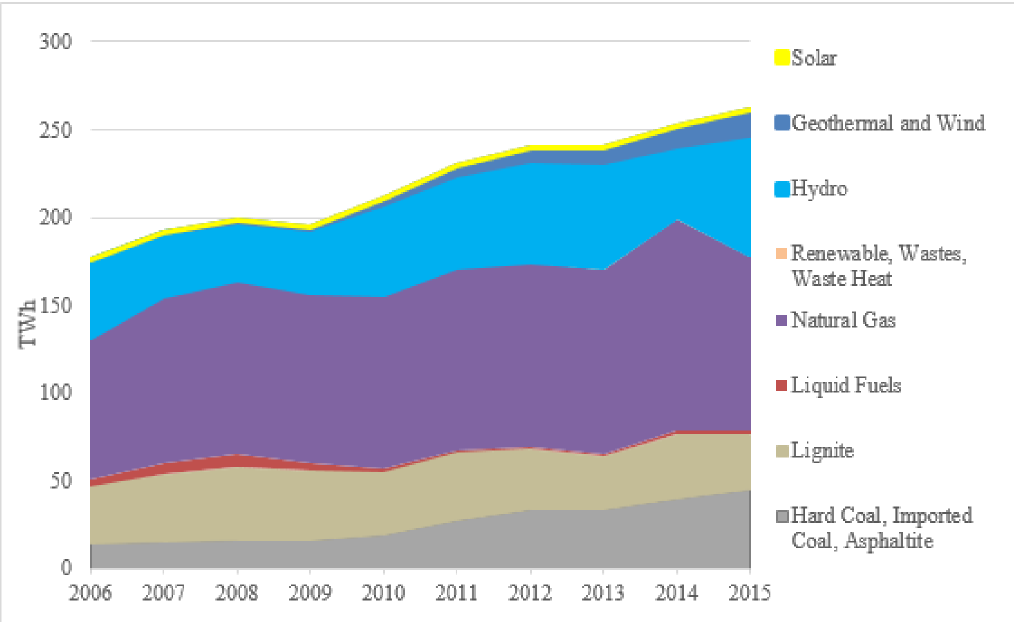

Figure 5. Electricity generation by primary energy resources in Turkey (TWh) [5]

5. Small hydropower in Turkey

Development of small hydropower began in 1902 in Turkey. Since then, private entrepreneurs and some government organizations and municipalities in rural areas have installed many decentralized small hydropower plants. Turkey has a mountainous landscape with an average elevation of 1,132 meters. This topography favors the formation of high gradient mountain streams with suitable locations for small hydropower development [18]. The low costs of investment offer attractive opportunities for either domestic or foreign entrepreneurs interested in small hydropower plants. Since 1990, the amount of small hydropower plants and their capacity have increased more than doubled. The bulk of all small hydropower plants (90%) have been constructed in the last two decades. Around 30% of generating capacity is in private hands. According to their gross head, the percentage of small hydropower plants is as follows: 5% have medium head (5 to 15m) and 95% high head (more than 15m) [17, 18].

By the end of 2015, the total number of small hydropower stations in operation throughout the country was 159 with a total installed capacity 3 5785 MW, covering less than 25% of the total hydropower potential (13,700MW). In addition to the large hydropower projects with installed capacities greater than 10 MW, it is estimated that there still is considerable small hydropower potential in Turkey. This estimation is provided in Table 3.

Table 3. SHP plants (below 10 MW) by stage of development in 2015

License type	Stage	Capacity (MW)	Number of power plants
Pre-License	Application stage	996.8	220
	Evaluation stage	54.6	15
	Granted	346.8	76
	Granted	2,287.8	468
Total		3686	779

Among the 25 hydrological basins in Turkey, the Eastern Black Sea Basin has great advantages in terms of small hydropower potential as the annual average precipitation is the highest in the country (2,329 mm in Rize Province). Furthermore, the basin covers sharp With regard to local small hydropower capacities, there are local consulting and engineering companies which provide multi-disciplinary engineering services, locally and internationally. Increasing demand for power-generating turbines and other equipment will benefit the industrial sector and reduce import demand [17-20].

5.1. A case of small hydropower in Bayburt

The Bayburt hydro scheme is on the Çoruh river in the Merkez district of Bayburt province, in Anatolia, central Turkey. Construction was completed, within two years, in December 2009 by Bayburt Insaat ve Ticaret AŞ, and the plant was officially commissioned in January 2010. The average annual output of the scheme is 63 GWh. Three Francis turbines, with a total capacity of 15 MW, were supplied by WKV AG of Germany. They operate under a head of about 83 m, with a discharge of 20 m^3/s [21].

This is the first power project to be developed and operated by Bayburt Enerji ve Üretim AŞ. The scheme has a water transmission system comprising 18.5 km-long trapezoidal conduits. On the water transfer conduit, with a capacity of 24 m^3/h, there are two siphons: one at 25 m and the other at 55 m. Water for the scheme is conveyed to the power plant from the Helva regulator on the Çoruh river and the Kop regulator on the Kop stream. A storage tank with a capacity of 25 000 m^3 is used to feed the powerhouse [21].

The powerhouse is equipped with three horizontal-axis Francis turbines as shown in Figure 6. They are designed for a 82.72 m head and a flow rate of 6.67 m^3/h. The units are performing with an extremely high overall efficiency of 92.7% at rated discharge. The turbine systems comprises the runner, turbine cover, speed regulation system, synchronous alternator, lubrication oil pumping and cooling systems and auxiliary equipment [21].

The turbine runner is overhung-mounted on the alternator shaft, which bears the hydraulic forces of the prime mover. Therefore the alternator is equipped with suitably reinforced bearings. The lubrication oil system is based on a mechanical oil pump which is mounted at the NDE shaft of the alternator, combined with a separate oil supply center required for emergency oil supply and oil cooling. With the use of a geared pump mounted on the generator shaft, the generator is able to produce its own lubrication when it reaches a certain speed. The lubrication oil quantity for the bearings is adjusted by needle valves, and is of course monitored. The generator bearing temperature, the coil temperatures and the circulating lubricant temperatures are measured by PT100 elements. The generators are rated at 5800 kVA apparent power, for an output voltage of 6.3 kV and a rated speed of 600 rpm.

The guide vanes are hydraulically controlled by WKV's SRE 2000 equipment. The digitally operated, and both digitally and manually adjustable, SRE 2000 control system ensures very accurate frequency and load settings. The butterfly valves were mounted together with the bypass valve. While opening the 1.4 m-diameter butterfly valve, the hydraulic governor provides support. The closing process is achieved by closing weights of about 2 t, which are connected to the valve axis.

Figure 6. The machine hall with the three Francis units for SHP in Bayburt province [21].

The first 80% stops the discharge for 26 s, and then the remaining 20% shuts the water off for 40 s. The opening of the butterfly valves takes 120 s. A bypass valve is provided to protect the penstock from water hammer. On the other hand, the Bayburt plant has three 6000 kVA block transformers. They step-up the generator's 6.3 kV output to 33 kV and connect it in parallel to the network. A 160 kVA auxiliary power transformer provides the internal demand of the power station. The generator-transformer-feeder protection at the plant is done by WKV's protection panels. The plant is normally operated completely automatically [21].

6. Conclusions

Small Hydropower (SHP) is a mature and versatile technology, effective for increasing access to clean and sustainable electricity in the developing world, particularly in rural communities. SHP also helps developed nations achieve renewable energy advancement and targets in reducing greenhouse gas emission. Through developing SHP, many countries have already taken steps—or are beginning to take steps—to alleviate poverty and increase access to electricity, both of which are key elements in the Sustainable Development Goals and the Sustainable Energy for All. The importance and advantages of SHP as a solution to rural electrification and inclusive sustainable industrial development also still remains underestimated. This is exposed particularly when SHP is compared to other small-scale renewable energies. Additionally, while the power obtained from SHP plants is significant, the initial costs of project implementation can be considerable in comparison to other technologies. This, too, discourages both government officials and private investors from taking interest in SHP. Lastly, SHP sometimes suffers from poor public perception concerning the environmental and social impacts normally associated with large-scale hydropower projects.

Energy is considered to be one of the key factors in economical development. Sustainable energy resources are of vital importance and the energy resources, which are continuously available for long durations and which have no detrimental social effects, are compulsory for sustainable development. The alternative energy resources, including hydropower, have some important advantages, such as being sustainable, renewable, environmentally friendly and clean resources. The inherent technical, economic and environmental benefits of hydroelectric power make it an important

contributor to the future world energy mix, particularly in the developing countries. Hydropower potential, especially small, is emphasized as Turkey's renewable energy sources. Turkey's hydroelectric potential can meet 33 to 46% of its electric energy demand in 2020 and this potential may easily and economically be developed.
Hydropower plants with an installed capacity of below 10 MW are widely considered small hydropower (SHP) in Turkey. Installed capacity at the end of 2015 was approximately 3686 MW with a total economically feasible potential capacity estimated at 6,500 MW indicating approximately 17.8% has been developed. In comparison to data from the 2013 report, the potential capacity remained the same while installed capacity has increased significantly. But this is due to an inaccurate assessment of capacity reported previously.

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