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Solar energy: Potential and future prospects

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ABSTRACT

The development of novel solar power technologies is considered to be one of many key solutions toward fulfilling a worldwide increasing demand for energy. Rapid growth within the field of solar technologies is nonetheless facing various technical barriers, such as low solar cell efficiencies, low performing balance-of-systems (BOS), economic hindrances (e.g., high upfront costs and a lack of financing mechanisms), and institutional obstacles (e.g., inadequate infrastructure and a shortage of skilled manpower). The merits and demerits of solar energy technologies are both discussed in this article. A number of technical problems affecting renewable energy research are also highlighted, along with beneficial interactions between regulation policy frameworks and their future prospects. In order to help open novel routes with regard to solar energy research and practices, a future roadmap for the field of solar research is discussed.

1. Introduction

The sun is a major source of inexhaustible free energy (i.e., solar energy) for the planet Earth. Currently, new technologies are being employed to generate electricity from harvested solar energy. These approaches have already been proven and are widely practiced throughout the world as renewable alternatives to conventional non-hydro technologies. Fig. 1 shows a comparison of the non-hydro renewable energy capacities between countries for 2012. Theoretically, solar energy possesses the potential to adequately fulfill the energy demands of the entire world if technologies for its harvesting and supplying were readily available [2]. Nearly four million exajoules (1 EJ = 10^{18}J) of solar energy reaches the earth annually, ca. 5×10^4 EJ of which is claimed to be easily harvestable [3]. Despite this huge potential and increase in awareness, the contribution of solar energy to the global energy supply is still negligible [4].

Another major prospect with regard to solar research is associated with the current drive toward reducing global carbon emissions, which has been a major global environmental, social, and economic issue in recent years [4]. For example, 696,544 metric tons of CO2 emissions have been reduced or avoided via the installation of 113,533 household solar systems in California, USA [5]. Therefore, the adoption of solar technologies would significantly mitigate and alleviate issues associated with energy security, climate change, unemployment, etc. It is also anticipated that its use will play an important role within the transportation sector in the future as it does not require any fuel transportation.

Policies, investment, and supports (such as research funding) from various governmental and non-governmental organizations for solar technologies have helped build up a solid foundation for the exploitation of this renewable energy system. While incentives and rebates can be effective motives for the development of these markets, there are also growing efforts to reduce the fiscal burden of these policy incentives. However, solar power subsidies have already faced sharp cuts in many countries, which may retard growth within the industry. To revert this potential decline, policies are changing to support the deployment of solar power systems for large-scale power generation. Furthermore, greater subsidies should be provided for residential solar generators over utility-scale generators. In this article, we provide a global scenario with regard to solar energy technologies in terms of their potential, present capacity, prospects, limitations, and policies. This will help us expand our understanding on how much further we can count on solar energy to meet the future energy demand.

2. Potential of solar energy technologies and comparisons between locations

Only three renewable energy sources (i.e., biomass, geothermal, and

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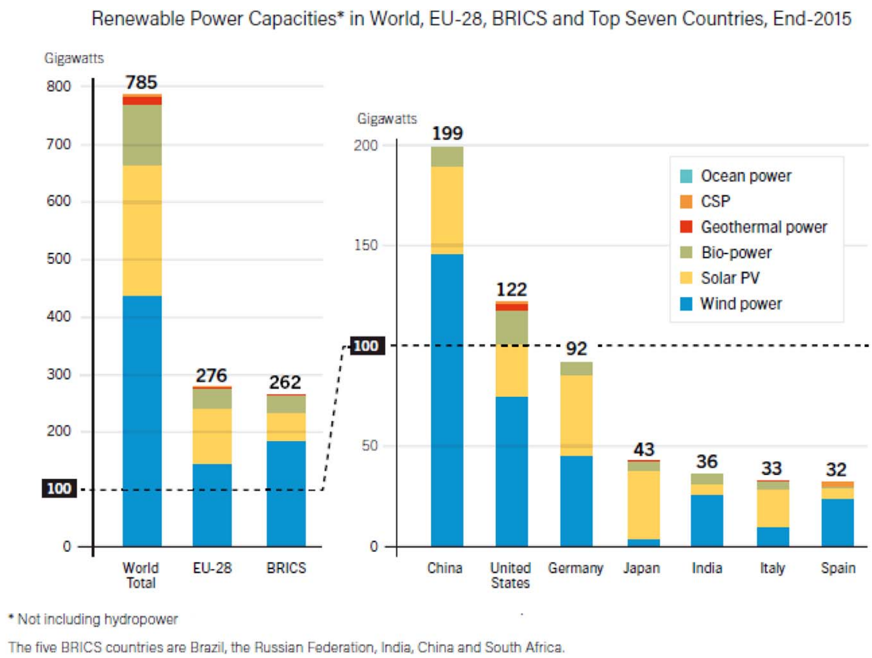

Fig. 1. Comparison of non-hydro renewable energy capacities between countries. [1].

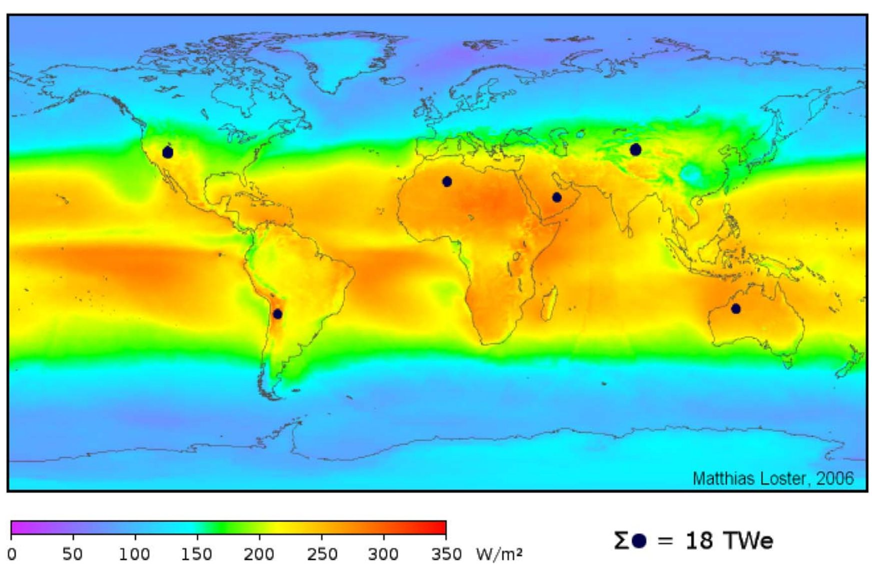

Fig. 2. Annual average solar irradiance distribution over the surface of the Earth. [11].

solar) can be utilized to yield sufficient heat energy for power generation. Of these three, solar energy exhibits the highest global potential since geothermal sources are limited to a few locations and the supply of biomass is not ubiquitous in nature [6,7]. A number of factors (e.g., latitude, diurnal variation, climate, and geographic variation) are largely responsible for determining the intensity of the solar influx that passes through Earth's atmosphere [8]. The average amount of solar energy received at Earth's atmosphere is around 342 W m^{-2}, of which ca. 30% is scattered or reflected back to space, leaving ca. 70% (239 W m^{-2}) available for harvesting and capture [9]. The annual effective solar irradiance varies from 60 to 250 W m^{-2} worldwide [10]. Fig. 2 depicts the annual average intensity of solar radiation over the surface of the earth. Research has shown that "black dot" areas could provide more than the entire world's total primary energy demand, assuming that a conversion efficiency as low as 8% is achieved [11].

In comparison, the sunniest places of the planet are found on the continent of Africa. As theoretically estimated, the potential concentrated solar power (CSP) and PV energy in Africa is around 470 and 660 petawatt hours (PWh), respectively [12]. However, in the regions other than Africa (like south-western United States, Central and South America, North and Southern Africa, Middle East, the desert plains of India, Pakistan, Australia, etc.), such potential is only limited to generate 125 gigawatt hours (GWh) from a 1 km^2 land area [13]. Hang *et al.* [14] estimated that around 6300 km^2 of the wasteland located in the northern and western regions of China (where solar radiation is among the highest in the country) has around 1300 GW electricity generation capacity. In contrast, the National Renewable Energy Laboratory (NREL) in the United States has estimated that the solar energy potential within the USA is capable enough to provide 400 zettawatt-hours annually (ZWh) [15], hugely exceeding the current electrical generation capacity (22,813 terawatt-hours (TWh) [16]). Morocco, a northern African country that enjoys about 3000 h of sunshine per year has recently launched one of the world's largest solar energy projects (including both PV and CSP technologies), targeting the generation of 2000 MW (MW) by the year 2020 [17]. Such a plan is ideal due to their suitable atmospheric conditions (such as high altitudes, low fugitive dust, high transparency, and low humidity). Similarly, the Tibetan plateau in Northern China has been reported to