Advances in Energy Research, *Vol. 5, No. 3 (2017) 239-254*
DOI: https://doi.org/10.12989/eri.2017.5.3.239

Importance of pumped storage hydroelectric power plant in Turkey

Egemen Aras*

Department of Civil Engineering, Faculty of Technology, Karadeniz Technical University, 61830 Trabzon, Turkey

(Received October 16, 2017, Revised May 5, 2018, Accepted May 15, 2018)

Abstract. The world began to search for new energy sources with increasing energy demand. Renewable energy sources are as hydropower important for alternative energy. Countries with high hydroelectric potentials continue to work to utilize hydroelectric power plants in the most efficient way. Pumped storage hydropower plants are an important investment to meet the growing energy needs at peak times and to store energy. Although it produces energy in many countries, pumped storage hydropower plants have not begun to be built in Turkey which has high hydroelectric potential. A new era will be opened for energy production in Turkey where a large number of pumped storage hydropower plants projects are in study phase with the construction of pumped storage hydropower plants and first nuclear power plant.

Keywords: pumped storage; hydroelectric; power plant; turkey; energy

1. Introduction

The necessity and efficiency of pumped storage hydroelectric power plants (PSHP) have been explored by many researchers around the world. These power plants, which can be seen as storage of electricity, can meet the sudden electricity need.

The storage of energy is one of the most critical components of the electricity value chain in the neoliberal market model that has developed in the world in recent years. The energy storage systems industry is a new, important and rapidly developing industry option all over the world. In liberal markets, system operators need to store energy in order to integrate large-scale renewable energy production into the system (Ayder 2015). Electric storage of energy is expensive and technologically inefficient. Many of the energy storage systems are indirect storage systems. In other words, it converts electricity into other forms of energy.

These storage systems; It can be classified as Magnetic energy (super capacitors), Electric energy (Superconducting Magnetic Energy Storage), Mechanical energy (PSHP, Compressed Air Storage, Flywheel), Chemical energy (Batteries). These systems are used for different purposes (Dunn *et al.* 2011). However, only PSHP and Compressed Air Storage methods are technologically and economically feasible for storing energies in large quantities (Fig. 1). Today,

*Corresponding author, Professor, E-mail: egemen@ktu.edu.tr

http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

the productivity of PSHP is 70-80% higher than the efficiency of Compressed Air Storage systems (Wood 1996, Ünver *et al.* 2015).

In pumped-storage plants, pumps are used to deliver water to the upper pool. The same transmission line can also be used for energy generation. In this case, the line serves as a penstock. Generally, between 00:00 and 05:00 hours, the pump is started with the surplus electric current and the water is collected in the pool above (Hadjipaschalis 2009). This pool is usually artificially created. The collected water is supplied to the turbines at the required times and is used to meet the peak energy demand (Sarac 2012).

The energy consumed by such plants will be more than the energy they produce. In these plants, the rate of produced energy/consumed energy is 0.5-0.6 (Connolly *et al.* 2011). However, since peak energy is much more valuable than base energy, such plants are widely used in industrialized countries. There are 120,000 MW installed power plants throughout the world. Countries like USA, Japan, Italy, Germany, France are in the first place in PSHP projects (Horsley and Wrobel 2002, Moghadam and Dunford 2015, Kyriakopoulos and Arabatzis 2016).

The power for the base load is provided by hydropower plants in strong geographical regions with strong water resources and regimes. In other regions, this task is characterized by high-capacity thermal and nuclear power plants (Pérez-díaz *et al.* 2015). The peak load fluctuates largely due to the low load factor. Hydroelectric power plants which can be easily operated and stopped and can adapt to full capacity load in a short time are needed to get ahead of this fluctuates. If the plants do not produce enough energy immediately, the frequency of the system falls, the units are switched off, the electricity is interrupted and therefore many problems arise. In order to avoid or minimize the problems, there is a need for power plants that can meet the reserve load in 20-30 seconds in sudden load increments (Steffen and Weber 2016). Time to reach full capacity of different types of plants is given in Table 1.

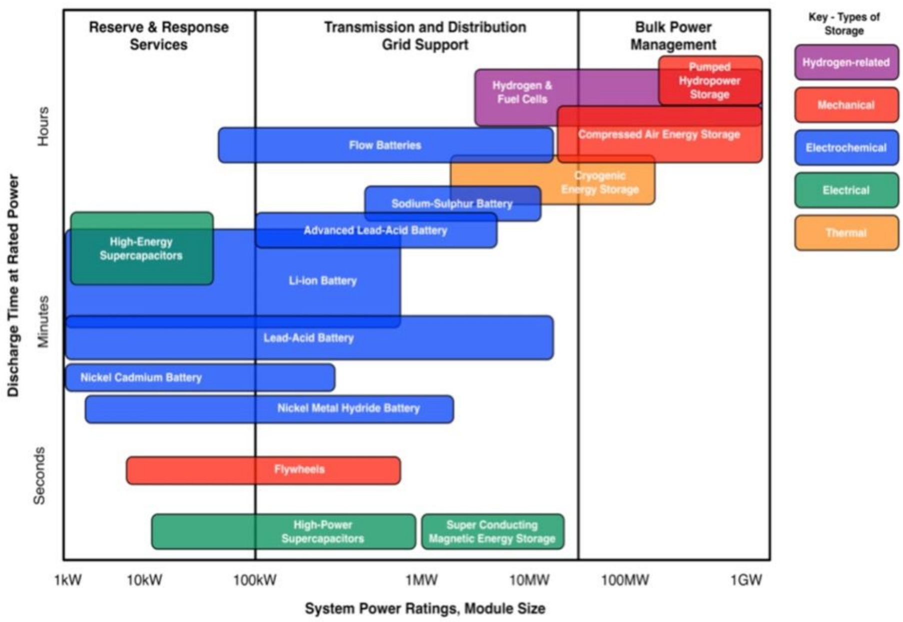

Fig. 1 Energy storage systems (URL-1, 2017)

Table 1 Different power plant types and switching times

Plant type	Time to reach full capacity	Installed power (MW) in Turkey (By the end of 2017)
Hydroelectric power plant	3-5 minutes	27211.7
Pumped storage hydroelectric power plant	3-5 minutes	--
Fuel oil stations	3 hours	303.6
Natural gas power plants	3 hours	23063.7
Cycle power plants	1 hour	5634.8
Coal plants	4 hours	18006.5
Nuclear power plants	5 days	--

As seen in Table 1, only PSHP and HEPPs have the ability to meet peak demand. It is beneficial that these systems are located near large consumption centers, in terms of system safety and efficiency of transmission lines. The water intake structure can be built beside or under the upper reservoir. In PSHP made as an underground power plant, pressure water wells and energy tunnels are mostly used as water transmission structure.

PSHP's regulate daily, weekly or seasonal operating conditions of the interconnected system installed from hydraulic, thermal, nuclear and wind power plants. As with conventional hydroelectric power plants, the system can be shut down when the demand is low and power generation is not needed. Pumped storage systems can be integrated into renewable energy plants with intermittent production such as solar and wind energy, in order to make the generated energy reliable. Long-term supply reliability can be provided by the construction of integrated systems (Ünver *et al.* 2015).

The most important physical issue that affects the economic coherence of pumped-storage power plants is the ratio of the transmission length to drop height between the two reservoirs. It is preferred that this ratio should be small. Generally, large values of 7:1 ratio are rarely encountered. In pumped-storage power plants, the elevation can rise to several hundred meters. Pumped-storage systems which work together with thermal and nuclear power plants operate with the daily regime in systems. However, it can also be established according to the seasonal working regime to provide additional power at seasons when the flow is low (Deb 2000).

In pumped storage plants, reservoirs can be artificial ponds, rivers, natural lakes, dam reservoirs or seas. Artificial ponds can be made impermeable by coating with various materials like asphalt, concrete or geomembrane. The water intake structure can be made to be next to or under the upper reservoir. In PSHPs with an underground power plant, shaft and energy tunnel are used as transmission structure and a connection between central and lower reservoir is provided by tailwater tunnel (Azevedo *et al.* 2010).

PSHPs have some disadvantages as well as positive aspects. These, first investment cost, long payback period, geological location, erosion conditions, visual impact, impact on fisheries, transport problems between reservoirs (Horsley ve Wrobel 2002).

Although the effects of the power plants on the river ecology are not very large within a very broad framework, it is possible to collect them in two general categories, namely the presence of the dam or the reservoir and the effect of the operation of the dam-power plant. The effects of the operation of the hydroelectric power plant are as follows: Change of downstream flow, change of seasonal flows, occurrence of short period fluctuations in flow, changes in very high and very low currents, change of downstream morphology due to changing current scheme, change of downstream water quality due to changing current scheme, the diversity of habitats in coastal and floodplain areas.

The effects of the presence of the dam and the reservoir may be as follows: The dam's position in the valley is not suitable (habitat loss), morphology of the downstream side due to the changing sediment load (erosion), variation of water quality on the downstream side: river temperature, nutrient loading, turbidity, amount of dissolved gas, effects on heavy metal and mineral concentrations, blockage of movements of organisms, and reduction of the biological varieties resulting from the above effects.

Hydroelectric power plants have climatic, hydrological, ecological, socio-economic and cultural effects. The water collection part of a passing hydroelectric power plant generates environmental impact. Climatic effects occur because of the wider surface area of the dam reservoir and increased evaporation. In this way, the air humidity increases and the air movements change. Temperature, precipitation and wind events are different. In this case, the natural vegetation of the above-mentioned agricultural vegetation is a sudden change of aquatic terrestrial beings, and the adaptable species are continuing their lives (Berkun *et al.* 2008).

2. Status of the PSHPs in the world

In recent years, efforts to increase the share of renewable energy sources have brought forward the need for PSHP in the whole world. PSHPs are the best, most convenient, and most used systems known in the world for the storage of excess power or the completion of missing power if the daily share of renewable energy resources is higher or lower than planned. New PSHPs for storing and regenerating the energy generated from wind power plants are being planned and constructed and the installed powers of existing PSHPs are being increased. With the increase in the number of power plants for renewable energy sources, PSHPs work in pump and turbine mode many times a day to eliminate the disruptive effects of these power plants on the grid. This situation prevents the excessive fluctuation of energy prices during the day (Rehman *et al.* 2015).

The first use of PSHPs was in Switzerland in 1890. Since then, technology has developed with applications in Germany and the USA. According to U.S. Energy Information Administration, The capacity of the world's PSHPs has increased by 56% over the past 20 years to 120 GW in 2010. The largest capacity increase has been in China with more than 15 GW. These plants, which have a history of about 125 years, reached about 46 GW of capacity in Europe. According to the data of 2011, it shows that there are 170 PSHP in operation in Europe and 50 projects in construction. Almost 50% of these projects are in Germany, Italy, France and Spain (Denholm *et al.* 2010, Iliadis and Gnansounou 2016, Guittet *et al.* 2016). PSHP potentials of world countries according to 2007 data are shown in Fig. 2 (Cetinkaya 2014). One of the remarkable points in this figure is Japan's leading countries with the installed power of 23600 MW. With Japan's 2010 data, the PSHP installed power is about 27000 MW. Japan has been using PSHP since 1930 to meet 10% of electricity consumption with 25GW installed power (Peltier 2006). 450 thousand population Luxembourg's PSHP potential is 1100 MW. This country has been operating PSHP since 1960's. This installed power is increased today to 1400-1600 MW. Norway's PHES installed power, which supplies 99% of its electricity from hydroelectric sources, is around 1300 MW. Norway is working on increasing this power. The installed power of the PSHP in Iran, which entered operation in 2010, is 1140 MW. The total power of the power plants to be operated and

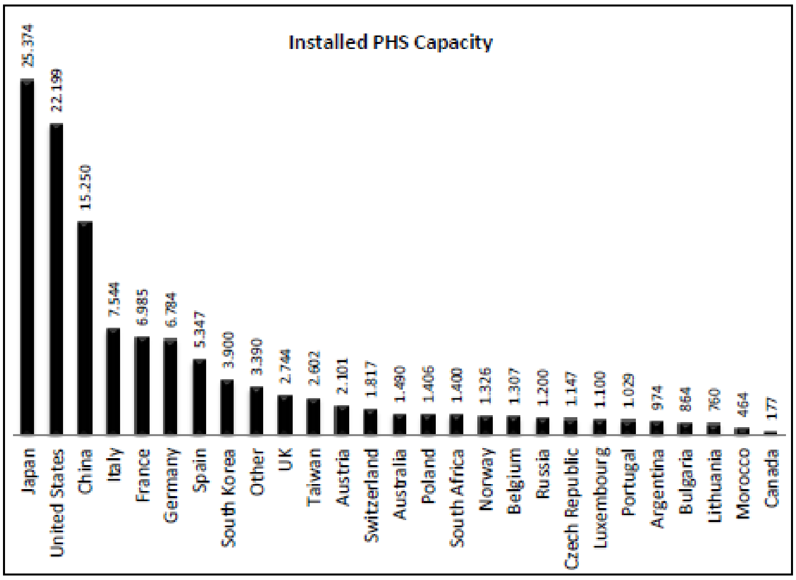

Fig. 2 Distribution of PSHPs in the world by country (Cetinkaya 2014)

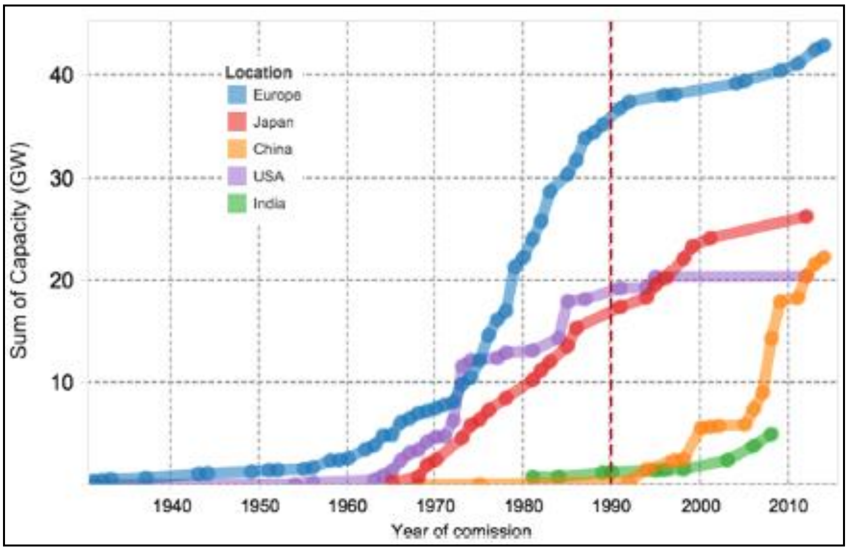

Fig. 3 Historical Cumulative sum of PHES deployment power capacity (GW) (Barbour *et al.* 2016)

operated in China is about 21000 MW (Yang and Jackson 2011).

Since the 1990s in Europe, PSHP has shown a significant increase in parallel to the increased energy demand (Fig. 3). Reisseck (430 MW) in Austria and La Muela (852 MW) in Spain are examples of the latest large power plants. In the US, in contrast to Europe, PSHPs were frequently made between 1960-1990 years. PSHPs have become an alternative energy source, especially during the energy crisis in the 1970s. 742 MW PSHP between 1981 and 1998 and 3450 MW

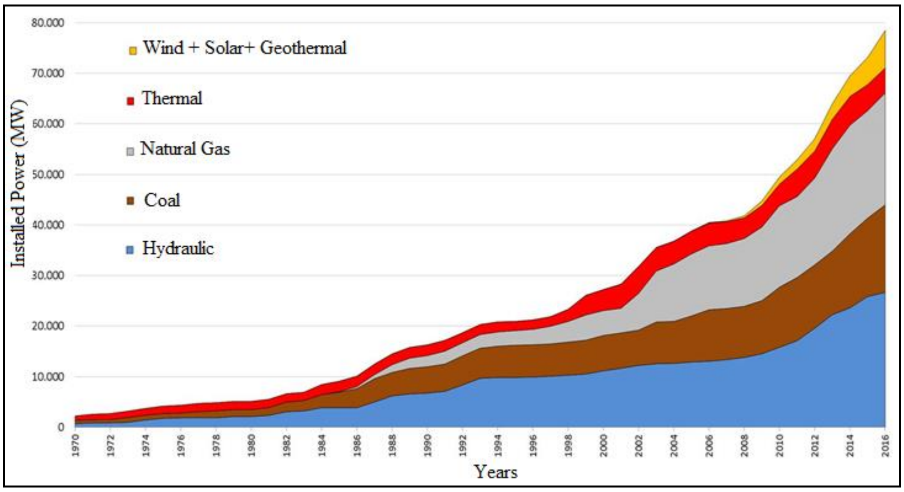

Fig. 4 Change of the installed power of electricity in Turkey according to years (1970-2016) (TEİAŞ 2017)

PSHP between 2003 and 2008 were established in India (Sivakumar *et al.* 2013). Austria and Switzerland are planning to double their capacities to about 5 GW by 2020. Scandinavian countries have met their electricity needs with traditional hydroelectric power plants, while Eastern European countries have not yet started using pumped storage power plants (Zuber 2011).

3. Turkey's energy map

Turkey's electricity consumption has reached 273 billion kWh by the end of 2016 and is expected to be around 450 billion kWh in 2023. By the end of 2016, Turkey's total electricity board power reached 78497 MW. In this total, the share of thermal power plants is 63% (34,656 MW) and the share of renewable fuel plants is 37% (20,724 MW). The amount of electricity produced from the beginning of 2012 to the date of August 31, 2012, is 163 TWh and the sources are based on 70% thermal and 30% renewable energy.

In May 2009, the Electricity Market and Supply Security Strategy Document was prepared and put into effect. In this document, increasing the share of domestic resources in the production of electricity is the primary objective. In line with these goals (YEGM 2017):

- Use the full of hydroelectric potential of 36,000 MW,
- Achieving 20.000 MW installed wind power at wind energy plants.
- 600 MW installed power in geothermal power plants
- Reach 600 MW installed power at solar power plants and
- It aims to increase the share of renewable energy in electricity supply by over 30%.

3.1 Turkey's hydroelectric potential

Turkey has improved 28.7% of its technical hydroelectric potential while this rate is 86% in the USA, 78% in Japan, 72% in Norway and 56% in Canada. The International Energy Agency (IEA) predicts that in 2020, the share of hydroelectric and other renewable energy sources in world

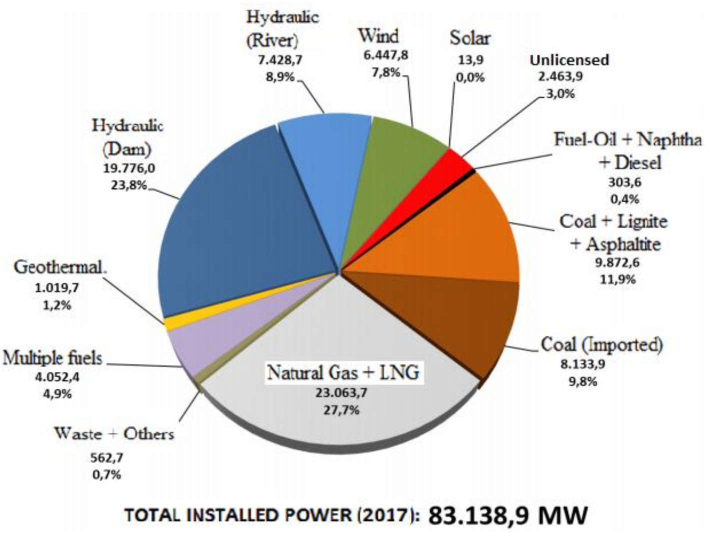

Fig. 5 Installed power for electricity in Turkey (by the end of 2017) (TEİAŞ 2017)

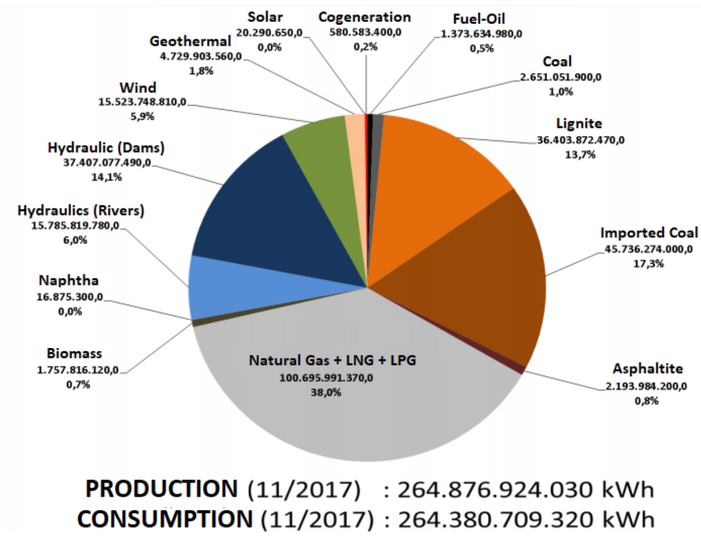

Fig. 6 Electricity generation and consumption in Turkey-By the end of 2017 (TEİAŞ 2017)

energy consumption will increase by 53%. This is interpreted as the use of every powerful hydroelectric potential. The European Union (EU) has enacted the necessary legal arrangements to increase the share of renewable energy in domestic gross energy consumption by 2020 to 20%.

The most important resource within the renewable energy potential in the country is hydraulic resources. In Turkey, the theoretical hydroelectric potential is 433 billion kWh, the technical potential is 216 billion kWh and the economic hydroelectric energy potential is 140 billion kWh / year.

Hydroelectric energy in Turkey supplies 14% of primary energy production and 3.9% of total energy consumption. Turkey’s hydropower potential corresponds to 5% of the world and 16% of

Europe. Turkey is second only to Norway in terms of the magnitude of its hydroelectric potential. 41.3% (19,619 MW / year) of Turkey’s hydraulic potential (47,947 MW / year) is in operation. Use of hydroelectric potential will increase to 58.9% with the 256 hydroelectric power plants with 8,343 MW/ year capacity (Aras 2012). These power plants are under construction. Turkey is currently unable to use its hydroelectric potential economically. In Turkey, climate-dependent hydroelectric production varies from year to year. The Southeastern Anatolia Project is important for hydraulic power. When the project is completed, 19 hydroelectric power plants will generate 7476 MW of installed power and 27 billion kWh / year of electricity.

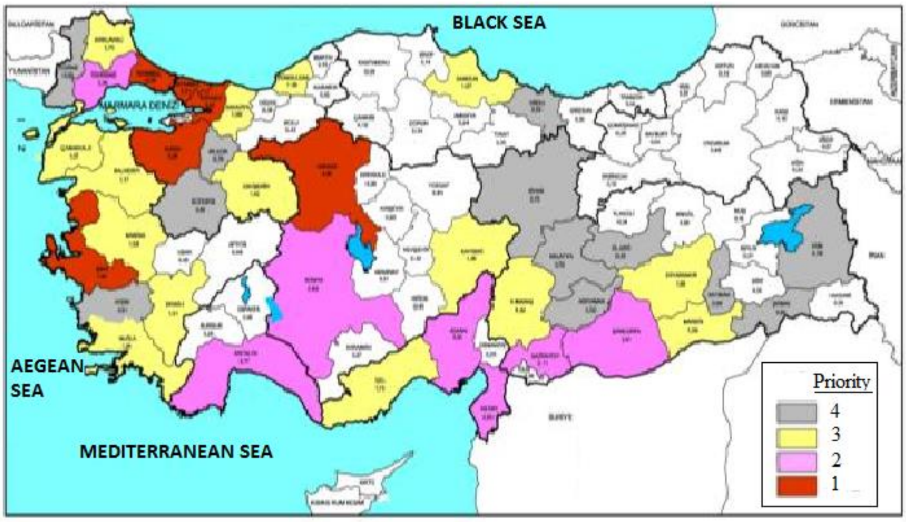

Fig. 7 Priority zones for the planned pumped storage power plants in Turkey

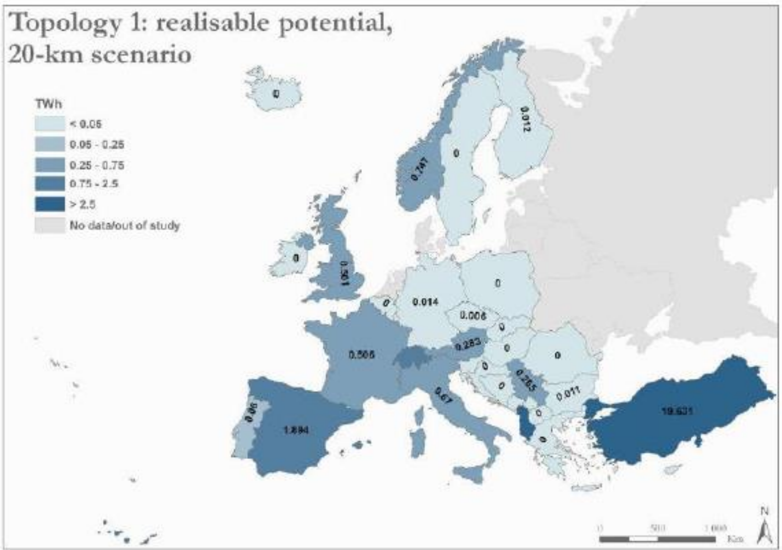

Fig. 8 PSHP potentials can be realized in European countries according to 20 km scenarios (Arantegui 2013)

Table 2 Pump stored power plant projects at the first survey level

PSHP Plant Name	Installed Power (MW)	City	Plant Type	Discharge (m^3/s)	Fall (m)
Gökçekaya	1600	Eskişehir	Integrated into the existing dam lake	193	962
Iznik-I	1500	Bursa	New power plant and lake	687	255
Sarıyar	1000	Ankara	Integrated into the existing dam lake	270	434
Bayramhacılı	1000	Kayseri	Integrated into the existing dam lake	720	161
Hasan Uğurlu	1000	Samsun	Integrated into the existing dam lake	204	570
Adıgüzel	1000	Denizli	Integrated into the existing dam lake	484	242
Burdur	1000	Burdur	New power plant and lake	316	370
Eğridir	1000	Isparta	New power plant and lake	175	672
Kargı	1000	Ankara	Integrated into the existing dam lake	238	496
Karacaören-II	1000	Burdur	Integrated into the existing dam lake	190	615
Yalova	500	Yalova	New power plant and lake	147	400
Yamula	500	Kayseri	Integrated into the existing dam lake	228	260
Oymapınar	500	Antalya	Integrated into the existing dam lake	156	372
Aslantaş	500	Osmaniye	Integrated into the existing dam lake	379	154
Iznik-II	500	Bursa	New power plant and lake	221	263
Demirköprü	300	Manisa	Integrated into the existing dam lake	166	213

3.2 Status of PSHP in Turkey

Preliminary work for the pumped storage plant in Turkey was started by the General Directorate of Electrical Power Resources Survey Administration (EIE) (EIE was closed in 2011 and became General Directorate of Renewable Energy) in 2005. For this purpose, project studies were carried out in various levels and 17 pumped storage hydroelectric power plant reports were prepared. These projects are shown in Table 2.

It was aimed to estimate the capacities and the commissioning times of the pumped storage hydroelectric power plants on the "Optimal Power Generation for Turkey Peak Demand Project" in 2011. This project also examined the peak power generation plan for Turkey between 2010-2030 years. Potential pumped hydroelectric power plant sites for Turkey have been investigated in terms of criteria including intensive areas, geological, topographical and environmental constraints.

Gökçekaya Pumped Storage HEPP (1400 MW) and Altınkaya Pumped Storage HEPP (1800 MW) with their lower reservoirs Gökçekaya Dam were conceptually designed as a result of the gradual elimination. Gökçekaya PSHP feasibility studies officially started on February 12, 2014 (Ü nver *et al.* 2015, YEGM 2017).

Pumped storage hydropower plants are planned to be commissioned in the case of hydroelectric power plants with reserves are insufficient to meet the peak demand. According to the PSHP demand study conducted by EIE, Turkey is primarily divided into 4 regions (Ayder 2015). While these 4 regions are determined, electricity consumption of cities is taken into consideration (Fig. 7).

1. Region Cities: Ankara, Istanbul, Izmir, Bursa, Izmir are the first priority,
2. Region Cities: Tekirdag, Antalya, Konya, Adana, Hatay, Gaziantep and Şanlıurfa are second priority
3. Region Cities: Zonguldak, Samsun, Kayseri, Kahramanmaraş, Diyarbakır, Mardin third priority
4. Region Cities: Edirne, Bilecik, Kütahya, Aydin, Ordu, Sivas, Malatya, Elazığ, Adıyaman, Batman, Şırnak, Van are the fourth priority

The European Commission’s report, published in 2013, assessed the PSHP potential of Turkey and other European countries using the data obtained from the geographic information system according to defined scenario (Arantegui 2013). The first scenario is based on the assumption of two existing ponds and the second scenario is based on the assumption of an existing pond and a new pond. It is evaluated that the distances between the ponds were 1, 2, 3, 5, 10 and 20 km. The minimum fall values are 150 m in the first scenario and 50 and 150 m in the second scenario. In both scenarios the minimum pond capacities are 100000 m3, the minimum distance to the settlements is 500 m, the minimum distance to the existing transport routes is 200 m, the minimum distance to the areas under UNESCO protection is 500 m and the maximum distance to the electricity transmission lines is 20 km. The report states that the highest PSHP capacity in the European countries is Turkey (Fig. 8). In the first scenario, there are 19,631 TWh PSHP capacities in Turkey according to the 20 km scenario. The country with the largest capacity after Turkey is Spain with a value of 1,894 TWh.

3.3 Wind-solar power plants and PSHP

Wind Energy Power Plant (WEPP) installations which have an important potential in renewable energy resources in Turkey are still continuing. According to the General Directorate of Electrical Power Resources Survey and Development Administration (EIE), the economic wind potential of 7 m/s velocity and 50 m height in Turkey is about 50.000 MW (YEGM 2017).

Legal arrangements have been made to connect the wind energy power plant (20000 MW installed power) to the network until 2023. For this potential, licensing procedures for the 11,000 MW project are still in progress. The first wind power plant in Turkey was established in 1998 in Izmir. The total installed power of 172 Wind Power Plants located in Turkey is 5789,39 MW. In 2016, 15669548 kWh of electricity production was made with Wind Power Plants. Today, about 6,3% of the energy consumed is from WEPP.

Some of the 165 wind power plants that connected to the network are under construction so they have not yet accessed the license board. With full capacity commissioning, the 714 MW capacity wind turbine will be commissioned and the installed capacity will reach .487 MW. In addition, there are 80 wind power plants with a total capacity of 1591 MW, which have not been commissioned. In this context, it can be seen that when all of the projects are completed, the power of the Turkish wind power plant will increase to 8078 MW. When all licensed and pre-licensed WEPPs are in operation, the wind power of the country will reach 10.800 MW and 12% of the country's electricity consumption will be covered by wind power plants. In addition, Turkey Energy Market Regulatory Board (EPDK) will accept applications for 3,000 MW wind power plants by the end of 2018. The amount of electricity generated from wind power plants from 1998 to 2017 is given in Fig. 9. The values in the figure are in gigawatt-hours (GWh). The value marked "365" represents the electricity generation value for the 365 days before 16.02.2017. The value marked 2017 represents the electricity production of wind power plants in 2017, between January 1 and February 16. The values in the last two columns are transitory and will be revised at the end of the year.

Solar energy power plants (SEPP) have not been widespread in Turkey yet. However, it seems that it will hold an important place in the coming period. Power changes in the solar power plants will be experienced even if not as much as the power changes in the wind power plants.

Karapinar Renewable Energy Resource Area tender, the biggest solar energy power plant in Turkey, was done by the Ministry of Energy and Natural Resources of Turkey on 20 March 2017. The tender was won jointly by two companies, one of which is the South Korean Firm and the other of the Turkish Firm.

Karapınar YEKA-1 SEPP, which will be Turkey's largest solar energy power plant (1000MW), will be the first application based on the condition of domestication in the energy sector. With an investment of $ 1.3 billion, about 1.7 billion kWh of electricity will be generated annually from the Karapinar Power Plant, and this energy will meet the need for 600 thousand homes. Berat Albayrak, Minister of Energy and Natural Resources of Turkey, describes this project as the "Crazy Project of Turkey". He said he thinks that an energy sector that can compete with the world in Turkey is growing (ETKB 2017a).

There may be problems of power changes in the networks based on the wind and solar energy. The solution to this problem is PSHPs. Therefore, PSHPs are energy regulation facilities that allow renewable energy sources to be found more in the network. When considering the need for PSHPs in Turkey, the existence of WEPPs in the network is sufficient for the construction of PSHPs. Otherwise, it will not be possible to operate the WEPP correctly and it will not be possible to connect the WEPP to the network at a sufficient capacity. Therefore, import-dependent resources will be needed.

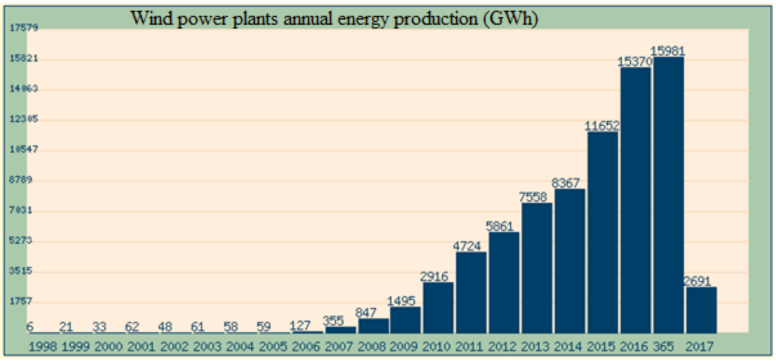

Fig. 9 Wind power plants annual energy production in Turkey

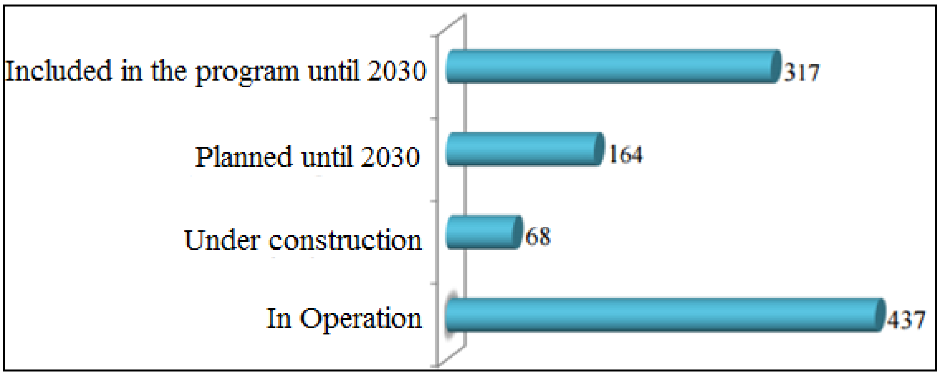

Fig. 10 Number of nuclear power reactors in the world

Table 3 Planned nuclear power plants in Turkey (ETKB 2017d)

Power plant	Approximate cost	Reactor type	Number of units	Installed power	Operating life	Date of operation
Mersin Akkuyu	$20 billion	VVER-1200 (AES-2006)	4 Unit (1200 MW*4)	4800 MW	60 years	2022
Sinop	$20 billion	ATMEA-1	4 Unit (1120 MW*4)	4480 MW	60 years	Not certain
İğneada	Planning phase					

3.4 Nuclear power plants and PSHP

It is predicted that by 2035 there will be an increase of 58% as installed power in nuclear power generation. The United States ranked first in terms of the number of nuclear reactors (104 reactors) and France ranked first in terms of share of nuclear power in electricity generation (78%). It operates 437 nuclear reactors in 31 countries around the world. In addition, 68 nuclear reactors in 14 countries are under construction. By 2030, 164 nuclear reactors are planned to be built and 317 nuclear reactors are included in the country's nuclear programs (Fig. 10). In 15 countries, the share of nuclear power plants in electricity generation is over 20%. The US has begun construction of 3 nuclear reactors as of March 2013. By 2025, England has identified 8 sites for the establishment of new nuclear power plants. The United Arab Emirates has begun construction of 1 nuclear reactor with 1400 MW power and plans to operate it in 2017. 7 countries with nuclear power plants in the world are energy exporters. The Russian Federation has 33 nuclear reactors and supplies 18% of its electricity to nuclear power (ETKB 2017b, c).

PSHPs are not planned solely for the purpose of meeting peak demand. The inability to consume the generated energy is also a problem. One of the solutions in case of insufficient energy is electricity interruption. In the case of energy surplus, it is possible to reduce the power in the power plants or to completely switch off the power plants. When power plants are analyzed for their ability to switch and power up, hydroelectric power plants can reach full power in 3-5 minutes, and PSHPs can reach full power in 15-20 seconds in special situations. Nuclear power plants operate within 3-5 days and power changes are not possible. Hydroelectric power plants can change 50-60% of their power in a minute. Because it is not possible to reduce power in nuclear power plants, they must be stopped completely or the energy produced in nuclear power plants must be consumed. This energy is consumed by PSHPs and water can be stored.

When we look at the relationship between PSHP and Nuclear Power Plant in the world;

-We see that all countries with nuclear power plants except Armenia have PSHP,

- Before the nuclear power plants enter the circuit, the PHESs become active,

-The installed power of the PSHP is close to the installed power of a unit of the nuclear power plant,

-These two plants are connected to each other by transmission lines

Project studies for the installation of two nuclear power plants in Sinop and Mersin Akkuyu in Turkey are continuing (Table 3). There will be a total of 8 units of these facilities with approximately 1200 MW per unit. The Akkuyu Nuclear Power Plant project, which started with an agreement signed between Russia and Turkey in 2010, is expected to cost 20 billion dollars. The Nuclear Power Plant which has 4 reactors aims to meet 10% of Turkey's energy needs. Each reactor will have a power of 1200 MW. The project will have an economic life of 60 years and will be operational in 2022. Akkuyu Nuclear Power Plant Marine Structure construction was begun on 14.04.2015 (Boran *et al.* 2013, Coskun and Tanriover 2016).

In accordance with the agreement signed with Japan on 03.05.2013, four French-Japanese joint venture ATMEA-1 type nuclear reactors are planned to be established in Sinop. The agreement was enacted on 10.04.2015.

4. Discussion: Can seawater pumped hydroelectric storage power plants be made in Turkey?

The seawater PSHP, located on the northern side of Japan's Okinawa island, is the first and only plant in the world with a power of 30 MW and an octagonal top reservoir. Tailwater channel is surrounded by a quad-grooved system to protect the canal outlet from sea waves. Initial survey and material testing studies started in 1981. Okinawa PSHP, which started construction in 1991, was completed in 1999. The octagonal upper reservoir is 25 m deep at 25 m wide and it has an active storage capacity of 564000 m^3. The underground power plant is located in a cavern of 17 m wide, 32 m high and 41 m long. In order to provide stable sea water inlet-discharge and safety, a water hammer structure consisting of prefabricated concrete blocks was applied. (Fujihara *et al.* 1998, Katsaprakakisa *et al.* 2013, Manfrida and Secchi 2014, Katsaprakakis and Christakis 2014, Foley *et al.* 2015)

Seawater PSHP has the following advantages over a standard PSHP in terms of price and system operation.

• No lower reservoir construction is required.

• They can be installed near large scale thermal or nuclear power plants or in residential areas where power demand is increasing.

However, Seawater PSHPs have various problems:

• Seawater stored in the upper reservoir may leak into the soil and/or groundwater,

• Because of the adherence of marine organisms to the water system and turbines, efficiency in power generation and pumping can be reduced,

• Corrosion may occur in metallic materials, at high pressure and high flow rate of sea water,

• It may be difficult to achieve stable power output from the steady inlet through the discharge of seawater against high ripples,

• It may be the effect on surrounding plants, animals and other biological systems as a result of the wind from the upper reservoir,

• Corals and other marine organisms living near the exit of the power plant can be affected (Deane *et al.* 2010, McLean and Kearney 2014, Yang 2016)

Parallel to the development of anti-corrosion engineering, it is expected that the obstacles in front of seawater PSHPs will disappear and the demand for construction will increase. Seawater PSHPs can be an important energy investment for Turkey, where the three sides are surrounded by seas. There are coastal areas with high hills that are not used for tourism purposes. Seawater PSHPs, for which there is no preliminary work, may come to a head for Turkey in the near future.

5. Conclusions

The impact of renewable energy sources on the market and the environmental impact of fossil fuel and nuclear power are the most important factors for the development of PSHP. PSHPs are expected to grow by 7.5 GW (60%) over the next 5 years. A large part of this growth is expected in China and about 20% in Europe.

The economic life of PSHPs is low, the operating and maintenance costs are low, they do not lead to environmental pollution, the energy costs are very low (no fuel costs), they do not create greenhouse gas emissions and they are compatible with the environment. When PSHP is built on the edge of a lake or sea, there is no negative effect on the environment. In addition, the ponds to be constructed are also suitable for multi purposes: irrigation, flood control, drinking and utility water management, fishery and sediment control.

Hydroelectric power plants can reach full power in 3-5 minutes, PHESs can go full load in 15-20 seconds in special situations. PSHPs store water in a reservoir using excess energy generated by nuclear power plants. This stored water can actually be thought of as the storage of electricity. Since there is no power reduction in nuclear power plants, it is the most logical thing to store excess energy in this way. After the nuclear power plants become operational, the PSHPs are where the sudden electricity needs will be met. PSHPs are very necessary in this regard for the country that has similar problems in the past.

There was a major electricity interruption in Turkey on 31 March 2015. The reason for this interruption is that a 1000-1200 MW power plant is out of order. They had not found a source to meet this power. After the nuclear reactor has been commissioned in Turkey, a possible reactor failure on the Sinop or Akkuyu Nuclear Power Plants will cause such power failures. In order to avoid such troubles, PSHPs must be in conjunction with nuclear power plants.

When the topic is viewed by wind energy, if the 20,000 MW wind power plant in the network is targeted until 2023, the initiated PSHP studies should be continued without delay.

Considering the targets of Turkey-2023 in terms of hydroelectric power plants, it should not be overlooked that HEPPs will be inadequate in meeting the peak demand and fulfilling their duties in the system. Complementary PSHPs must be made absolutely.

Because the southern and western coasts of Turkey are mostly used for tourism purposes, these coasts may not be suitable for Seawater PSHPs. But the North Coasts of the Turkey may be appropriate for this job. A large part of the Black Sea coast is not being used for tourism purposes and this region which is very close to the shore is very suitable for seawater PSHPs. Especially Middle Black Sea Region has high and flat lands where close to the sea. If these areas are evaluated as Seawater PSHP, huge gains can be achieved in the country's economy.

Turkey has plans to reduce the use of natural gas in energy production from 50% to 30% for

2023 targets. To achieve this goal, PSHPs must be deployed as soon as possible in order to meet the energy needs of 450-500 billion kWh.

References

Arántegui, R.L., Corsatea, T. and Suomalainen, K. (2013), *JRC Wind Status Report: Technology, Market and Economic Aspects of Wind Energy in Europe-JRC77895*, Joint Research Centre of the European Commission.

Aras, E. (2012), "The effects of small scale hydroelectric power plants located in the eastern black sea basin in Turkey", *Energy Explor. Exploit.*, **30**(6), 999-1015.

Ayder, E. (2015), *Pumped Storage Hydroelectric Power Plants*, Technical Report, Istanbul Technical University, Istanbul, Turkey.

Azevedo, K., Demars, R., Gomez, T. and Kumar, P. (2010), *Pumped Storage Hydroelectricity HW3: Energy-Based Systems Modeling in Modelica ME6105*, <http://www.srl.gatech.edu/>.

Barbour, E., Wilson, G., Radcliff, J., Din, Y. and Li, Y. (2016), "A review of pumped hydroenergy storage development insignificant International electricity markets", *Renew. Sust. Energy Rev.*, **61**, 421-432.

Berkun, M., Aras, E. ve Koç, T. (2008), "Barajların ve hidroelektrik santrallerin nehir ekolojisi üzerinde oluşturduğu etkiler", *Türkiye Mühendislik Haberleri*, **452**, 41-48 (in Turkish).

Boran, F.E., Etöz, M. and Dizdar, E. (2013), "Is nuclear power an optimal option for electricity generation in Turkey?", *Energy Source Part B Econ. Plan. Policy*, **8**(4), 382-390.

Cetinkaya, S. (2014), "Capacity determination of pumped storage projects using market electricity prices", M.Sc. Dissertation, Middle East Technical University, Ankara, Turkey.

Connolly, D., Lund, H., Finn, P., Mathiesen, B.V. and Leahy M. (2011), "Practical operation strategies for pumped hydroelectric energy storage (PHES) utilising electricity price arbitrage", *Energy Policy*, **39**(7), 4189-4196.

Coskun, M.B. and Tanriover, B. (2016), "An investigaton on nuclear energy policy in Turkey and public perception, *EPJ Web Conf.*, **128**, 1-5.

Deane, J.P., Gallachóir, B.Ó. and McKeogh, E.J. (2010), "Techno-economic review of existing and new pumped hydro energy storage plant", *Renew. Sust. Energy Rev.*, **14**(4), 1293-1302.

Deb, R. (2000), "Operation hydroelectric plants and pumped storage units in a competitive environment", *Elect. J.*, **13**(3), 24-32.

Denholm, P., Ela, E., Kirby, B. and Milligan, M. (2010), *The Role of Energy Storage with Renewable Electricity Generation*, Technical report NREL/TP-6A2-47187, National Renewable Energy Laboratory, Golden, Colorado, U.S.A.

DSI (2017), *General Directorate of State Hydraulics Works*, <http://www.dsi.gov.tr/>.

Dunn, B., Kamath, H. and Tarascon, J.M. (2011), "Electrical energy storage for the grid: A battery of choices", *Science*, **334**(6058), 928-935

ETKB (2017a), *Ministry of Energy and Natural Resources of Turkey*, <http://www.enerji.gov.tr/tr-TR/BakanlikHaberleri>.

ETKB (2017b), *Ministry of Energy and Natural Resources of Turkey*, Nükleer Güç Santralleri Ve Türkiye, Nükleer Enerji Proje Uygulama Daire Başkanlığı Yayın No.2.

ETKB (2017c), *Ministry of Energy and Natural Resources of Turkey*, Türkiye'nin Nükleer Santral Projeleri: Soru-Cevap, Nükleer Enerji Proje Uygulama Dairesi Yayın Serisi, 11 Ocak 2016.

ETKB (2017d), Ministry of Energy and Natural Resources of Turkey, <http://www.enerji.gov.tr/tr-TR/Sayfalar/Ulkemizde-Planlanan-Nukleer-Santral-Projeleri>.

Foley, A.M., Leahy, P.G., Li, K., McKeogh, E.J. and Morrison, A.P. (2015), "A long-term analysis of pumped hydro storage to firm wind power", *Appl. Energy*, **137**, 638-648.

Fujihara, T., Imano, H. and Oshima, K. (1998), "Development of pump turbine for seawater pumped storage power plant", *Hitachi Rev.*, **47**(5), 199-202.

Guittet, M., Capezzali, M., Gaudard, L., Romerio, F., Vuille, F. and Avellan, F. (2016), “Study of the drivers and asset management of pumped-storage power plants historical and geographical perspective”, *Energy*, **111**, 560-579.

Hadjipaschalis, I., Poullikkas, A. and Efthimiou, V. (2009), “Overview of current and future energy storage technologies for electric power applications”, *Renew. Sust. Energy Rev.*, **13**(6-7), 1513-1522.

Horsley, A. and Wrobel, A.J. (2002), “Efficiency rents of pumped-storage plants and their uses for operation and investment decisions”, *J. Econ. Dyn. Control*, **27**(1), 109-142.

Iliadis, N.A. and Gnansounou, E. (2016), “Development of the methodology for the evaluation of a hydro-pumped storage power plant: Swiss case study”, *Energy Strat. Rev.*, **9**, 8-17.

Katsaprakakis, D.A. and Christakis, D.G. (2014), “Seawater pumped storage systems and offshore wind parks in islands with low onshore wind potential. A fundamental case study”, *Energy*, **66**, 470-486.

Katsaprakakis, D.A., Christakis, D.G., Stefanakis, I., Spanos, P. and Stefanakis, N. (2013), “Technical details regarding the design, the construction and the operation of seawater pumped storage systems”, *Energy*, **55**, 619-630.

Kyriakopoulos, G.L. and Arabatzis, G. (2016), “Electrical energy storage systems in electricity generation: Energy policies, innovative technologies, and regulatory regimes”, *Renew. Sust. Energy Rev.*, **56**, 1044-1067.

Manfrida, G. and Secchi, R. (2014), “Seawater pumping as an electricity storage solution for photovoltaic energy systems”, *Energy*, **69**, 470-484.

McLean, E. and Kearney, D. (2014), “An evaluation of seawater pumped hydro storage for regulating the export of renewable energy to the national grid”, *Energy Proc.*, **46**, 152-160.

Moghadam, M.F. and Dunford, W.G. (2015), “Demand side storage to increase hydroelectric generation efficiency”, *IEEE Trans. Sust. Energy*, **6**(2), 313-324.

Peltier, R. (2006), “Kanagawa hydropower plant, Japan”, *Power*, **150**(6), 54-54.

Pérez-díaz, J.I., Chazarra, M., García-González, J., Cavazzini, G. and Stoppato A. (2015), “Trends and challenges in the operation of pumped-storage hydropower plants”, *Renew. Sust. Energy Rev.*, **44**, 767-784.

Rehman, S., Al-Hadhrami, L.M. and Alam, M.M. (2015), “Pumped hydro energy storage system: A technological review”, *Renew. Sust. Energy Rev.*, **44**, 586-598.

Sarac, M. (2012), “Energy storage systems and pump storage hydroelectric power plants”, *Proceedings of the Türkiye Energy Congress*, Ankara, Turkey, November

Sivakumar, N., Das, D., Padhy, N.P., Kumar, A.S. and Bisoyi, N. (2013), “Status of pumped hydro-storages chemes and its future in India”, *Renew. Sust. Energy Rev.*, **19**, 208-213.

Steffen, B. and Weber, C. (2016), “Optimal operation of pumped-hydro storage plants with continuous time-varying power prices”, *Eur. J. Oper. Res.*, **252**(1), 308-321.

TEİAŞ (2017), *Turkey Electricity Transmission Company*, <http://www.teias.gov.tr/>.

Ünver, Ü., Bilgin, H. and Güven, A. (2015), “Pumped storage hydroelectric systems”, *Mühendis ve Makina*, **56**, 663, 57-64.

URL-1 (2017), <http://energystoragesense.com/energy-storage-technologies/>.

Wood, A.J. and Wollenberg, B.F. (1996), “Power Generation Operation and Control”, Wiley-Interscience, New York, U.S.A.

Yang, C.J. (2016), “Chapter 2-Pumped hydroelectric storage”, *Storing Energy*, **2**, 25-38

Yang, C.J. and Jackson, R.B. (2011), “Opportunities and barriers to pumped-hydroenergysto-rage in the United States”, *Renew. Sust. Energy Rev.*, **15**(1), 839-844.

YEGM (2017), *General Directorate of Renewable Energy*, <http://www.eie.gov.tr/>.

Zuber, M. (2011), “Renaissance for pumped storage in Europe”, *Hydro Rev. Worldwide*, **19**, 3.

CC