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Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India

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ABSTRACT

Equality between economic progress and environmental sustainability is essential for a developing country like India. In the present time, the economy of India is growing rapidly in a vibrant mode and an efficient way, which in turn demands huge uninterrupted energy supplies. The country's energy needs are met mostly by the usage of fossil fuels and nearly 70% of electricity is generated from coal based power plants. In India, nearly 840 million people depend on traditional biomass to satisfy their energy necessities. Approximately 74 million rural people do not have access to modern lighting systems and around 81 million households do not have access to electricity, which is a major challenge to India's energy security. In order to achieve stable sustainable energy in the long-run, significant progress in renewable energy sectors is needed. Favorably, due to India's geographic location, the country is blessed with abundant renewable energy resources, which has not yet been exploited completely. So the central and state governments of the country have framed various policies and are providing subsidies to encourage the utilization of solar photovoltaic systems. In this paper, a comprehensive review of the potential, current developmental status and prospects of solar energy of India is briefed. The various applications of solar energy such as water heaters, desalination units, pasteurizers, food drying units, water purifier, space heating systems, air-conditioning units, cookers, water pumps, aerators, solar-wind hybrid systems and grid connected photovoltaic systems are explained. The study also mentions the current renewable energy policies, the barriers blocking the progress of the solar manufacturing units and some possible future recommendations that might speed up renewable energy developments in India.

1. Introduction

The consumption of energy varies from person to person in India. In the earlier days, agricultural waste, animal residues, and fuel wood were used to meet the energy requirements. With progressing time, these energy sources were replaced by commercial fuels like natural gas, coal, petroleum, electricity, lignite etc. The rapidly growing Indian economy initiates the need of extra energy capacity as there is a shortage of electricity. When comparing to a Chinese, an Indian citizen consumes only one fourth amount of energy. However, according to the International Energy Agency (IEA), the primary consumption of energy in India has doubled and has reached an estimated value of 32 quadrillion British thermal unit (Btu) between 1990 and 2012 [1]. The per capita energy consumption in India is one-third of the global average, which indicates a higher demand of energy in future [1]. In recent decades, people of the country have started relying on other energy sources instead of using traditional biomass. The increasing demand and the rapid economic growth led to rising prices of various energy sources. Indian government has made regulatory framework and policies, which is the backbone of renewable energy development in the country. In 2014, India has invested 7.40 billion dollars in the Indian market for rapid development of renewable energy, which was 14% greater when compared to the year 2013 [2]. With various policies and programs of the Government of India, the Renewable Energy (RE) industry is growing significantly in these recent years. The modern India has committed to make investments in renewable energy sectors that would help to achieve a clean and green environment. India ranks fourth (after China, Brazil and the United States of America (USA)) in the world to employ 0.40 million people in the RE sectors [3].

India is amongst the steadily developing countries in the world after China and the fourth largest energy consumption country in the world after China, the USA and Russia [4]. The nominal Gross Domestic Production (GDP) of India in 2015 is about 2,308 billion dollars, which ranks seventh in the world and third in terms of Purchasing Power

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Parity (PPP) [5]. By 2020, India is projected to be in sixth place replacing France in terms of nominal GDP. India is the third largest coal consumer and fifth largest coal producer in the world as per reports of 2014 [5]. The country has produced 38.90 million tons of coal in 2014, which is largest in the world and a highest spike in the country's history [6,7]. It is well known that coal mining negatively impacts the environment and ecology by (1) releasing various toxic gases such as carbon monoxide (CO), sulphur dioxide (SO_2), selenium (Se), mercury (Hg), arsenic (As) and dust, (2) causing devastation of earth and surrounding greenery, (3) degrading the land by excavation, (4) resulting in piling of waste and changing the local topography, (5) dislodging the people from their locality due to hollowing of earth, (6) reducing the water quality with increased dissolved particulate suspended solids and heavy metals, and (7) decreasing air quality [8,9]. The growing population and rapid economic development in India has degraded the environment, exhausted the resources and severely damaged the ecosystem. In order to meet both the environmental and economic challenges, India realizes the necessity for harvesting the renewable resources and progress has been made through framing various eco-friendly policies. India is the first country in the world to establish a separate ministry exclusively for renewable energy development, in the year 1992, which is the Ministry of New and Renewable Energy (MNRE). It is continuously framing policies to expand the contributions of renewable energy throughout India. The MNRE has established National Institute of Solar Energy in Gurgaon, near New Delhi to co-ordinate research and technology in the field of solar energy. The National Institution of Wind Energy is an autonomous research organization established by MNRE at Chennai in 1998 to find possible solutions for the difficulties faced by the wind energy sector. The MNRE started Sardar Swaran Singh National Institute of Renewable Energy (SSS-NIRE) in Punjab for research activities in biomass energy. The Indian Renewable Energy Development Agency (IREDA) is a non-banking financial institution under MNRE, which provides loans for renewable power and energy efficiency projects. The Alternate Hydro Energy Centre (AHEC) was established in the Indian Institute of Technology, Roorkee (IITR) to promote power generation through small hydro power projects in 1982. Solar Energy Corporation of India (SECI) under the control of MNRE was established in 2011 at Delhi with the objectives of developing solar technologies and generating power through renewable resources [10]. India, a country with dense population and abundant insolation is an ideal combination for generating solar power and fulfilling the requirements. At present, according to MNRE, India has solar cell manufacturing capacity of 1,216 MW and module capacity of 2,348 MW, but the industry is facing chronic under utilization because only 19.73% of cell manufacturing and 28.15% of module manufacturing are currently under operation [11]. Major Research and Development (R & D) initiatives, lower cost of finance and suitable policies could provide better support for Photovoltaic (PV) manufacturing sector, which should be given priority because of the abundant free insolation in the country.

This article addresses the existing scenario of solar photovoltaic systems in India. Firstly, the geographic location of India and its existing solar energy status are explained. Then, various policies initiated by the government and the manufacturing sectors of PVs are described. The subsequent sections describe the various solar applications in India, PV technologies, efficiency improvement techniques, various renewable energy policies in India and the developmental barriers. Finally, the future prospects of PV in India along with possible renewable strategies to address the barriers and issues are mentioned in this paper.

2. Geographic sketch of India

India is the seventh largest country by area and the second most populated country in the world with over 1.20 billion people [12]. India lies in the northern part of Indo-Australian plate and north of the equator between 8°4′ and 37°6′ north latitude and 68°7′ and 97°25' east longitude. The country is bounded by water bodies in three sides, Indian Ocean in the south, Arabian Sea in the south-west, and Bay-of Bengal in the south-east. It shares maritime borders with Indonesia and Thailand and land borders with Pakistan in the west, Burma and Bangladesh in the east and China, Nepal, Bhutan in the north-east. India has a long coastline of 7,517 km as well as different terrains that includes Deccan Plateaus in the south, Thar Desert in the west, Gangetic Plains and Himalayas in the north. India, the populous democratic country in the world consists of 29 states and 7 union territories. The Indian rivers mostly originate from three watersheds: Himalaya and Karakoram Ranges in the north; Vindhya, Satpura and Chota Nagpur Plateaus in the central India and Western Ghats in the western India.

3. Solar energy status in India

India is the seventh largest energy producer and the fourth largest energy consumer in the world and is well equipped with both exhaustible as well as renewable energy sources. The most important of them is the coal, which is the mostly available fossil fuel in India that meets 55% of India's energy needs. Huge mining of coal reserves have polluted the air, water, and have created an imbalance in the natural environment, which is the biggest challenge that currently India faces. About 0.08–0.15 million premature human deaths and more than 20 million asthma cases are reported because of continuous exposure of Particulate Matter up to 10 μm in size (PM10) pollution arising from the coal plants [16]. The largest river in India, the Ganga flowing along the banks of Varanasi and Patna supplies water to more than 500 million people and is reported to be the sixth most polluted river in the world [17]. Human and Industrial waste that are dumped to this river causes great negative impact on the marine life (especially fish and dolphins) as they have high concentrations of mercury. It is reported that nearly 58% of waste is being dumped to the river Yamuna, which supplies water to New Delhi, the capital city of India [18].

According to the United States Energy Information Administration, India's consumption of coal, petroleum and other liquids and natural gas is 44%, 22%, and 7% respectively, which is 73% of the total energy consumed. The share of renewable energy comprises 22% of biomass and waste, 3% of hydroelectricity and 1% of other renewable sources, which is significantly less. The increase in population and a steady economic development in India are requiring a huge amount of energy in the present time. Due to this, India imports huge amount of crude oil from the foreign countries [14]. The primary source of energy in India is coal and the estimated coal reserve is 186 billion tones [13]. India is the fifth largest coal reserve in the world and the third largest in terms of production and consumption [1,14]. India is the fourth largest natural gas importer after Japan, South Korea and China [15] and the fourth largest consumer in petroleum and crude oil products after the USA, China and Japan mainly because of the rising demand in transport and industrial sectors [15]. According to International Energy Association, nearly 36% of India's total population depends on cow dung, wood and farm waste for biomass cooking [19]. Energy imports according to India's planning commission could be 53% by 2031, which was 25% in 2003 [20]. A study by Institute for Energy Economics and Financial Analysis states that the extractable coal reserves by Coal India Limited will exhaust within 17 years after considering the high usage of coal by power plants that are operating presently and those under construction [21]. This report suggests that the government of India must concentrate more on renewable and nonconventional energy sources, which may not bear benefits in the near term, but in the long run, it has the potential to improve India's energy security and achieve financial benefits.