



Emerging renewable and sustainable energy technologies: State of the art

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ABSTRACT

In this paper, five most emerging renewable energy sources are analyzed. These emerging renewables are either special or advanced forms of the mainstream energy sources (solar, wind, geothermal, biofuels, biomass, and hydro) or brand new technologies. The five emerging renewable technologies discussed in this paper include marine energy, concentrated solar photovoltaics (CSP), enhanced geothermal energy (EGE), cellulosic ethanol, and artificial photosynthesis. Marine energy is divided into wave energy, tidal energy, tidal/ocean currents, salinity gradient, and ocean thermal energy conversion. CSP technologies are divided into parabolic troughs, linear Fresnel reflectors, parabolic dishes, and solar towers. The process for developing EGE reservoirs is also explained in detail. Cellulosic ethanol energy extraction is explained for both cellulolysis and gasification. Artificial photosynthesis is explained by considering semiconductor particles, electrolyzers, artificial leaves, and dye-synthesized solar cells. Each emerging renewable source's explanation is followed by its market share, challenges, implications for increased adoption, future prospects, and drawbacks.

1. Introduction

The essence of energy to our society is growing to ensure the quality of life and to smoothly run the other elements of our economy. Energy-resource usage has been considered as the most important and ongoing issues of the modern time. About two billion people across the globe lack electricity today [1]. The reliance on technology, enhanced living standards of developed countries, and continuous increase of population in the developing countries certainly results in the rise of demands for energy. In order to fulfill the energy demands, consumption of fossil fuels is increasing, resulting in depletion of the ozone, climate changes, environmental issues, and increased health risks to the living creatures on earth. In order to maintain the thermodynamic balance of the planet at a constant temperature, the amount of absorbed energy as solar radiations must be equal to the amount of energy emitted back into space at longer wavelengths, infrared [2]. The greenhouse gasses in the atmosphere absorb and reemit infrared radiations while keeping the lower atmosphere and earth's surface warm [3]. It is observed in the survey [4] that fossil fuels and cement are increasing their shares in global CO₂ emission and established forests are decreasing their role as CO₂ sinks.

The increased CO₂ results in a significant increase in the average CO₂ level in the atmosphere, which was 280 ppm in the pre-industrial era and has been increased to 390 ppm [5]. In order to keep the earth

safe and to counter the potential environmental threats sustainable and pollutant free technologies have been introduced, known as renewable energy technologies.

Energy sources can be divided into three main categories: fossil fuels, nuclear resources, and renewable energy sources [6]. Renewable energy sources have a potential to play an important role in the world's future. Renewable sources can be used to produce energy again and again i.e. solar energy, wind energy, geothermal energy, marine energy, biomass energy, biofuels, and many more [7]. Renewable energy sources have the ability to provide energy free of air pollutants and greenhouse gasses by emitting zero or nearly zero percent of these gasses [8]. It is a reliable, affordable, and environmentally sustainable way to harvest the renewable energy in a decentralized manner to meet rural and small-scale energy needs [9,10]. Several renewable energy technologies are in practice in the 21st century, but many of these technologies are still under development.

Currently, renewable energy sources supply about 23.7% of the total world energy demand [11], which was 2% in 1998 including seven exajoules of modern biomass, and two exajoules of all other renewable sources [12]. Currently, some of the renewable energy technologies i.e. hydropower, wind energy, solar energy, biomass energy, biofuels and geothermal energy are now mainstream and contributing.

towards the safety of the planet earth and its living creatures. Apart from these mainstream renewable technologies, there are some new

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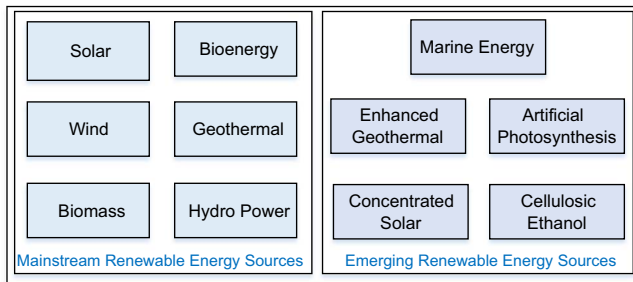


Fig. 1. Mainstream and Emerging Renewable Energy Sources.

renewable energy technologies, which are equipotential and sustainable for countering the greenhouse gasses and air pollution risks to the earth. These emerging renewable technologies comprise of marine energy, concentrated solar photovoltaics (CSP), enhanced geothermal energy (EGE), cellulosic ethanol, and artificial photosynthesis (AP), and many more. An overview of these mainstream and emerging renewable energy sources is shown in Fig. 1.

In this paper, the five emerging renewable technologies mentioned above are discussed. Potential of each emerging technology, different technologies in the energy extraction process, sustainability, current state of development, future prospects, and drawbacks of each technology are analyzed in detail. This paper is aimed to help the researchers get insight into the new and emerging renewable energy technologies and their current state of development.

This paper first explains the development of renewable and sustainable energy (mainstream energy sources especially). Then emerging technologies are discussed, followed by an explanation of each emerging technology in detail. Each section is concluded by future prospects and drawbacks of each technology. Finally, conclusions and a summary of all the five emerging renewable technologies are presented.

2. Renewable and sustainable energy development

In the previous section, an overview of both the mainstream and emerging renewable technologies has been presented. However, in order to be a sustainable energy source, the energy source should fulfill the defined social, economic, and environmental aspects. Fig. 2 provides a comprehensive definition of the sustainable development process.

At present, more mature and reliable renewable energies are on the rise and competitive to the conventional energy sources. Shore wind, solar, concentrated solar, geothermal, marine energy, and bio-energy are on track; and in some circumstances, they have overcome the economic constraints. The share of renewable energy sources in the global final energy consumption is increasing.

In 2012, renewable energy provided an estimated 19% of the global final energy consumption, and it increased to 23.7% in 2014 [11]. The

Aspect	Bearable	Equitable	Viable	Sustainable
Social	○	○		○
Economical		○	○	○
Environmental	○		○	○

Fig. 2. Sustainable Development Scheme (Source: Sustainable Development Portal).

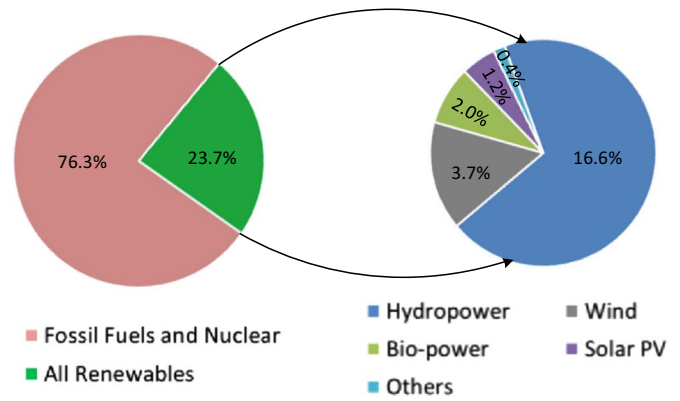


Fig. 3. Estimated Renewable Energy share of Global Energy [11].

contribution of different renewable energy sources to the world's renewable energy can be seen in Fig. 3. The year 2015 has been an extraordinary year for renewable energy, with the largest global capacity additions seen to date [11]. It has been observed that, among various renewable energy sources, the hydropower share is on the top at 16.6% of the total 22.7%, while the wind, biopower, and solar power shares are 3.7%, 2.0% and 1.2%, respectively. Other renewable energy sources, concentrated solar photovoltaic, marine, geothermal, and others contribute to only 0.4% as depicted in Fig. 3.

It has been reported in the global status report (GSR) on renewables in 2016 [11] that the most significant growth in sustainable energy occurred in the power sector with the global capacity exceeding 1560 GW (including small hydropower). The investment on the renewable energy resources has also increased significantly over the last ten years. A summary of the investment over last 12 years is shown in Fig. 4. A total of 40 billion USD was invested by global investors in the field of renewable energies in 2004. The investment kept on increasing and reached 279 billion USD in 2011; but after 2011, it began decreasing. This decline is due to the drastic reduction in technology costs especially for solar PV, which saw a record of new installations in despite a reduction in dollar investment [13].

A considerable shift in the global perceptions of renewable energy has been observed since 2004. The rapid progress in the technological field of several renewable energy technologies in the last decade has shown that their potential is achievable. Renewable energies have advanced closer to realizing that potential within the last decade [13] and many technologies are at par with conventional energy generation technologies.

According to GSR-2016, in terms of the total installed renewable power capacity, China, the United States, Brazil, Canada and Germany remain the top countries. China, the United States, and Germany were the also the top countries for non-hydrogen capacity and are followed by Spain, Italy, and India. From an investment point of view, Mauritania, Honduras, Uruguay, Morocco, and Jamaica were among the top countries for investment in new renewable power and fuels

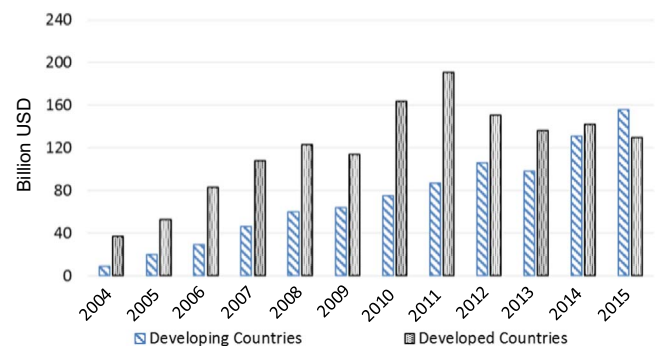


Fig. 4. Developed and developing countries investment in renewable energies [13].

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