



## Potential and utilization of hydroelectric energy in Turkey

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### Abstract

Hydropower or water power is derived from the energy of falling water or fast running water, which may be harnessed for useful purposes. The most common type of hydroelectric power plant uses a dam on a river to store water in a reservoir. Water released from the reservoir flows through a turbine, spinning it, which in turn activates a generator to produce electricity. 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. By the commissioning of new hydropower plants, which are under construction, 36% of the economically usable potential of the country would be tapped. This paper discusses the clean and sustainable electricity from hydropower in Turkey.

*Keywords:* hydropower; renewable electricity; electric generation; Turkey

### 1. Introduction

Growing energy demand together with increasing environmental concerns has widened the interest in hydropower generation [1]. In addition to conventional large-scale dam-operated hydropower technologies, several smaller scale hydropower machines are being explored for providing local energy solutions [2]. Advantages of such machines are that they are cheaper to produce and are likely to have less environmental impact [4]. Such technologies seem of particular interest for developing countries where technical solutions rely on the schooling of communities to operate machines with a new technology. The implementation of such technologies requires trained staff that is to be employed on site [1-7].

Modern large hydropower plants use turbines to generate electricity. Sites are chosen based on energy demand, hydrological, geological and environmental conditions of the region [2]. Legal aspects and the social structure of the inhabitants of the region are also considered. Depending on the conditions at the power plant, different types of turbines are used. They are supplied with water stored in a reservoir with a dam or are constructed in rivers with considerable structural requirements [1]. Fluctuations in energy production are small and the power generated is fed into centralized electricity grids. The environmental aspects of large hydropower plants are important as these structures block the natural flow of the river system. The incorporation of ecological solutions

increase the costs of such projects and are often overlooked in the planning of such projects in developing countries [1, 2].

The role of small hydropower is becoming increasingly important on a global level. The potential in terms of sustainability is rapidly expanding as fossil resources and nuclear fuels are being depleted [1]. Rapid industrial and economic growth in developing countries is leading to shortages of electricity, in particular peak demand. Economic growth is often given priority over environmental issues. In developing countries, particularly in rural areas, energy availability is not receiving the priority it deserves [2]. Hence the possibility of creating power generation for local consumption based on sustainable technologies can improve living conditions as well as bring employment benefits to local communities [1-3].

Hydropower potential in the world is considerable (Figure 1) [1]. Economic feasibility shows that only an estimated two-thirds of the potential can be feasibly utilized. The gross share of hydropower in the energy mix is estimated to lie at 15% till 2035 [1]. The technical potential which is still underdeveloped begins with the African continent at 92%. This is followed by Asia (80%), Australia and Oceania (80%), and Latin America (74%). Here increases in power output are significant in emerging economies in Asia and South America with China and India and

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Brazil respectively. Social, economic as well as environmental issues predominate the implementation

of large-scale projects [1-8].

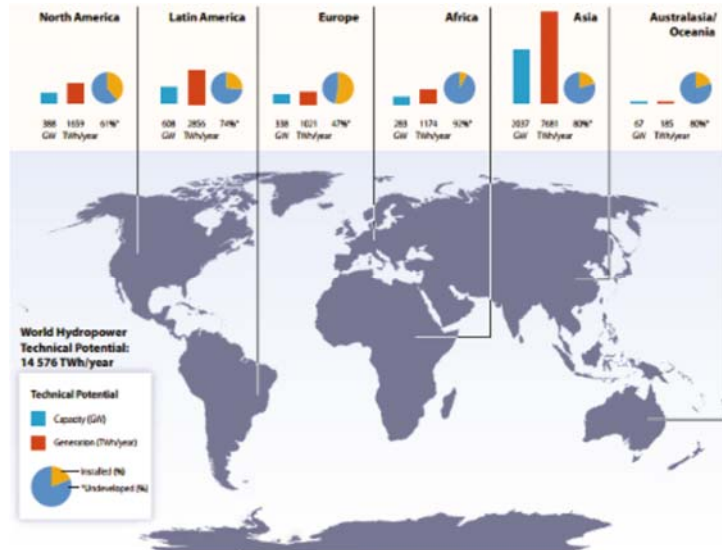


Figure 1. Worldwide technical hydropower potential in 2009.

Hydropower is a renewable form of energy since it uses the power of flowing water, without vested or depleting it in the generation of energy. Because they are clean energy generation plants hydropower can contribute to reducing air pollution and slowing down global warming. Any other air pollutants or toxic wastes are not produced and it promotes energy safety

independence and price stability. Hydropower is an electricity sources with long viability and low operation and maintenance cost [1-6]. Figure 2 shows the global historical growth of hydropower since 1980. The blue arrow represents a general historic increase in hydropower in response to growing demand for electricity worldwide.

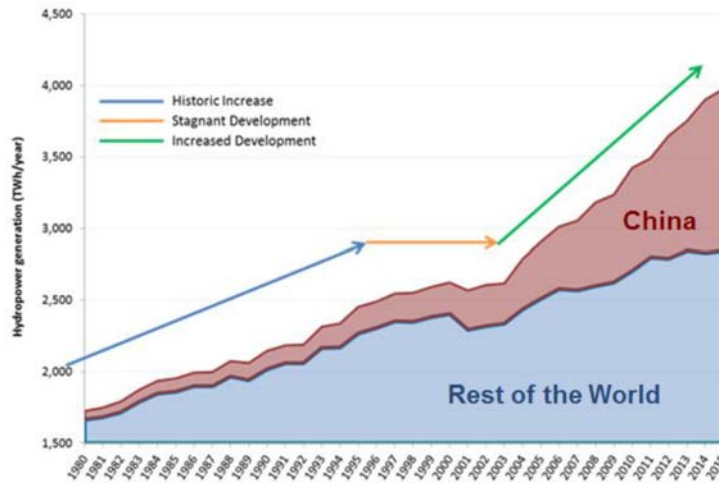


Figure 2. Global total hydropower generation.

Water in rivers, oceans, and estuaries experiences motion and, therefore, possesses kinetic energy that may be captured for producing electricity. River flow rates vary, but some flow typically occurs constantly [4]. Tides cause water currents to flow into and out of estuaries and cause periodic changes in water depth. Waves cause periodic increases and decreases in water

depth. Ocean currents, such as the Gulf Stream, possess energy that may someday be tapped to produce electricity to be transferred to shore [4-10].

Turkey has a gross annual hydro potential of 433,000 GWh, which is almost 1% of the world’s total potential. Of the total hydropower capacity in Europe,

Turkey's share is about 14%. Almost half of the gross potential is technically exploitable, and 28% (122,322 GWh/year) is economically exploitable [8]. As of November 2017, there were 160 hydro plants in operation. These have a total installed capacity of 16,588 MW and an annual average generation capacity of 62,015 GWh, amounting to almost 34% of

the total exploitable potential, which is at present meeting about 35% of the electricity demand. Thirty-four hydro plants with an installed capacity of 4305 MW and an annual generation capacity of 13,981 GWh, which is almost 9% of the total potential, are under construction [8-30].

## 2. Fundamentals of Hydropower

### 2.1. The working principle

Hydropower plants capture the energy of falling water to generate electricity. A turbine converts the kinetic energy of falling water into mechanical energy. Then a generator converts the mechanical energy from the turbine into electrical energy. Energy flows in the hydrologic cycle of evaporation, precipitation, and surface runoff of water, and can be harnessed to generate energy. A simple schematic diagram of a hydroelectric plant is shown in Figure 3. The water, often stored behind a dam, falls through a height (or head) of distance. The water's potential energy is

converted to kinetic energy, and the flowing water turns a water turbine. The rotating shaft of the turbine turns the electric generator, which yields the electricity. As river water flows toward eventual discharge into the sea, it may pass through regions where impoundment with dams is feasible. It is generally desirable to build dams in locations where dam height can be maximized with minimum land area flooded behind the dam. Therefore, mountainous or hilly regions are preferred over flat terrain for impounding water [1-6].

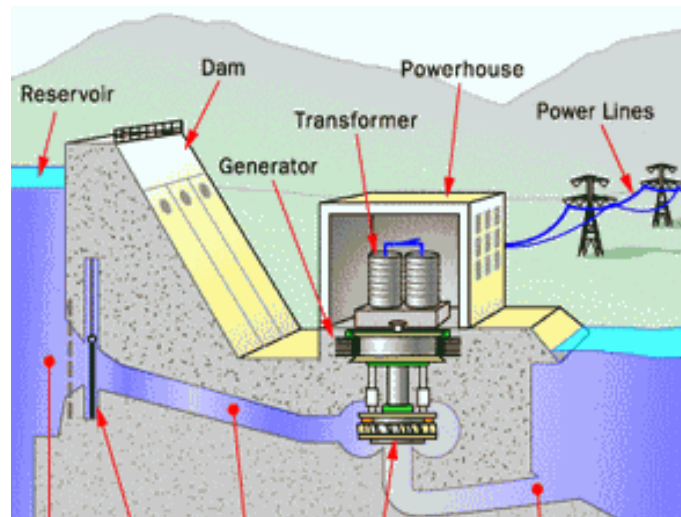


Figure 3. A schematic overview of the hydroelectric dam.

Most conventional hydroelectric plants include four major components such as [1-4]:

- **Dam:** Raises the water level of the river to create falling water. Also controls the flow of water. The reservoir that is formed is, in effect, stored energy.
- **Turbine:** The force of falling water pushing against the turbine's blades causes the turbine to spin. A water turbine is much like a windmill, except the energy is provided by falling water instead of wind. The turbine converts the kinetic energy of falling water into mechanical energy.

- **Generator:** Connected to the turbine by shafts and possibly gears so when the turbine spins it causes the generator to spin also. Converts the mechanical energy from the turbine into electric energy. Generators in hydropower plants work just like the generators in other types of power plants.
- **Transmission lines:** Conduct electricity from the hydropower plant to homes and business.

The amount of electricity a hydropower plant produces depends on two factors [1-4]:

- **How Far the Water Falls:** The farther the water falls, the more power it has. Generally, the distance that the water falls

depends on the size of the dam. The higher the dam, the farther the water falls and the more power it has. Scientists would say that the power of falling water is "directly proportional" to the distance it falls. In other words, water falling twice as far has twice as much energy.

- *Amount of Water Falling:* More water falling through the turbine will produce more power. The amount of water available depends on the amount of water flowing down the river. Bigger rivers have more flowing water and can produce more energy. Power is also "directly proportional" to river flow. A river with twice the amount of flowing water as another river can produce twice as much energy.

## 2.2. Types of hydropower

There are four broad hydropower types [1-6]:

- *Run-of-river hydropower:* a facility that channels flowing water from a river through a canal or penstock to spin a turbine. Typically, a run-of-river project will have little or no storage facility. Run-of-river provides a continuous supply of electricity (base load), with some flexibility of operation for daily fluctuations in demand through water flow that is regulated by the facility.
- *Storage hydropower:* Typically, a large system that uses a dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator. Storage hydropower provides base load as well as the ability to be shut down and started up at short notice according to the demands of the system (peak load). It can offer enough storage capacity to operate independently of the hydrological inflow for many weeks or even months.
- *Pumped-storage hydropower:* provides peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand.

When electricity demand is high, water is released back to the lower reservoir through turbines to produce electricity.

- *Offshore hydropower:* A less established but growing group of technologies that use tidal

currents or the power of waves to generate electricity from seawater.

## 2.3. Environmental impacts of hydropower plants

Hydropower does not pollute the water or the air. However, hydropower facilities can have large environmental impacts by changing the environment and affecting land use, homes, and natural habitats in the dam area. Most hydroelectric power plants have a dam and a reservoir. These structures may obstruct fish migration and affect their populations. Operating a hydroelectric power plant may also change the water temperature and the river's flow. These changes may harm native plants and animals in the river and on land.

Reservoirs may cover people's homes, important natural areas, agricultural land, and archeological sites. So, building dams can require relocating people. Methane, a strong greenhouse gas may also form in some reservoirs and may be emitted to the atmosphere. The gas is released at the reservoir surface, at turbines, spillways and downstream of the dam. This is also produced by various other dam related impacts including the fossil fuel and building materials used during dam construction [1-6].

## 2.4. Advantages and Disadvantages of Hydropower

### 2.4.1. Advantages of hydropower

- Hydropower is fueled by water, so it's a clean fuel source, meaning it won't pollute the air like power plants that burn fossil fuels, such as coal or natural gas.
- Hydroelectric power is a domestic source of energy, allowing each state to produce their own energy without being reliant on international fuel sources.
- The energy generated through hydropower relies on the water cycle, which is driven by the sun, making it a renewable power source, making it a more reliable and affordable source than fossil fuels that are rapidly being depleted.
- Impoundment hydropower creates reservoirs that offer a variety of recreational opportunities, notably fishing, swimming, and boating. Most water power installations are required to provide some public access to the reservoir to allow the public to take advantage of these opportunities.
- Some hydropower facilities can quickly go from zero power to maximum output. Because hydropower plants can generate power to the grid immediately, they provide essential back-up power during major electricity outages or disruptions.

- In addition to a sustainable fuel source, hydropower efforts produce a number of benefits, such as flood control, irrigation, and water supply.

#### 2.4.2. Disadvantages of Hydropower

- Building power plants in general is expensive. Hydroelectric power plants are not an exception to this. On the other hand, these plants do not require a lot of workers and maintenance costs are usually low.
- Electricity generation and energy prices are directly related to how much water is

available. A drought could potentially affect this.

- The environmental consequences of hydropower are related to interventions in nature due to damming of water, changed water flow and the construction of roads and power lines.
- Limited reservoirs, whereby we, have already started using up suitable reservoirs for hydroelectric power plants

### 3. Energy situation and policies in Turkey

#### 3.1. Overview

With a population reaching 82 million, Turkey's energy consumption based on primary energy resources is continuing to increase and this is compounded by the rapidly growing economy [5-16]. Turkey's increasing energy demand is mostly met by fossil fuels, of which a large portion is imported. The total installed capacity of power is 69,516 MW and the breakdown by resource is 59.7% fossil fuels (natural gas, coal, liquid fuel, etc.), 34% hydro, 5.2% wind and 1.1% other renewables [17-20]. Turkey pays millions of dollars for its energy imports every year. In addition to this, the number of buildings has reached 9.3 million and the number of residential and commercial units in these buildings reached to 22 million in 2014, which consume 28.2 million tons of oil equivalent (Mtoe), mainly natural gas, coal and wood for heating and electricity for cooling [17-30].

As a developing country in conjunction with its fast growing economy and population Turkey's energy consumption has increased rapidly. For example,

while total primary energy consumption in 2009 was 106 Mtoe in 2013 it raised 120 Mtoe and total energy production in 2009 was 28 and 31 Mtoe in 2013. Turkey is an energy importing country and dependent on the imported energy sources (Table 1 and 2) [17, 18]. Furthermore this trends seems to be continuing in the future. Although it has a wide variety of energy sources, the quality and quantity of most of the sources are not sufficient to produce energy. Some of the energy sources in Turkey are coal/lignite, asphalt, oil, natural gas, hydropower, geothermal, wood, animal and plant wastes, solar and wind energy [15, 16, 17]. The proven reserves of lignite, the most abundant domestic energy source, is 7300 million ton and found in almost all of the country's regions. Lignite has the largest percentage in total energy production with its 43% share. After lignite, wood has the greatest share in total energy production with its 20% and oil accounts for 13%, 12.4% hydro and the final 15% includes animal wastes, solar, hard coal, natural gas, geothermal electricity and geothermal heat [14-18].

Table 1. Total energy production in Turkey (Mtoe)

Energy Sources	2014	2020	2030
Coal and Lignite	12.15	32.36	<b>35.13</b>
Oil	2.64	0.49	<b>0.17</b>
Gas	0.32	0.14	<b>0.10</b>
Nuclear	-	7.30	<b>14.60</b>
Hydropower	5.78	10.00	<b>10.00</b>
Geothermal	4.80	1.71	<b>3.64</b>
Wood and Biomass	5.75	4.96	<b>4.64</b>
Solar/Wind/Other	1.85	2.27	<b>4.28</b>
<b>Total production</b>	<b>33.29</b>	<b>59.23</b>	<b>72.56</b>

#### 3.2. Indigenization by renewables

Indigenous production by using national resources is important in reaching energy without being dependent on external energy resources. In this regard, indigenization, the second item on the National

Energy and Mining Policy, is critically important for Turkey to add a new dimension to its policies and strategies for the reduction of the country's years-long import dependency. Many public and private sector

institutions and organizations, in particular the MENR, are spending tremendous efforts to increase the use of national energy resources. As part of the country's 2023 vision, efforts on the indigenization of energy have continued with the 2015-2019 Strategic Plan prepared by the Ministry [9-30].

To increase production from indigenous energy resources is critical in terms of ensuring security of supply for a country, such as Turkey, that meets about 76% of its energy need from imported energy sources.

As Turkey's population has increased over the years, it is necessary for the country to place importance on indigenous energy projects in order to lower economic and/or political risks concerning security of supply [26]. In this regard, significant efforts have been made to meet energy demand by using indigenous resources. That being said, Turkey has accelerated investments in sustainable energy in the last 15 years. Accordingly, renewable energy investments that aim to bring natural resources into the economy are extremely critical for diversifying energy resources [24-26].

Table 2. Total energy consumption in Turkey (Mtoe)

Energy Sources	2014	2020	2030
<b>Coal and Lignite</b>	33.87	107.57	<b>198.34</b>
<b>Oil</b>	42.05	71.89	<b>102.38</b>
<b>Gas</b>	39.65	74.51	<b>126.25</b>
<b>Nuclear</b>	-	7.30	<b>14.60</b>
<b>Hydropower</b>	5.78	10.00	<b>10.00</b>
<b>Geothermal</b>	4.80	1.71	<b>3.64</b>
<b>Wood and Biomass</b>	5.75	4.96	<b>4.64</b>
<b>Solar/Wind/Other</b>	1.85	2.27	<b>4.28</b>
<b>Total consumption</b>	<b>133.75</b>	<b>280.21</b>	<b>464.13</b>

Increasing investments in renewable energy – particularly in recent years - are addressed in the National Energy and Mining Policy as Turkey has made noteworthy progress in the production of energy via renewable energy sources. Renewable energy sources in Turkey are used inadequately. Therefore, the policy aims to bring renewable energy resources into the economy as soon as possible and promotes producing energy from indigenous resources [12-16]. According to the data of 2016, Turkey, having a total of 35 GW installed capacity in renewable energy, strives to increase the level of renewable energy in total energy consumption by at least 30 percent as part of its 2023 targets. As hydropower plants, a conventional renewable energy resource, constitute a large part of the installed capacity, significant investments have mostly been made in modern renewable energy sources such as wind, solar, biomass and geothermal energy [26].

Owing to the country's geographical location, Turkey's potential to benefit from solar energy is high. In fact, compared to other renewable energy resources, Turkey's solar energy potential is the highest among other renewables. The country's solar energy capacity has reached 1,000 MW as of March 2017 [12-14] while there are works underway to increase the current capacity. Meanwhile, the bidding process for Turkey's and the world's largest solar energy power plant in the region of Konya-Karapınar, with the capacity of 1,000 MW has been concluded and, as a result, Turkey has stepped up to a new level

in the use of modern renewable energy resources. A total of 1.3 billion U.S. dollars will be invested in this project and the objective is to deliver electricity to 600,000 houses. In parallel with the indigenization strategy, this project is also intended to encourage job growth through stipulating the employment of Turkish engineers in up to 80% of the available jobs. With this and similar projects, Turkey aims to reach a total of 5,000 MW installed solar energy capacity by 2023.

A similar project is also intended for wind energy. As of the end of 2016, installed power capacity in wind energy reached 6,081 MW. However, tremendous efforts have also been made to increase this figure to 20,000 MW in accordance with the 2023 targets. Accordingly, the bidding deadline for the wind energy in the scope of the Renewable Energy Resource Area (YEKA in Turkish) with 1,000 MW of installed capacity is set at the end of July 2017; it has been decided to finalize the bidding and put the project into effect in 2017. Also, the use of domestic equipment (at least 65%) and the employment of native Turkish engineers (80%) are stipulated in the conditions of the project [12-26].

In recent years, significant progress has been made in the field of geothermal energy. Geothermal energy, as a completely indigenous energy source, also contributes to the security of supply. Since it is a low-cost and environment-friendly source, policy makers in Turkey have given special attention to geothermal energy. Geothermal energy had 17.5 MW of installed

capacity in 2002; since then, however, remarkable progress has been made, and as of March 2017, the figure had increased to 850 MW. In the scope of the

2023 targets, the total installed capacity of geothermal energy is projected to be 1,000 MW (Table 3).

Table 3. Turkey renewable electricity generation capacities (MW).

Renewable energy	2015	2017	2019	2023
Hydropower	25 526	28 763	32 000	34 000
Wind energy	5 660	9 550	13 300	20 000
Solar energy	300	1 800	3 000	5 000
Geothermal	412	560	700	1 000
Bioenergy	377	530	690	1 000

#### 4. Hydropower for electricity generation in Turkey

The first hydroelectric plant in Turkey was constructed at Tarsus in 1902. This plant only produced 60 kW, but nonetheless was a great technical achievement for the country. In later years there were many more projects including: Seyhan, Sariyer, Hirfanli, Kesikköprü, Demirköprü, and Kemer. These projects were either dams or hydroelectric power plants and by 1940 there were a total of 28 hydroelectric power plants in Turkey. After the State Hydraulic Works (DSI) was established in 1954 projects were better funded and the power produced per year was greatly increased.

Today, though some 60% of the country's hydropower potential remains undeveloped. With respect to the situation in this country, contrary to the general perception, Turkey is neither a country rich in freshwater resources nor the richest country in the region in this respect [17]. Turkey is situated in a semi-arid region, and has only about one fifth of the water available per capita. This is well above the 2 000 m<sup>3</sup> per capita in Turkey. Turkey's water is not always in the right place at the right time to meet present and anticipated needs. Certain regions of Turkey such as the Black Sea region have ample but unusable freshwater, while some of the more heavily populated and industrialized regions such as the Marmara and the Aegean regions lack sufficient fresh water [14-17].

Turkey has a significant hydropower capacity, estimated at some 433 TWh a year in total, of which some 176 TWh a year is thought economically viable (2016). At an average elevation of 1100 meters above

sea level, there is ample head available for development in a number of regions, including the area around the Black Sea, the Mediterranean, and Eastern Anatolia. The geography provides considerable opportunity for hydropower development.

Turkey produces more than 67 billion kWh of hydroelectric power per year [15], which corresponds to 25,6% of its total power generation [12]. Turkey's energy consumption is rising about 5.7% a year on average due to rapid urbanization and industrialization. In 2002, the electricity consumption peaked at 126.9 billion kWh, but in 2016, it increased to 274 billion kWh. It is estimated to rise to 528 billion kWh in 2020 [9-17].

The total gross hydroelectric power potential and total energy production capacity are nearly 50 000 MW and 112 TWh/yr, respectively (MENR, 2015). On the average, 26% of the total gross potential may be economically usable. At present, only about 14% of the total hydroelectric power potential is exploited (See Fig. 4 and Table 3 and 4). The national development plan aims to harvest all the hydroelectric power potential by 2030. The contribution of small hydroelectric plants to total electricity generation is estimated to be 4%. There remain some rivers for which the small hydropower potential has not been completely evaluated. Since total energy losses in hydroelectric power generation were about 3.6 TWh in 1985, another issue involves improvement of electricity generation in hydropower stations.

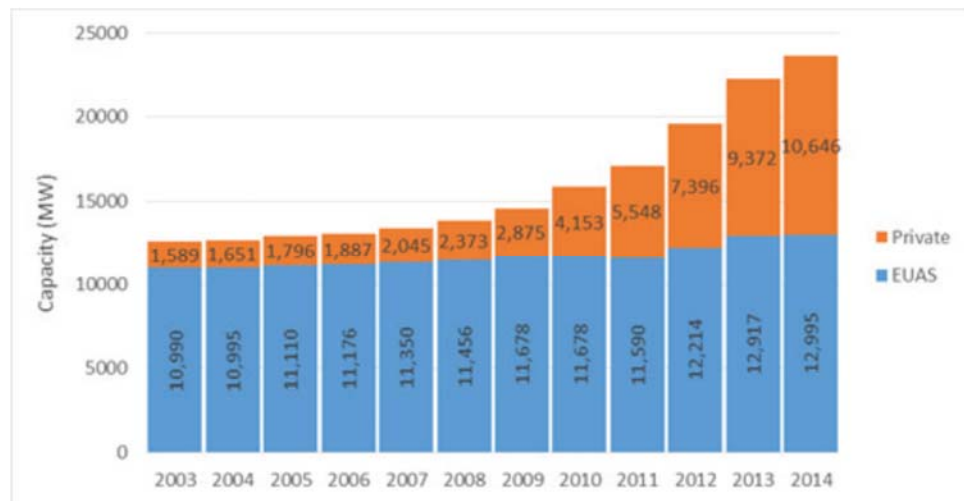


Figure 4. Development of hydroelectric power plant capacity in Turkey.

Table 4. Turkey's hydropower potential in 2015.

	Number of Hydroelectric power	Total installed Capacity (MW)	Average yearly generation (GWh/year)	Ratio (%)
<b>In operation</b>	562	26 161	90 773	58
<b>At construction level</b>	104	5 927	17 875	11
<b>At planned level</b>	717	13 984	48 911	31
<b>Total</b>	1 383	46 072	157 559	100

Among the other renewables, hydropower makes the largest contribution to electricity generation in Turkey, as it does in the world. The installed capacity of hydropower increased to 27,000 MW as of the end of 2016, however the goal is to improve this figure to 36,000 MW as part of the 2023 targets. As the hydropower potential of the country is high due to its geological structure, Turkey makes great efforts to turn its potential into an advantage. In addition to the

current working hydropower plants (HPPs), works are underway to increase the installed capacity by 6,500 MW of licensed HPPs and 3,500 MW of pre-licensed HPP projects. Moreover, compared to modern renewable energy types, as a fully indigenous energy source, HPP systems generate electricity at a lower cost. In other words, these systems have a reducing effect on the price of electricity generation [17, 18, 26].

## 5. Conclusions

Turkey is using about 30% of its hydro potential, and its unused potential consists of small hydro projects. At the end of 2017, the installed capacity of hydroelectric plants in Turkey stood at 13 393 MW. Small hydro projects have been one of the most attractive options for private investors in Turkey. The capacity of the small hydroelectric plants to be put in service over the next five years is expected to be about 44 000 GW, which corresponds to some 22 % of the current electricity generation capacity in Turkey. The following concluding remarks may be drawn from this study:

- In Turkey, the energy ministry has adopted to use all the hydro potential, for big and small hydro projects, local people's right to access to water has been violated with many projects and protecting the river ecosystems has been

disregarded. In a few years, the rapid expansion of hydro became an example of how renewable energy policies can go wrong if a balanced approach on using different renewable energy sources together with energy efficiency is not adopted.

- Hydropower is an important energy source for Turkey because it is renewable, clean, and less impactful on the environment. Plus it is a cheap and domestic energy source.
- Turkey's hydropower potential can meet 40-60% of its electric energy demand in 2030. By evaluating small hydropower plants, Turkey will provide an important part of its total electric energy demand from its own hydropower resources.

- Only 5% of economically feasible small hydroelectric potential has been developed. If all the remaining small hydro energy potential of Turkey was completely exploited, it would bring about an amount of about 20 TWh/yr of electricity generation, which means almost 10 percent of the annual total electricity demand of the country.
- In Turkey, only 30 percent of economical hydropower potential is currently utilizable. If Turkey could efficiently exploit its remaining hydro potential having an amount of 100 TWh/yr hydropower capacity.

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