Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 5(1), June 2016, pp 359-369
ISSN 2147-3471 © 2016

Hydropower as clean and renewable energy source for electricity generation

K.Kaygusuz[1,a]

[1] Karadeniz Technical University, Chemistry, Trabzon, Turkey.

Accepted 08 Feb 2016

Abstract
Hydropower is a mature and fairly simple technology: the potential energy of a water source is converted into kinetic energy that spins a turbine driving an electricity generator. The kinetic energy of falling water was used for grinding wheat more than 2 000 years ago. Since late 19^{th} century, hydropower has been used to generate electricity. At present, about 160 countries worldwide use hydropower technology for power generation. With a total installed capacity of 1 060 GW_e, hydropower generates approximately 3 500 TWh per year, equivalent to 15.8% of global electricity generation. Hydropower plants provide at least 50% of the total electricity supply in more than 35 countries. They also provide other key services, such as flood control, irrigation and potable water reservoirs. Turkey's energy market is going through a rapid change. Over the last decade, power demand has grown by 70%; this is a trend that is expected to continue. Turkish government is compelled to make critical decisions: on the one hand it has to meet the power demand, on the other it has to minimize dependency on energy imports. As of the end of 2015, Turkey had 530 operational hydropower plants with a total capacity of almost 26,000 MW. This corresponds to 34% of total capacity. Within the first two months of 2016, 2 more hydropower plants came online with a capacity of around 340 MW. The share of hydro in power generation capacity went up by 1% during the first five months of the year reaching 35% from its previous 34% level in 2015.

Keywords: Electricity generation; renewable energy; hydropower; Turkey

1. Introduction

Hydropower is a mature and fairly simple technology: the potential energy of a water source is converted into kinetic energy that spins a turbine driving an electricity generator [1, 2]. The kinetic energy of falling water was used for grinding wheat more than 2 000 years ago [3-5]. Since late 19th century, hydropower has been used to generate electricity [6-9]. At present, about 160 countries worldwide use hydropower technology for power generation [10-13]. With a total installed capacity of 1 060 GWe, hydropower generates approximately 3 500 TWh per year, equivalent to 15.8% of global electricity generation (Table 1). Hydropower plants provide at least 50% of the total electricity supply in more than 35 countries [14-16]. Table 2 shows top ten hydropower producer. They also provide other key services, such as flood control, irrigation and potable water reservoirs. Hydropower is an extremely flexible electricity generation technology [17]. Hydro reservoirs provide built-in energy storage that enables a quick response to electricity demand fluctuations across the grid, optimization of electricity production and compensation for loss of power from other sources [18-23].

The development and construction of hydropower plants requires a long lead time, especially for the dam-with-reservoirs configuration [5, 10, 12]. The investment costs for new hydro plants, including site preparation and civil engineering work, depend significantly upon the specific site. Investment costs include planning and feasibility assessments, environmental impact analyses and licensing. Recent investment cost figures for large hydropower plants ranged from USD 1 050/ kW to USD 7 650/kW [16]. For small hydro projects, the range varies even more, from USD 1 000/kW to USD 10 000/kW. Hydropower production depends upon rainfall in the upstream catchment area. Reserve capacity may be needed to compensate for periods of low rainfall and this may increase the investment cost [5, 10, 19].

Globally, technical hydropower potential is estimated at around 15 000 TWh [5]. In the European region, a significant fraction of the economically viable hydropower potential is already being exploited,

[a] Corresponding author;
Phone: +90-462-377-2591, Email: kamik@ktu.edu.tr

although about 50% of the technical potential is still untapped. The most untapped region is Africa, where 92% of the total potential has not yet been developed. High investment costs and long payback periods are also major characteristics of hydropower development [10, 16]. Other barriers, such as stringent environmental standards for water management, can also hamper hydropower development. Hydropower has been a mainstream renewable energy technology for decades, and currently represents about 16% of global electricity generation. However, while hydropower has been a steady constant in the energy supply scene, the energy mix as a whole is undergoing rapid and dramatic change. In the present study, we discussed the hydropower as clean and renewable energy sources detailed.

Table 1. Global hydropower market in 2014

Region	Cumulated Installed Capacity (GW)	Installed Capacity (GW)	Estimated Electricity Generation (TWh/yr)
North America	173.4	0.9	708.2
South America	147.9	1.4	675.8
Europe	186.0	1.0	576.8
Asia	509.6	35.5	1694.1
Oceania	13.4	0.0	37.4
Africa	28.0	0.2	122.5
World Total	1059	39.0	3815

Table 2. Top ten hydropower producer in 2010

Country	Hydroelectricity (TWh)	Share of electricity Generation (%)
China	694	14.8
Brazil	403	80.2
Canada	376	62.0
USA	328	7.6
Russia	165	15.7
India	132	13.1
Norway	122	95.3
Japan	85	7.8
Venezuela	84	68
Sweden	67	42.2

2. Technical highlights

2.1. Process and Technolog

Hydropower is a mature technology that is currently used in about 160 countries to produce cost-effective, low-carbon, renewable electricity [4]. With a total capacity of 1 209 GWe, hydro generates about 3 500 TWh per year, equivalent to 15.8% of 2011 global electricity generation [5]. Hydropower plants provide at least 50% of the total electricity supply in more than 35 countries. They also provide other key services, such as flood control and irrigation. Hydropower plants consist of two basic configurations: the one based on dams with reservoirs and the other run-of-the-river plants [10]. The dam scheme can be sub-divided into small dams with night-and-day regulation, large dams with seasonal storage and pumped storage reversible plants for energy storage and night-and-day regulation, according to electricity demand. Small-scale hydropower is often used for distributed generation applications as an alternative to, or in combination with, diesel generators or other small-scale power plants for rural applications [4, 5, 12, 13, 16].

2.2. Performance and costs

Hydropower is a cost-effective electricity source [4]. It offers high efficiency and low operating and generation costs, though its upfront investment cost is relatively high. One of the advantages of hydropower is its operational flexibility. The capacity factor of hydropower plants varies between 23%-95%, depending on targets and the service of the specific power plant. The investment costs for large hydropower plants (>10 MWe) range from $ 1 000-7 500/kWe and are very site-sensitive [19]. The investment costs of small (1–10 MWe) and very small hydropower plants (VSHP) (≤1 MWe) may range from $1 000-4 000/ kWe and $ 3 400-10 000/kWe, respectively. Operation and maintenance (O&M) costs of hydropower plants are typically between 1%-4% of annual investment costs. The levelised cost of electricity (LCOE) typically ranges from USD 20-190/MWh for large hydropower plants, from USD 20-100/MWh for small plants and USD 270/ MWh or more for very small plants [4, 10, 19].

2.3. Potential and barriers

The global technical hydropower potential is estimated at around 15 000 TWh per year. Half of this total potential is available in Asia and 20% in Latin America. Large untapped technical potential is still available in Africa, Latin America and Asia, while in Europe it is only around half of the total technical potential. However, large hydropower projects can encounter social opposition because of their impact on water availability, ecosystems and the environment, and the need to relocate populations that may be affected by the project. Major hydropower issues include public acceptance, high initial investment costs and long payback periods, long approval and construction cycles, and long lead times to obtain or renew concession rights and grid connections [1, 4, 5, 16]. Environmental protection is also a key issue that deserves consideration. These challenges are likely to limit the implementable hydropower potentiall.

3. Process and technology

Hydropower is a mature technology. Since the late 19th century, the kinetic energy of falling water has been used to produce electricity in hydropower plants. Today, hydropower is used in about 160 countries worldwide. With a total installed capacity of 1 060 GWe (19.4% of the world's electric capacity) in 2011, hydropower generated approximately 3 500 TWh per year, equivalent to 15.8% of all global electricity generation. Hydropower plants provide at least 50% of the total electricity supply in more than 35 countries [3, 5, 7, 13, 16].

The world's largest hydropower electricity producer is China, which generated about 700 TWh in 2010, followed by Brazil, Canada and the United States. The hydropower capacity installed in these four countries alone generates half of the world's total hydropower electricity. Hydropower also provides other key services, such as flood control, irrigation and potable water reservoirs [4, 5]. Hydropower is an extremely flexible electricity generation technology. Hydro reservoirs provide built-in energy storage that enables a quick response to electricity demand fluctuations across the grid, optimization of electricity production and compensation for power losses from other sources [4, 5, 13, 16].

Hydropower plants have two basic configurations: dams with reservoirs and run-of-river plants, with no reservoirs. The dam scheme can be sub-divided into small dams with night-and-day regulation, large dams with seasonal storage and pumped storage reversible plants for energy storage and night-and-day regulation, according to fluctuating electricity demands [4]. Small-scale hydropower is normally designed to run in-river [23]. This is an environmentally friendlier option because it does not significantly interfere with the river's natural flow. Small-scale hydro is often used for distributed generation applications to provide electricity to rural populations [14, 16, 18, 20].

A generic hydro plant scheme based on a dam and reservoirs is shown in Figure 1. The scheme is quite simple: water released from the reservoir at the inlet dam on higher side that has a potential energy flows through a pipe or tunnel to a turbine [10]. The water's potential energy is converted to kinetic energy and spins the blade of a turbine, which activates a generator to produce electricity [5]. One of the advantages of hydropower is its operational flexibility. In other words, the capacity factor of hydropower varies depending on the specific plant and its services between 23%-95% [5, 10, 16].

Figure 2 shows a depiction of different types of small-scale hydropower plants by head height, discharge and capacity [10]. A large flow-rate and small head characterizes large run-of-the-river plants equipped with Kaplan turbines, a propeller-type water turbine with adjustable blades. By contrast, low discharge and high head features are typical of mountain-based dam installations driven by Pelton turbines, in which water passes through nozzles and strikes spoon-shaped buckets arranged on the periphery of a wheel. Intermediate flow-rates and head heights are usually equipped with Francis turbines, in which the water comes to the turbine under immense pressure and the energy is extracted from the water by the turbine blades [5, 10, 16].

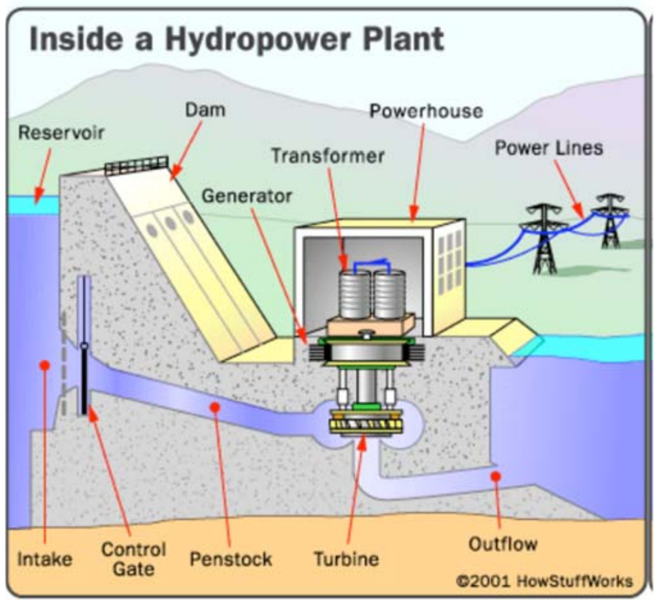

Figure 1. A schematic of hydropower plant.

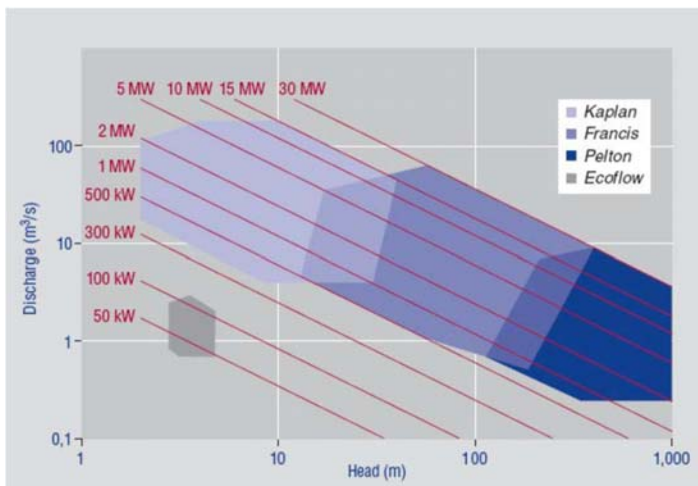

Figure 2: Types of small hydropower by head height, discharge, or capacity (IEA, 2010).

Pumped storage plants consist of two or more natural dams reservoirs at different elevations. When electricity generation exceeds grid demand, the energy is stored by pumping water from the lower to the higher reservoir [10]. During peak electricity demand periods, water flows back to the lower reservoir through the turbine, thus generating electricity [13]. In these kinds of plants, reversible Francis devices are used both for pumping water and for generating electricity [16]. The energy conversion efficiency of recently pumped hydropower is over 80%. Pumped storage plants can be combined with intermittent renewable electricity sources. They can also serve as an optimal complement to nuclear-based electricity designed for base-load operation, but with only limited capability to adapt to daily and seasonal load fluctuations [16].

Currently, pumped storage capacity worldwide amounts to about 140 GWe. In the European Union, there are 45 GWe of pumped storage capacity [16]. In Asia, the leading pumped hydropower countries are Japan (30 GWe) and China (24 GWe). The United States also has a significant volume of the pumped storage capacity (20 GWe). Hydropower generation plants do not produce CO2 emissions, other than those associated with materials and construction. However, there are concerns about GHG emissions from reservoirs, both from the decomposition of organic material inundated initially, and organic material from further upstream, deposited throughout the lifetime of a large hydropower scheme [16].

Many hydropower plants were built in the early decades of the 20th century and are still in operation, although most of them have undergone rehabilitation, modernization or re-development. The era of really large hydropower projects began in the 1930s in North America and has since spread worldwide. Today’s major projects under construction are located in China, Brazil, India, Myanmar, Ethiopia and Pakistan. Significant potential remains around the world, both for developing a large number of small hydropower projects and for upgrading existing power plants and dams. Current hydropower growth options can be categorized into three types [10, 16]:

- Large hydropower (>10 MWe);
- Small hydropower (≤10 MWe)
- Mini-hydro (100 kWe to 1 MWe)

The market for large hydropower plants is dominated by a few manufacturers of large equipment and a number of suppliers of auxiliary components and systems. Over the past decades, no major breakthroughs have occurred in the basic machinery; however, computer technology has led to significant improvements in many areas [16]. Manufacturers and suppliers need to invest significant resources into research and development (R&D) to meet advances in technology and deal with market competition. Also, large hydropower plants may have a considerable impact on environmental and socioeconomic aspects at the regional level. Therefore, the link between industry, R&D and policy institutions is important to the development of this energy sector. Throughout all development stages, the stakeholder involvement is crucial. Unlike large plants, small-scale hydropower installations comprise a huge variety of designs, layouts, equipment and materials. Therefore, state-of-the-art technologies, knowledge and design experience are key to fully exploiting local resources at competitive costs and without significant adverse environmental impact [16, 18, 20, 22].

Upgrading offers a way to maximize the energy produced from existing hydropower plants and may offer a less expensive opportunity to increase hydropower production. Gains of between 5%-10% are realistic, cost-effective targets for most hydropower plants. Potential gains could also be higher at locations where non-generating dams are available. Investment in repowering projects, however, involves risks, both technical and legal. As a result, significant potential is left untapped. However, today’s technologies allow for an accurate analysis of geology and hydrology, as well as precise assessments of potential gains [16].

4. Hydropower generation costs

Existing hydropower is one of the most cost-effective methods to generate electricity. Most plants were built a long time ago and the initial investment for dams and hydro-geological infra-structure has meanwhile been fully amortized. After this amortization, the remaining costs have to do with operation and O&M, and the possible replacement of machinery components after several decades of operation (Figure 3). Small hydropower plants may be operated for around 50 years without substantial replacement costs [10].

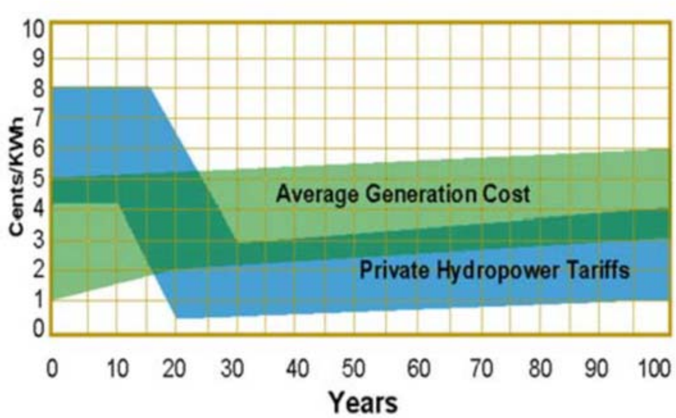

Figure 3. Hydropower generation costs and investment amortization.

Hydropower generating facilities need long lead times for their development and construction. The investment costs for new hydropower installations, which include the civil engineering works and electro-mechanical components, are highly site-dependent [4, 5]. Civil engineering works include dams and reservoir construction, tunneling and canal construction, powerhouse construction, site access infrastructure and grid connections, the cost of which depends largely on local labor and materials costs. Contract and other developer costs, such as planning and feasibility assessments, environmental impact analyses, licensing, environmental protection, and water quality monitoring are also needed. The electro-mechanical components include turbines, generators, transformers, cabling and control systems. The cost of these components, while reflecting international market prices, does not have much impact on final investment costs [10, 13, 16].
The total installed cost for a large-scale hydropower project typically ranges from a low of $ 1 000/kW up to around $ 3 500/kW. However, exceptions abound. If the site is far from the transmission line and without access and infrastructure, the cost may be significantly higher than $ 3 500/kW. A recent study shows the total installed cost of large-scale hydropower facilities with storage range from as low as $ 1 050/kW to as high as $ 7 650/kW. The investment cost of small-scale hydropower plants of 1-10 MW range from less than $ 1 000/kW to about $ 4 000/kW. However, the cost of very small-scale hydropower plants of less than 1 MW is significantly higher compared to larger plants.

A recent studies show that the typical ranges of levelized cost of electricity (LCOE) are from $ 0.02-0.19/kWh for large hydropower projects, from $ 0.02- 0.10/KWh for small-scale hydropower and $ 0.27/kWh or more for very small-scale hydropower plants. The cost of pumped storage systems also depends strongly on the site configuration. The operational service of pumped hydropower plants is also a key parameter for assessing overall operating costs. No cost reduction is expected from technology learning since pumped hydro is a mature technology and is virtually the same in all hydropower plants. The current capital cost of new pumped hydro facilities is estimated to range between $ 2 000–4 000/kW.

5. Global trends

In 2014, 3,081 MW added of which 1,995 MW was in Canada and 760 MW in Mexico. New government incentives introduced in the USA to add hydropower to existing reservoirs. Costa Rica operated on 100% renewable energy for 75 days, powered largely by hydropower. The 1,800 km SIEPAC transmission line reaching from Guatemala to Panama was completed in October 2014. In South America, total 4,979 MW added in 2014 and 3,312 MW commissioned in Brazil. On the other hand, 875 MW commissioned in Colombia, including the 820 MW Sogamoso project, which will meet about 8% of the country's electricity demand. Development continuing on the lower Caroni cascade in Venezuela, with the commissioning the 'Manuel Piar' project (2,300 MW) expected in early 2016 [5, 16].

In Africa, total 128 MW added in 2014. Ethiopia completed construction of the 1,870 MW Gilgel Gibe III in 2015, and is well into construction of the Grand Renaissance project, which will bring a further 6,000 MW to the region in the coming years. On the other hand, Burundi, Rwanda and Tanzania signed an agreement to build the 80 MW Rusumo Falls hydropower plant, with output shared equally between the three countries [16].

In Europe, total 405 MW capacity added in 2014. Pumped storage remains a focus of activity, with 8,600 MW planned or under construction, including 2,500 MW expected in the Swiss Alps by 2017. In South and Central Asia, total 4,073 MW added in 2014. The policy environment is shifting in support of more hydropower in India, with the government considering market incentives and encouraging private sector investment. Russia added 1,168 MW of new capacity to the mix and completed the restoration of the 6,400 MW Sayano station [5-10].

In East Asia and Pacific region, total 24,724 MW capacity added in 2014, 90% of which is in China. China leads global hydropower development, with 21,850 MW installed in 2014, including the final 4,620 MW of the 13,860 MW Xiluodu project – the third-largest hydropower plant in the world [5]. Malaysia commissioned 836 MW in the state of Sarawak, including the final two 300 MW turbines at Bakun (2,400 MW) and the first of four 236 MW turbines at Murum (944 MW), while also announcing plans to begin construction on the 1,285 MW Baleh project in 2016 [16].

6. Hydropower and climate change

The energy supply sector is the largest emitter of greenhouse gases (GHG) globally, and is already under increased pressure to decarbonize [5]. In light of this, it is useful to understand hydropower's relationship to climate change in terms of contributions, uncertainties, risks, opportunities and strategies [4]. As the energy sector accounts for 35% of global emissions, the options for slowing climate change will continue to be heavily focused on this sector. Decarbonizing the electricity system is possible by improving energy efficiency of the system and through increased use of renewable energies in place of fossil fuel generation is offsetting the use of fossil fuels with cleaner technologies [5, 10, 13].

It is here that hydropower has a two-pronged role to play: it is both a renewable energy that can directly offset fossil fuel use when it is deployed in place of fossil fuel generation, and it is also an energy storage technology enable a greater penetration of more variable forms of renewable energy such as wind and solar power [11]. This is why, as the world's leading renewable energy technology in terms of both installed capacity (1,036 GW) and total generation (3,900 TWh/year) in 2014, hydropower is recognized as a clean, renewable, low-carbon energy technology. It is recognized as a tool for mitigating climate change by offsetting the use of fossil fuels [4, 5, 10]. Hydropower's generally low emissions of 28 g CO2e/kWh are significantly lower than other electricity generation technologies, with mean values ranging from 490 g CO2e/kWh for gas-fired generation up to 820 g CO2e/kWh for coal-fired generation [4]. Given the current uncertainties around the GHG impact of a specific reservoir, the UNFCCC has produced an interim methodology for ascribing emissions, based on the reservoir area and the capacity of the hydropower station. This 'power density' approach creates three categories and allocates an emissions profile to each of the three categories allowed by the Clean Development Mechanism (CDM) as given in Table 3 [4].

In the absence of a more refined methodology, these rates of emissions from hydropower are used for calculating the GHG offset that hydroelectricity provides. While it is clear that hydropower gains credit from this, it is also apparent that some power density approach largely over-ascribes emissions from hydropower, in relation to the average emissions of the power system it is feeding into [4]. In addition to being the world's largest supply of renewable electricity, the unique characteristics of storage hydropower make it well suited to enabling the increased penetration of other more variable renewable energy technologies, specifically wind and solar power [5]. Hydropower reservoirs already play a significant role in providing energy storage to the grid, which helps to smooth the fluctuating relationship between supply and demand [4, 5, 10, 13].

Estimates indicate that hydropower today represents 99% of the world's electricity storage capacity [11]. It is widely recognized that as the penetration of all renewables increases, especially variable renewables such as wind and solar, there will be a greater need for more energy storage capability to smooth increased fluctuations and firm up supply of the electricity system. Specifically, when water is pumped into a reservoir or stored through natural inflows, it can be released at any time that it is needed by the grid system. So when the wind stops blowing or the sun's energy is interrupted by cloud and rain, stored energy in the form of reservoir water can be released to compensate for the loss of electricity in the system. Similarly, when there is excess wind or solar power in the system, the excess can be used to power pumps to store this renewable energy for later use. Hydropower operations can also provide ancillary services that support grid stability by stabilizing voltage and frequency. Hydropower's role as facilitating technology is expected to increase as more energy storage is needed as part of the global shift towards increased use of renewable energy [10-13].

Table 3. Power density per reservoir area

Power density Per reservoir area	Allocated emissions for use in calculating offsets
≥ 10 Watts per m^2	0 g CO_2e/kWh
4-10 Watts per m^2	90 g CO_2e/kWh
< 4 watts per m^2	Not effective in offsetting carbon emissions

7 A case study in Turkey

7.1. Introduction

Turkey became a party to the United Nations Convention on Climate Change in 2004 and ratified the Kyoto Protocol in 2009 [1, 2]. Having no quantitative carbon emission reduction commitment during the protocol's first commitment period between 2008 and 2012, Turkey is not allowed to participate in the flexible mechanisms created by the protocol. Consequently, Turkish players can only sell carbon credits on voluntary carbon markets [9]. Although the specifics of the post-Kyoto regime and Turkey's role in it are far from clear, Turkey could assume a more active role by taking on emission reduction obligations and obtaining the right to trade on compliance-based emissions trading markets. The international negotiations in the second half of 2011 will shape the post-2012 regime [7-9].

Within the scope of the Kyoto Protocol, "flexible mechanisms" were created to help countries with emissions reduction commitments meet their targets. International Emissions Trading enables Annex B (Annex I excluding Turkey and Belarus) countries to trade amongst each other, whereas the Joint Implementation Mechanism allows Annex B countries to claim emissions reductions by investing in projects in other Annex B countries [21]. The Clean Development Mechanism makes it possible for emission reduction projects in non-Annex I countries to sell their reductions to Annex B countries [18].

Although Turkey cannot participate in the flexible mechanisms, it is quite active in the voluntary carbon markets. As of January 2016, 124 projects were registered in these markets. While the overwhelming majority of these projects are hydro and wind plants, there are several landfill gas, geothermal and biomass projects [6-9]. Regulators are showing greater awareness about the need to support investors' participation in emissions markets. According to a new regulation on the YEK Mechanism, the EPDK shall publish the amount of power produced by each license holder in April every year. Non-licensed facilities may receive "generation resource certificates" to demonstrate the amount of electricity they produced during the preceding year [6-9].

The Ministry of Energy and Natural Resources (MENR) released the Communiqué for the Registration of Projects Providing Carbon Emission Reduction in August 2010 [17]. The communiqué aims to register the projects that have or have applied to obtain carbon certificates from institutions like the Gold Standard Foundation. Within the framework of the communiqué, the projects are legally registered and double counting is prevented. Starting a registry for carbon emissions projects is just the first step in the long process of setting up the regulatory and institutional framework ahead of the post-Kyoto regime [7-9].

Participation in voluntary markets can constitute valuable experience for Turkey's greater involvement in carbon markets. If bilateral arrangements gain greater prominence in the post-Kyoto regime, Turkey may conclude bilateral agreements with the EU region. In that case the renewable energy producers will have more space to trade their carbon certificates. While industries with high carbon emissions are likely to show resistance to emissions reduction obligations, renewable energy-based power plants will have much to gain from obtaining access to compliance-based markets. Power plants will also have the opportunity to trade their carbon emissions reductions domestically. As for the large groups that are active in multiple sectors including renewable energy, they will have the opportunity to compensate for their carbon emissions with the credits from their renewable power plants [8, 9]

7.2. Turkish energy policy landscape

Despite the considerable development of Turkey's abundant hydropower and other renewable resources, the country's energy mix is still dominated by fossil fuels [7]. Currently gas supplies around a third of the country's total primary energy demand, while coal and oil products provide 27% and 29%, respectively [8]. Much of the country's oil and gas comes by way of imports from Iran and Russia. Hydropower, wind and other renewables produce around 17% of Turkey's electricity supply [9].

However, the government has introduced policies aimed at diversifying the energy supply sector by supporting domestic sources in particular, in a bid to curb the share of natural gas to lower than 30% of total demand [7]. As part of this policy, renewables, including hydropower, have been the beneficiaries of feed-in tariffs to encourage their development. In the case of hydropower projects beginning operations before the end of 2015, the feed-in tariff is US$ cent 7.3/kWh (€ cent 5.6/kWh) with an additional 'local-content' bonus of US$ cent 1-2.3/kWh (€ cent 0.7-1.8/kWh) which is payable for 10 years, with the local content bonus available for five years [8].

Other reforms centered on the liberalized electricity market accelerated private investment in Turkey's energy sector and by 2012, independent power producers were supplying some 26 TWh of energy annually. In addition, the government established a target to deliver 30% of its primary energy demand from renewables by 2023. In other examples, the Energy Market Regulatory Agency (EMRA) has license fee exemption for renewable energy investors and the Turkish Electricity Trading Company, TETAS, can provide buying guarantees to renewable energy, further supporting inward investment [8].

Certainly, the government continues to pursue its market liberalization program and with it the privatization of the bulk of the nation's existing hydropower assets. It plans to move to a fully deregulated electricity market by 2015. The most recent figures available note that of 613 offers to privatize hydroelectric plants the treasury has achieved an overall revenue of more than $427 million [7, 8]. For example, the privatization process for 52 hydroelectric power plants belonging to the state-owned Electricity Generation Company (EÜAŞ) divided the assets into 19 groups for the purpose [6-9].

In recently, the Privatization Administration of Turkey tendered for the operational rights of a further five hydropower installations [6]. According to media reports, in the first round, Metek Hydro made the highest bid for the operating rights of the power plants Vicera and Esendal for 49 years with a bid of $1.85 million. In the second round, two power plants, Dere and Ivriz were put out to tender, Ulke Investment placed the highest bid with $2.3 million, again for 49 years. And in the third round the Kayakoy plant was tendered and Veysi Mining won with a US$8.3 million bid [6-9].

7.3. Turkey's hydropower development

Turkey remains one of Europe's leading markets for future hydropower development due to a combination of abundant resources and favorable policy framework. Sitting at the crossroads of Asia and Europe, Turkey is a high-altitude country with over 25 river basins, including the trans-boundary Tigris and Euphrates rivers. As part of its potential accession to the EU, Turkey has integrated its electricity infrastructure with that of Europe, while at the same time pursuing a strategy of overall energy diversification, including the development of all types of renewable energy. Furthermore, electricity demand in Turkey is forecast to grow by more than 90% over the next ten years, adding to the suite of drivers for hydropower development.

Turkey has ambitious plans for hydropower over the coming decade. The country is aiming to mark its 100 years as a republic in 2023 with a total installed electric power capacity of 100 GW with 30% of electricity generation coming from renewables [6]. This rate was around 20% in 2014 due to low rainfall. The country is pushing ahead with its formidable goal to exploit all of its estimated 166,000 GWh/year of economical hydropower potential, which would include an expected total of about 24,000 hydropower plants. To date, roughly 50% of this potential has been tapped, with a further 15% under construction, leaving the country with some way to go in achieving its target. At the end of 2015, Turkey's installed hydropower capacity was 25.8 GW, producing 66 898 GWh/year of electricity (Table 4).

Turkey has a suite of policies that will support hydropower development, including a 30 per cent target for renewables by 2023, a feed-in-tariff for projects completed by the end of 2015, VAT and customs exemptions, and licence fee exemptions for renewable projects. In early 2015, the Turkish Government announced it would allocate $16 billion to hydropower development until 2018 as part of its Tenth Development Plan. In addition, deregulation of the power sector has encouraged private investment, with independent power producers taking on the bulk of new developments. Hydropower development will be further supported by Turkey's interconnections into the European grid and potential for further linkages east into Asia [6-9].

In 2003, Turkey liberalized its energy market and embarked on a process of privatizing existing assets as well as attracting private sector investment into new projects, although several strategic hydropower facilities will be exempted from the privatization program. In 2015, Turkey commissioned seven projects, adding 688 MW of new capacity, including the Arkun Barajı (245 MW), Kavşak Bendi (190 MW), and Yamanly (88 MW) stations. It is estimated that there is now up to 15 GW of new capacity currently under construction in Turkey, including the Yusufeli (540 MW), Çetin (517 MW), Kığı (180 MW), and Kargı (100 MW) projects [6-9].

Table 4. Hydropower capacity in Turkey

Years	Installed Capacity (MW)	Generation Capacity (GWh)
2002	12 241	33 684
2003	12 579	35 330
2004	12 646	46 084
2005	12 906	39 561
2006	13 063	44 244
2007	13 395	35 851
2008	13 829	33 270
2009	14 553	35 958
2010	15 831	51 796
2011	17 137	52 339
2012	19 609	57 865
2013	22 494	59 420
2014	23 646	40 645
2015	25 870	66 898

6. Conclusions

Hydropower is the largest single renewable electricity source today, providing 16% of world electricity at competitive prices. It dominates the electricity mix in several countries, developed, emerging or developing. In many others it provides significant amounts of clean, renewable electricity. It also helps control water flows and availability. Its extreme flexibility is a strong asset for electric systems, and will be vital to accommodate and facilitate the growth of variable renewables such as wind and solar photovoltaics. It can foster social and economic progress, especially in developing countries.

Hydropower development continued its strong growth trend. Globally, the drivers for this include a general increase in demand not just for electricity, but also for particular qualities such as reliable, local, clean and affordable power. An estimated 36 GW of hydropower capacity was put into operation, bringing the world's total installed capacity to 1,036 GW. Total hydropower generation for the year is estimated at 3,900 TWh. China once again dominated the market for new development, adding 21.85 GW of new capacity within its borders. Other countries leading in new deployments include Brazil (3.31 GW), Canada (1.72 GW), Turkey (1.35 GW), Russia (1.22 GW) and India (1.20 GW).

Turkey has energy demand and develops hydropower potential of the country. The most important rivers for hydropower development are Euphrates and Tigris, both of which are trans-boundary rivers originating in Turkey. Hydropower plants in Turkey are capital intensive, yet have lower operational costs than thermal options. Hydropower is the only renewable source that is capable of providing huge amounts of power in Turkey. Hydropower is competitive in terms of capital cost and perfectly superior to them in terms of fuel cost, which is zero in hydro plants. Investment and operating cost in Turkey are very low in comparison with many developed countries because of low construction and labor cost.

Acknowledgment

The author acknowledged to the Karadeniz Technical University and the Turkish Academy of Sciences for their financial supports for accomplished to this study..

References

[1] Kaygusuz, K. Clean energy policies for sustainable development in Turkey Journal of Engineering Research and Applied Science 2012; 1(2): 1-10.

[2] Kaygusuz, K., Toklu, E. Energy issues and sustainable development in Turkey.Journal of Engineering Research and Applied Science 2012; 1(1): 1-25.

[3] Kaygusuz, K. Renewable energy technologies for clean and sustainable development Energy and Diplomacy Journal 2015; 1(3): 29-47.

[4] Hamududu, B. , Killingtvelt, A. Assessing climate change impacts on global Hydropower. Energies 2012; 5: 305-322.

[5] IHA, International Hydropower Association. 2015 Hydropower status report. IHA, 2015.

[6] DSI, State Hydraulic Works. Energy sources and hydropower in Turkey. Retrieved March 9, 2016, from DSI: http://www.dsi.gov.tr/docs/hizmet-alanlari/enerji.pdf

[7] WECTNC, World Energy Turkish National Committee. Turkish energy report in 2013. WECTNC, Ankara, Turkey, 2013.

[8] MENR, Ministry of Energy and Natural Resources. Blue Book. Ankara, Turkey, 2015.

[9] The World Bank. Turkey's energy transition: milestones and challenges. Report No: ACS14951. The World Bank, Washington DC, 2015.

[10] IEA, International Energy Agency. Technology roadmap: hydropower. IEA, 2012.

[11] IEA, International Energy Agency. World energy outlook 2014. IEA, Paris, 2014.

[12] REN21. Global renewable energy report 2015. www.ren21.net/(accessed 04.06.2015).

[13] WEC, World Energy Council. World energy resources: charting the upsurge in hydropower development 2015. WEC, London, UK, 2015.

[14] Kaygusuz, K. Hydropower in Turkey: the sustainable energy future. Energy Sources, Part B 2009; 4: 34-47.

[15] TEIAS, Turkish Electricity Transmission Company. Percentages of electricity generation by primary energy resources in 2014. TEIAS, Ankara, Turkey, 2014.

[16] Metzger, B., Vorobyev, R. Hydropower maintaining its supremacy in 2014. Renewable Energy Focus, Volume 16, Number 5-6, December 2015.

[17] WWF, World Wide Fund for Nature. Turkey's renewable power: alternative power supply scenarios for Turkey. WWF, Istanbul, Turkey, 2014.

[18] IEA, International Energy Agency. Energy technology perspectives 2008: scenarios and strategies to 2050. OECD/IEA, Paris, 2008.

[19] IRENA, International Renewable Energy Agency. Renewable energy technologies: cost analysis series, Volume 1: Power Sector Issue 3/5, Hydropower, IRENA, 2012.

[20] ETSAP, Energy Technology Systems Analysis Program. Hydropower. IEA ETSAP - Technology Brief E12 - May 2010 - www.etsap.org

[21] IPCC, Intergovernmental Panel on Climate Change. Renewable energy sources and climate change mitigation special report of the IPCC (Eds. O. Edenhofer, et al.), 2011, http://srren.ipcc-wg3.de/report/(accessed date 12.10.2015).

[22] WCD, World Commission on Dams. Dams and development: a new framework for decision-making, 2000, www.internationalrivers.org/(accessed date 01.12.2014)

[23] Voith Hydro (2009): Small hydro. Voith Hydro, Germany, 2009. http://www.voithhydro.com/media/VSHP090017_Small_Hydro_72dpi_neu.pdf..