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Review

Current status and future of ocean energy sources: A global review

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ABSTRACT

In this study, detailed information about the fundamentals, energy and power potentials, devices, technologies, installed capacities, annual generation, and future of ocean energy sources: tidal, wave, temperature and salinity gradients are given as an up to date global review. Detailed analysis showed that aggregate global annual potential of different ocean energy sources is significantly greater than our global annual electricity demand. As a result, many countries around the globe aim to utilise ocean energy sources for power generation. However, this is currently not possible on a large scale because most of the ocean energy technologies are still under development and there are many economic, technical and environmental problems to be solved. Therefore, the research and development in ocean energy engineering should be fostered by governments and private sector around the globe so that we can use these reliable and clean renewable energy sources for supplying our increasing global electricity demand. Finally, this study could offer some assistance to the academia and industry for the utilisation of different ocean energy sources for achieving a sustainable future.

1. Introduction

In the second half of the 20th century, there was a general belief that the 21st century would be the age of nuclear and renewable energy sources (Melikoglu, 2017a, 2014). However, as of today, most of global electricity is still being generated from fossil fuels (Valente et al., 2017). Besides the economic burdens, fossil fuel consumption pollute the environment and accelerate global warming (Lonngren and Bai, 2008). The share of fossil fuels in global electricity generation is simply immense. According to the United States (U.S.) Energy Information Administration (EIA) International Energy Outlook 2016 (IEO2016) nearly 67.2% of global net electricity generation was supplied from fossil fuels (coal, petroleum and natural gas) in the year 2012 (EIA, 2017a). According to the same study, the share of renewable energy sources were only 21.9% of global net electricity generation (EIA, 2017a). This means slightly more than one-fifth of global electricity generation was supplied from renewable energy sources in the year 2012. Details of global net electricity generation in 2012 is shown in Fig. 1 (EIA, 2017a). As a note of caution, % values are calculated based on the data for 5 energy sources/groups (coal, natural gas, nuclear, petroleum, renewable energy sources).

Renewable energy sources have huge economic and environmental benefits (El-Farra and Christofides, 2017; He et al., 2016; Hua et al., 2016; Noel, 2017). They are regenerative resources and do not deplete over time (Hil Baky et al., 2017). There is an immense potential for renewable energy sources, which are abundant and diverse around the globe. Therefore, if utilised properly, renewable energy sources could eventually provide energy security for countries around the globe, reduce greenhouse gas emissions, and help us tackle (may be stop) global warming, which is one of the key global problems of the 21st century. As a result, there is a global trend of using more renewable energy sources and it is expected that the share of renewable energy sources in global electricity generation will increase in the next decades (Melikoglu, 2017b).

According to the IEO2016 reference case, renewable energy sources are the fastest growing source of electricity generation; and in the year 2040, nearly 29.2% of global net electricity generation is projected to be supplied from renewable energy sources (EIA, 2017a). Although this sounds promising it also means that renewable energy sources still would not dominate global electricity market in the next 25 years. IEO2016 shows that in the year 2040, nearly 58.5% of global net electricity generation is projected to be supplied from fossil fuels (coal, petroleum and natural gas) (EIA, 2017a). It simply means that the share of renewable energy sources would still be smaller than one-third of global net electricity generation and more than half of global net electricity generation would still be supplied from fossil fuels in the year 2040. Details of global net electricity generation projection for 2040 is given in Fig. 2 (EIA, 2017a). Again, as a note of caution, % values are calculated based on the aforementioned data for 5 energy sources/groups.

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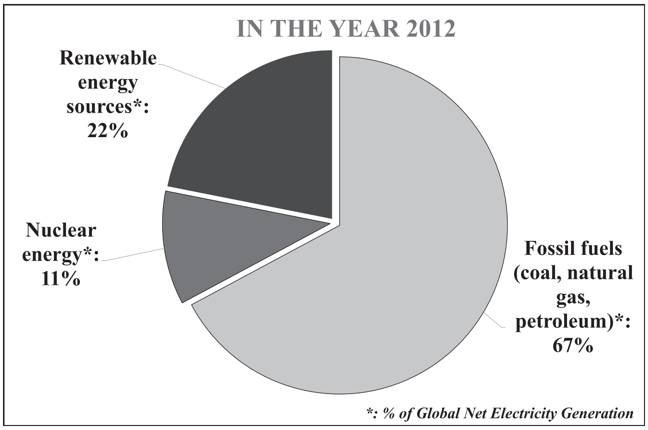

Fig. 1. Percentage supply of global net electricity generation by different energy sources based on data for 2012 (EIA, 2017a).

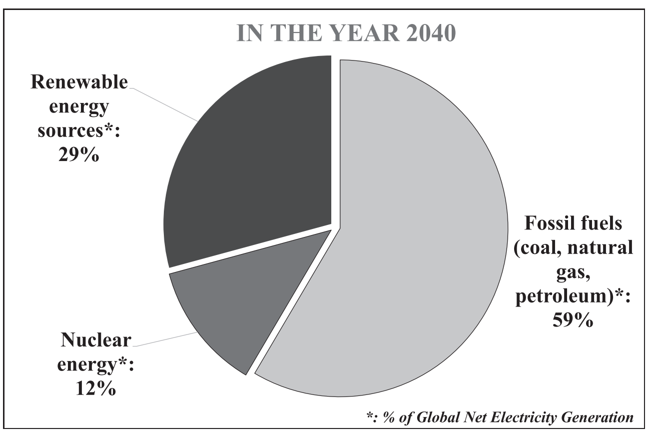

Fig. 2. Percentage supply of global net electricity generation by different energy sources based on projection for 2040 (EIA, 2017a).

solar, and wind are different types of renewable energy sources (CT, 2017; IN, 2017). Hydropower, wind, solar, geothermal and biomass are currently used in different parts of the world at commercial scale. However, progress in the commercialization of ocean energy is much slower than other renewable energy sources. This is because the technology for the exploitation of ocean energy sources is still mostly under development and there are a number of challenges standing between the sector's current status and the aim of commercial utilisation (Adrian de Andres et al., 2017a,b).

According to the International Energy Agency (IEA) ocean power can be exploited using the following five different technologies: (i) tidal rise and fall (barrages); (ii) tidal/ocean currents; (iii) waves; (iv) temperature gradients; and (v) salinity gradients (IEA, 2017a). Out of these five technologies so far focus has been mostly given to tidal and wave power (i)-(iii). Whereas, technological development for the (iv) temperature and (v) salinity gradients remained behind. This is also reflected to the number of publications in the literature.

According to the IEA 2016 Medium-Term Renewable Energy Market Report global ocean energy power capacity in the year 2014 was nearly 530 MW and it was predicted that this could reach to 640 MW by the year 2021 (IEA, 2017a). This is almost negligible when compared with global installed capacities of other renewable energy sources. For example, in the year 2014, global total installed solar photovoltaic (PV) capacity was nearly 180,000 MW (BP, 2017). This clearly shows the lag in technological and concurrent capacity development of ocean energy sources.

Aforementioned lag is not related to the energy potential of oceans. On the contrary, there is a great potential of renewable energy that is stored in oceans (Khan et al., 2017). More than 70% of Earth's surface is covered by oceans (Ressurreição et al., 2011) and they act as the largest solar collectors and capture thermal energy from the sun (Khan et al., 2017), gravitational pull of the moon drives tides and wind generates ocean waves (Energy, 2013a). Compared to other renewable energy sources, ocean energy sources have a number of important advantages that include abundance (Homma, 1985), availability, high load factor (Benbouzid et al., 2017), lower environmental impact (should be validated again when commercial utilisation increases (Hammar et al., 2017)), and source predictability (Yaakob et al., 2016).

In a recent study, the theoretical annual potential of marine/ocean energy is reported between 4 and 18 million tonnes of oil equivalent (toe) per annum (Derakhshan et al., 2017). The global deployment potential of ocean power is estimated to be 337 GW, and over 885 TWh of electricity could be generated from this potential annually (A de Andres et al., 2017a,b). In another study, global marine energy potential is estimated 32 TW (Wahyudie et al., 2017). Khan and colleagues reported around the globe ocean energy sources have the following potentials: tidal 800 TWh per annum; osmotic 2000 TWh per annum; wave between 8000 and 80, 000 TWh per annum; and thermal sources are between 10,000 and 87, 600 TWh per annum, potential total of which is significantly greater than global electricity demand of 16,000 TWh per annum (valid for the year when that study was conducted) (Khan et al., 2017). Finally, according to the IEA Ocean Energy Systems Technology Collaboration Programme (OES TCP) if worldwide deployment could be achieved different ocean energy technologies could supply current global electricity demand of close to 20,000 TWh (valid for the year when that study was conducted) (IEA, 2017b).

As stated above, technological development is the key parameter for the exploitation of ocean energy sources. Therefore, in order to accelerate the research and technological development in the field of ocean energy an up to date solid review about the fundamentals, energy and power potentials, devices/technologies that can be used for the exploitation, and future of different ocean energy sources is urgently required by the academia and industry. As a result, this paper is prepared with the intention of providing this information. The focus will be given mostly on tidal and wave energy sources since much of the work in the field of ocean energy is focused on these two sources. In Sections 2 and 3, information in the published literature about tidal and wave energy will be scrutinised. After that in Section 4, concise facts about temperature and salinity gradients will be given since the information about these two is lesser in the published literature. Finally, the conclusions drawn from this analysis will be given in last section of this paper.

2. Tidal energy

2.1. Fundamentals of tidal energy

Tidal energy is a type of renewable of energy, which is classified under ocean/marine energy. The elevation differences between high and low tides can be used for electricity generation (Polis et al., 2017). Tidal energy appears in two forms: tidal potential energy and tidal current energy (Soleimani et al., 2015). There are different technologies being developed to harness the energy stored in tides (Polis et al., 2017). Tidal potential energy is generally extracted by constructing a dam or barrage along an estuary or river; whereas, tidal current energy is generally extracted using different types of turbines (Soleimani et al., 2015) or fences. Overall, tidal energy presents high energy density, low environmental impact and high predictability (El Tawil et al., 2017).

Tidal energy was first used in Europe to operate grain mills more than a 1000 years ago (EIA, 2017b). Today, it is mainly used for electricity generation; however, a tidal range of at least 10 feet (or 3.05 m) is required for economically feasible power generation (EIA, 2017b). For tidal energy, the potential power (P) is essentially proportional to the square of the water head difference (H^2) facilitated between the upstream and downstream sides of the impoundment and the impounded wetted