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# Potential of solar energy in developing countries for reducing energy-related emissions

Amir Shahsavari*, Morteza Akbari

*Faculty of Natural Resources and Environment, Ferdowsi University of Mashhad, Mashhad, Iran*

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ABSTRACT

The growing global demand for energy from fossil fuels plays a key role in the upward trend in greenhouse gas (GHG) emissions and air pollutants. Rapid population growth and increasing energy demand in the developing countries have brought many concerns such as poverty, pollution, health and environmental problems. While for these countries, particularly the poorest ones, modern energy is necessary to stimulate production, income generation and social development plus reduce the serious health issues that are caused by the use of fuelwood, charcoal, animal dung and agricultural waste. Solar energy is the best answer to energy poverty and it can provide excellent opportunities for reduction of GHG emissions and indoor air pollution through substituting kerosene for lighting and firewood for cooking. Solar photovoltaic (PV) can be an appropriate technology for a source of renewable electricity in developing nations especially in remote rural areas where grid extensions are financially or technically not viable. PV can also be used to reduce demand for fossil fuels and associated emissions, including carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$) and sulfur dioxide ($SO_2$). The use of PV systems can reduce 69–100 million tons of $CO_2$, 126,000–184,000 t of $SO_2$ and 68,000–99,000 t of $NO_x$ by 2030. In case countries use concentrating solar power (CSP) systems, each square meter of concentrator surface is enough to save about 200–300 kg (kg) of $CO_2$ emissions annually. Although there are excellent renewable opportunities in many developing countries, several key barriers have prevented large-scale deployment of solar energy technologies in these countries. This study reviews the sources of energy-related emissions, risks of climate change, global solar energy potential, sustainability indicators of renewable energies, environmental impacts of fossil fuels and renewable energies, benefits of solar energy utilization. It also discusses barriers to widespread use of solar energy.

## 1. Introduction

The role of energy is vital to human well-being and it is also crucial for economic development and energy fosters economic growth. Access to sufficient energy resources is a serious global concern, particularly in developing countries that do not have access to a secure supply of energy [1–3]. Worldwide primary energy demand is expected to rise by approximately 1.5–3 times by 2050 because of increasing energy demand in various regions of the world [6]. Demand for energy is increasing sharply in the developing countries as a result of rapid population growth, particularly in the continents of Africa and Asia and rapid economic development, particularly in China and India [3–7].

Population growth and rising the living standard of people are the key drivers behind increasing demand for energy [3,8]. It is estimated that global population will continue to increase by more than one billion persons and reach to 8.5 billion by 2030, 9.7 billion by 2050 and also increase to approximately 11.2 billion persons by 2100. World's population is rising by 1.18% annually or almost an extra 83 million persons every year. The highest growth rates of population belong to Africa, with 2.55% [9], while all these communities require modern energy services in order to meet their basic needs such as lighting, cooking, space comfort, mobility, communication and to assist productive processes. Currently, conventional energy sources constitute more than 80% of worldwide energy consumption [10–13].

Most current types of energy production and utilization cause environmental issues at local, regional and global scales, reducing the quality of life and endangering the human health as well as the well-being of present and future generations of humankind. The energy production and utilization are responsible for 80% of carbon dioxide and two-thirds of total greenhouse gas (GHG) emissions worldwide [14]. In 2016, the annual mean atmospheric carbon dioxide ($CO_2$) concentration reached to 400 ppm (ppm), which is 40% higher than the pre-industrial time's carbon dioxide level (280 ppm), while half of the global $CO_2$ emissions have risen since the 1980s [15,16].

* Corresponding author.
*E-mail addresses:* amir.shahsavari@mail.um.ac.ir (A. Shahsavari), m_akbari@um.ac.ir (M. Akbari).

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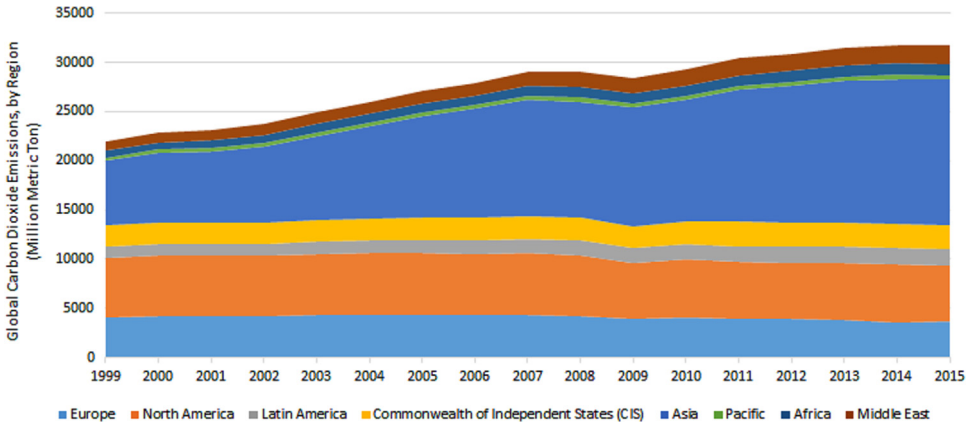


**Fig. 1.** Total carbon dioxide ($CO_2$) emissions from consumption of energy in the world during 1999–2015 (Million Metric Tons) [20]. Source: This data provided by the Global Energy Statistical Yearbook.

Historically, developed countries have produced the large majority of anthropogenic greenhouse gas (GHG) emissions, while in recent years, the share of GHG emissions from developing countries have surpassed those of developed countries, and these shares have kept rising very rapidly [14,17]. For the first time in history, the aggregate energy-related $CO_2$ emissions of developing countries surpassed those of developed and transition countries in 2008 [18]. $CO_2$ emissions from China and India are rising rapidly, where energy production and consumption have increased significantly [1,19]. In recent years, developing countries have generally experienced a constant growth of $CO_2$ emissions compared to developed countries of the world. Energy-related carbon dioxide emissions in Asia, Middle East, Africa and Pacific region increased very rapidly in recent years, as indicated in Fig. 1 [20].

The increase of $CO_2$ emissions from developing countries is mostly the result of significant increase in the use of conventional fuels (e.g. coal, oil and natural gas) to meet the pace of fast growth of energy demand [21]. Nowadays, electricity production from conventional energy sources is the main source of greenhouse gases emissions worldwide, particularly in developing economies [5], and almost 40% of global primary energy is currently utilized for electricity generation [22], and approximately 40% of global electricity generation is based on conventional coal [23,24]. Consequently, the fossil-fueled power plants produce large amounts of environmental harmful emission of gases such as carbon dioxide ($CO_2$), nitrogen oxides ($NO_x$) and sulfur dioxide ($SO_2$). Today, the power generation sector produces nearly 530 g of $CO_2$ per Kilowatt-hour ($gCO_2$/kWh) on a global average [14]. The electricity and heat sectors constitute the significant sources of energy-related carbon dioxide emissions, accounting for 42% of the world [14,19]. Furthermore, the power sector is the major source: approximately 70% of $SO_x$ emissions in the European countries and also it is the most significant source of $SO_2$ emissions in the United States (US), South and East Asia [25]. $SO_2$ and $NO_x$ pollutants cause both regional and trans-border problems of acid rain [3]. Using fossil fuel for electricity generation results in the loss of billions of American dollars of economic value via health endpoints as well as premature mortality yearly [26].

According to the United Nations Environmental Program (UNEP), the environmental damages via GHG emissions also come with a huge price tag. Only in the continent of Africa, it is estimated that these environmental damages will reach to 50 billion USA dollars per annum in 2050 [23,27]. Moreover, the majority of the world's poor nations rely largely on forests to meet their own energy requirement of their livelihood, particularly for cooking. In developing nations, 56% of total primary energy use comes from traditional biomass, mostly firewood. The further loss of forests threatens the livelihoods of the poor people and also destroys ecosystems and habitats that harbor biodiversity.

Since 1990, forest losses deforestation has been considerable (more than 1.4 million square kilometers), particularly in East Asia, Latin America and the Caribbean, the Pacific and in Sub-Saharan Africa (SSA). Some of this deforestation is because of excessive harvesting of biomass fuel [28,29]. As a result, deforestation accounts for over 15% of global GHG emissions and also over-exploitation of these forests is causing ecological disasters which could become irrecoverable [30–32]. The use of conventional fuels could have the capacity in local, regional and environmental challenges. Therefore, a clean energy system has the capacity to reduce the negative environmental impacts.

Renewable energies are widely and easily available to mankind in many areas around the world. The most significant benefit of renewable energy sources application is the abatement of environmental pollution, particularly greenhouse gas emissions. This is accomplished due to a decrease in the atmospheric emissions via substitution of fossil-based electricity and conventional fuels [33]. Solar energy is an inexhaustible and pollution-free energy resource that plays a remarkable role in providing energy services in a sustainable way. In comparison to conventional fuels, solar energy does not pollute the atmosphere via releasing harmful gases such as $CO_2$, $SO_2$, and $NO_x$. Many countries around the globe have already chosen solar energy as a clean and alternative energy source to overcome the negative environmental impacts of conventional fuels. Solar energy technologies are also one of the main options to meet small and large-scale energy demands in a reliable, affordable, practical and environmentally sustainable manner.

The solar photovoltaics (PVs) produce electric power directly from sunlight. It is a considerable power source for meeting electricity demand in the developing countries, especially in rural and remote locations without emitting pollutants into the atmosphere. The increased efficiency and continuing cost reduction of PV systems imply a significant role for photovoltaic generating systems in the coming years [34]. Also, solar thermal power plants generate thermal or electrical energy by converting solar radiation into high-temperature heat. It can supply energy needs for domestic, industrial, commercial and agricultural sectors [35]. The most important role of solar energy systems is reducing the $CO_2$ emissions of developing economies and easing the burden of energy production for daily tasks in developing nations. Thus, solar energy technologies will address regional and local environmental matters, reduce poverty, greenhouse gas emissions and increment energy security.

## 2. The sources of energy-related emissions in developing countries

As mentioned above, greenhouse gas emissions, particularly $CO_2$ emission from developing countries have surpassed those of industrialized countries. Burning carbon fuels has led to a rapid increase in $CO_2$ emissions in the developing world over the last decades. $CO_2$