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Review

The role of hydropower installations for sustainable energy development in Turkey and the world

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ABSTRACT

Hydropower has the largest share among renewable energy sources in the world, supplying more than 16.6% of total global electricity to over 160 countries around the world. Global hydropower capacity increased to approximately 1096 GW with the addition of 25 GW of new hydropower capacity in 2016. With a 216 TWh per year generation capacity, Turkey's hydropower potential is the largest in Europe. The increased rate of installed capacity in Turkey was ranked 7th in the world in 2016 with an annual installed hydroelectric capacity of 0.8 GW. The main objective of this paper is to review the developments of hydropower installations around the world and in Turkey with an emphasis on the potential of small scale hydropower systems such as waterwheels in utilizing low head water flow for household electricity usage. In the first part of this study, the growth of worldwide hydropower capacity is reviewed and the countries with the largest installed and new built hydropower capacities are reported. In the second part of this study, the current status of Turkey's hydropower plants is discussed in detail with respect to annual regional rainfall, gross water mass flow and potential of Turkey's major water basins to demonstrate the potential energy output that can be harnessed from small-scale systems implemented in low-head water sources. In addition, the most recent information on Turkey's electricity generation and consumption rates are reported.

Contents

1. Introduction

Over the last few decades, in response to an increasing demand for electricity as a result of a growing population and advancement in technologies, fossil energy sources are quickly depleting. For this reason, remaining fossil fuel resources must be rationed not only because they are being depleted, but also because the combustion

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of fossil fuel causes environmental pollution. The International Energy Agency's (IEA) World Energy Outlook estimates an increase of about 50% in the global energy-related CO_2 emissions by 2030 [1] if fossil fuels remain the principle energy source. Projections indicate that the demand of oil may be an issue and energy-related CO_2 emissions will more than double. According to the IEA Energy Technology Perspectives Baseline Scenario, CO_2 emissions will increase from 35.9 Gt in 2014 to 42 Gt by 2030. If growth in CO_2 emissions continues as in this scenario, 57 Gt of CO_2 will be emitted by 2050 [2]. Naturally, in response to this situation, global warming and the threat of climate change have been forcing industry to use energy sources more efficiently while energy-related greenhouse-gas (GHG) emissions have become the most attractive issue of our decade [3].

In this respect, research and development efforts in renewable energy technologies are paramount in bringing solutions to these environmental challenges [4–9] by offering clean and reliable energy sources. Also, from an economic perspective, renewable energy technology helps create new jobs and save money. Renewable energy technologies are especially effective in rural areas in which distances are greater, where there are fewer people, and there is less of an energy demand [10]. Shares of renewable energy, among the other energy sources in the world, have increased in recent years, and are projected to grow in the future. Hydropower has the greatest potential to be an emission-reducing sustainable system, making it an important asset in the global renewable energy supply and especially in small-scale systems in Turkey [11–23].

In this study, the development of hydropower [1–112] installations both around the world and specifically in Turkey is reviewed as well as the increase of global installed hydropower capacity from 2007 to 2016. In the later portion of this review, the countries with the greatest number of new additions and their total installed hydropower capacities are investigated. In addition, the current status and developments of Turkey's hydropower stations are discussed in detail as well as the potential application of small-scale systems. Application of small-scale hydropower systems, such as waterwheels, is discussed in this review in order to revisit this technology's usage in today's world for household electricity usage.

2. Hydropower technologies in the world

Hydropower stations are categorized into three types based on their function; storage, run-of-the-river, and pumped-storage technologies [19,24]. Rivers or creeks feed water to reservoirs in storage technologies. Run-of-the-river technologies take advantage of the natural flow of streams [20]. Water is channeled from a lake, river, or reservoir to a powerhouse in storage and run-of-the-river technologies.

According to the size of their installed capacity, hydropower stations are expressed as small, medium and large (Table 1) [20]. Table 2 depicts four categories of small-scale hydropower systems together with their installed capacities. It is important to consider the advantages and disadvantages of different sized plants according to the environment in which they will be implemented. This paper is especially focused on the utilization of small-scale plants for household usage. Although generally hydropower capacity of 10 MW or less can be considered small-scale, categorization of small-scale hydropower plants can vary according to the country and time period they are found in Ref. [25].

Disadvantages of large hydropower plants are energy loss due to long transmission lines harming the surrounding ecology, waste of important forest and underground resources, and extended production periods [26–28]. Advantages of small-scale hydropower plants are pollution free generation, maturity in technology selection, reliable and flexible operations, ease of maintenance, and abundance of financial sources. In addition, small power plants have gained attention because they are environmentally friendly and have the highest potential for electrification in rural areas and developing areas at a low cost. With these advantages, small hydropower plants provide affordable and accessible electricity in remote areas in which grid connection is not available [28].

Hydropower plants vary in terms of the type and size of their generation unit or plant, their function (electricity generation, capacity or multi-purpose), their size, and the height of the water fall (head). Hydropower plants are designed specifically according to local conditions. Head and discharge pressures are the most critical parameters in choosing a site specific hydraulic turbine [19]. Making use of very low head water resources is an innovative development in renewable-energy technologies, and has become more widespread in its use due to low environmental impact. Implementation of low water technology can be key in harnessing renewable energy in Turkey. Although low-head hydropower systems seem to be the only option for supply of electricity to inaccessible areas, implementation costs have created a barrier against their widespread use [29–35]. Alternative implementation with advanced hydraulic systems, controllers and electrical equipment made it possible to reduce costs of mini hydro systems. These developments will positively affect rural or remote areas in which energy from an electrical grid transported via interconnected transmission lines is not cost effective [28].

Today, there are many regions that may be used for hydropower that remain untouched. These regions have very low head below 2.5 m, and include old mill sites, irrigation canals, and weirs in the river. Utilizing these regions to produce power may help satisfy the growing interest in renewable energy. Hydropower has great potential in harnessing energy from these regions given the appropriate technology without damaging the environment [12]. This energy alternative is preferred both technically and economically for its relatively high efficiency ranging from 75% to 85% over a wide range of flow. Environmental concerns of the water wheel systems can be minimized by slow rotation speed and large cells, which will reduce its impact on aquatic life and enable sediment transport to tolerate floating debris [12].

3. Development of global hydropower installation

Fig. 1 presents the distribution of global electricity production among fossil, renewable and nuclear sources. As shown in the figure, renewable energy sources have increasingly contributed to global electricity capacity every year. In the power sector, installed capacity and renewable energy technology output increased rapidly from 2010 to 2016. Between 2010 and 2016, electricity generation from solar technologies had the greatest capacity growth rates among all energy technologies, while wind had the greatest increase in installed capacity of any renewable technology. Renewable energy sources provided almost one fourth of electricity consumed in the world [36–39]. As can be seen from Fig. 1, electricity generation from hydropower remained around 17% of the total electricity generation in the world between 2010 and 2016. Considering the rise in electricity consumption in the world to be a result of increased population, the absolute value of electricity

Table 1
Hydropower Types [20].

Type	Capacity	Stream	Load
Small	Less than 10 MW	Run-of-the river	base
Medium	Between 10 and 100 MW	Run-of-the river	base
Medium	Between 100 and 300 MW	Reservoir	base and peak
Large	Greater than 300 MW	Reservoir	base and peak