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

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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].

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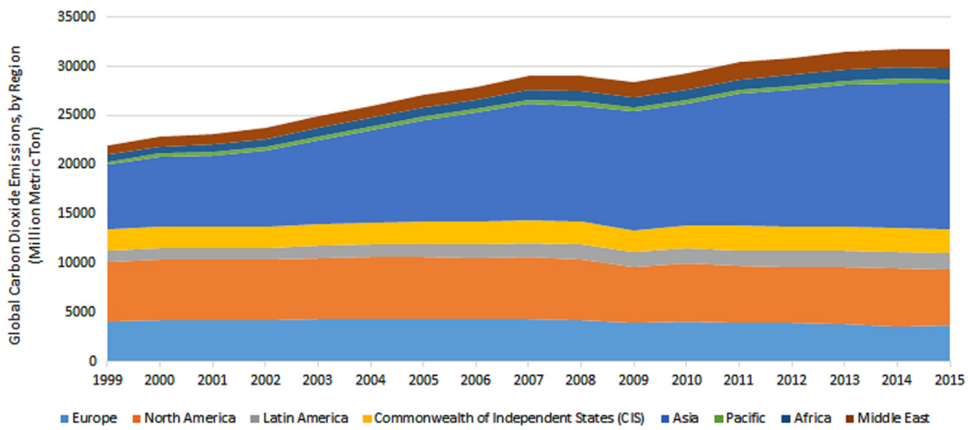

Fig. 1. Total carbon dioxide (CO_2) emissions from consumption of energy in the world during 1999–2015 (Million Metric Tons) [20]. Source: This data provided by the Global Energy Statistical Yearbook.

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

emissions from the developing countries such as China, India, Iran, Saudi Arabia, and South Africa are considerable because these countries rely heavily on carbon-intensive fuels to meet their energy demand.

2.1. China

China is by far the largest CO_2 emitting country in the world. In 2015, this country produced about 30% of all carbon dioxide emissions in the world [36]. The high rank is largely due to the size of its population and the current economic state. However, the large share of carbon-polluting coal in its energy mix is also a factor. In China, the electric power sector is responsible for nearly 50% of the country's total CO_2 emissions [37]. Increasing energy demand for electricity generation and industrial production in China is largely met by using conventional coal. More than 70% of China's energy needs are in large met by using conventional coal. Among energy consumption sectors, China's massive power generation sector is heavily dependent on cheap energy (i.e. coal). Coal-fired power stations produce about 78.6% of China's electricity [38].

2.2. India

India is the third largest producer of carbon dioxide emissions in the world after China and the USA. The major fossil fuels used in India are coal, natural gas, refined oil and crude petroleum [39]. In this country, 72% of carbon dioxide emissions come from coal combustion [36]. About 58.6% of India's energy needs are met by using conventional coal, which is abundant, locally available and cheap compared to other energy sources. Conventional coal, natural gas, and diesel are the main sources of power production in India. Coal-based power stations account for about 60.8% (167.2 GW) of India's installed capacity. In addition, an enormous portion of forestland in India is cleared for non-forest use such as agricultural use, construction of power stations, roads and canals [40].

Also, the two large developing nations i.e. Brazil and Indonesia ranked in the top 10 CO_2 emitters in the world, as a remarkable part of their national CO_2 emissions come from the land-use change sector [41]. As mentioned earlier, after burning fossil fuels, deforestation is the second main source of man-made CO_2 emissions. Forests are the major source of carbon sequestration in this planet.

2.3. Iran

As a least developed country, Iran is located in the Middle East. In 2015, Iran produced about 1.7% of all carbon dioxide emissions around the globe. Over the last decade, CO_2 emissions in this country increased by 10.3%, with an annual average of 1.4% [36]. The increase in CO_2 emissions in Iran has caused it to be one of the ten largest carbon dioxide producers in the world and also the top contributor to atmospheric carbon dioxide in the Middle East. Recently, the rate of CO_2 emissions from various sources in Iran have passed the Kyoto Protocol (KP) limitations. In this country, fossil fuel use is the primary source of carbon dioxide (CO_2) emissions. The major fossil fuels used in Iran are natural gas and crude oil. In recent years, almost 54.4% and 44.1% of its energy needs are being met by natural gas and oil, respectively. Nearly 80% of the energy demand of Iran's power generation sector is provided by fossil fuels [42].

2.4. Saudi Arabia

Saudi Arabia is one of the most important countries in the Middle East. Saudi Arabia is among the top ten emitters of carbon dioxide in the world and stands as the 2nd largest CO_2 emitting country in the Middle East after Iran [43]. In 2015, its share of CO_2 emissions was 1.4% worldwide. In 2013, the combustion of oil products and natural gas was responsible for about 70% and 30% of total CO_2 emissions, respectively. In this year, 45% of its national total CO_2 emissions came from the power generation sector [37]. Saudi Arabia's economy relies intensively on crude oil and is it the major consumer of oil in the Middle East, especially in the transportation sector as well as the power generation sector. In 2013, the total oil consumption in this country was about 3.07 million barrels per day (mbd), 7.5 times more than that in 1971. The increasing oil consumption in different sectors, particularly in the transport sector causes high carbon dioxide emissions, which adversely affect the environment. The high growth rate of domestic consumption of oil in Saudi Arabia has many effects at national and international levels as well [43].

2.5. South Africa and Sub-Sahara Africa

The continent of Africa is the smallest producer of carbon dioxide in the world. However, its share is increasing. Africa's contribution to the global man-made CO_2 emissions is much lower than that of other continents such as Asia and Europe [44]. South Africa is the 12th largest producer of carbon dioxide in the globe and it is responsible for about half of the CO_2 emissions in the entire African continent [45]. South Africa is the largest producer of GHGs and accounts for 65% of Africa's emissions. Its economy relies heavily on combustion of fossil fuels. Therefore, fossil-fuel combustion is the major source of GHG emissions, mainly carbon dioxide in this country [46]. Among fossil fuels, coal accounts for about 70% of South Africa's total energy consumption. In this country, coal contributed to more than 92% of its power production [45]. Consequently, electricity production by coal combustion leads to increasing concentration of carbon dioxide and other environmental pollutants in the atmosphere. In this country, the process of electricity generation is responsible for about 45% of total GHG emissions [47].

In Sub-Saharan Africa, about 50% of energy consumption has been provided by biomass and its combustion leads to increases in CO_2 emissions and air pollutants. Also, demand for biomass energy is the main cause of deforestation and land degradation which leads to increases in GHG emissions. One of the main drives for the use and demand for biomass in the SSA is rapid urbanization with the excessive use of biomass. Furthermore, CO_2 emissions of countries with a large population like Nigeria and Ethiopia tend to grow faster following energy consumption as compared to countries with a small population such as Equatorial Guinea and Cape Verde [44].

In summary, energy demand has increased rapidly in the developing countries due to progress in socio-economic developments in recent years. In the developing countries, the power generation sector is the major sector with respect to conventional fuel consumption. Indeed, energy consumption based on fossil fuels, mostly conventional coal, which is the most carbon-intensive fossil fuel and deforestation are the two main causes of environmental degradation. Therefore, some new strategies should be adopted by governments of developing countries for the energy mix. Further mitigation of use of conventional fuels will be absolutely essential to decrease worldwide CO_2 emissions.

3. Energy poverty

Energy poverty is a significant problem for human health, economic development and environmental sustainability in many parts of the world. Despite the fact of raising the standards of living in many developing nations, more than 2.7 billion people worldwide especially in Sub-Sahara and developing Asia are still using wood and other solid fuels for cooking and heating. In Asia, about 1.9 billion people rely largely on traditional biomass energy for cooking and also many people rely largely on kerosene for lighting. Also, in Sub-Saharan Africa, about 80% of the human population depends mainly on biomass to meet their energy demand [28]. In the continent of Africa, around 600 million people do not have access to modern energy services. It is predicted that the population of this continent will reach to 700 million by 2030 [23].

Lacking access to reliable and affordable electricity generation source and heavy dependence on the inefficient traditional biomass fuels such as fuelwood, charcoal, wood waste, agricultural residues and dried animal dung are indications and reasons of poverty [2].

Moreover, utilization of solid fuels and kerosene for cooking and lighting creates smoky environments. Many times, indoor air pollution levels due to solid-fuel use by households are higher than typical outdoor air pollution levels, even those in most polluted cities [48]. Indoor air pollution due to the burning conventional fuels is responsible for many health, environmental and social problems that disproportionately and adversely affect children's health [49]. Population exposure to gaseous air pollutants has increased the rates of mortality and morbidity in the world [4,50]. In 2012, indoor air pollution due to inefficient use of solid biomass for cooking and use of kerosene for lighting was responsible for almost 4.3 million premature deaths mainly concentrated in low- and middle-income nations [28,51–54]. Furthermore, some pollutants in biomass smoke such as nitrous oxide and methane are also climate active. Both well-understood greenhouse gases (GHGs) with much higher global warming potentials per ton than CO_2. Also, in biomass smoke, carbon monoxide (CO) and the entire mixture of non-methane volatile organic compounds (NMVOCs) act also as indirect global warming agents [48,55]. In addition, in South Asia and East Africa are on-going risks from wood-fuel lead to land degradation and deforestation. For example, more than half of the Senegal energy supply is provided through carbon-intensive coal and also wood that comes from natural forests [56].

Provision of modern and efficient energy services to the poor people in developing nations is a very important prerequisite to meet the Millennium Development Goals (MDGs) [1]. One solution to solve today's energy shortage needs to use more clean energy sources, particularly solar energy technologies. To shift towards a low-carbon world, mitigation efforts must occur globally; shifting developing countries onto a low-carbon development path and decarbonizing the energy supplies of industrialized nations. Concerns about energy-related environmental impacts (e.g. global climate change and local air pollution) can motivate governments of developing countries to support low-emission technologies such as solar energy systems. Solar energy as a pollution-free source will play a promising alternative energy source in the future where reducing the reliance on conventional fuels and addressing environmental issues are a priority.

4. Risks of climate change in developing countries

Climate change is one of the main human being concerns in the 21st century. Currently, the rapid rise of GHGs, particularly CO_2 emissions from human activities is threatening the planet. Natural ecosystems and many human-environment systems are sensitive to climate change. It is believed that if average temperatures rise by higher than 2 °C annually, the whole world will suffer more from natural disaster, hotter and longer droughts, failure of agricultural areas and huge losses of species [57,58]. There will also be positive feedback changes that fortify the trend. Less snow and ice cover will mean that more heat is absorbed through darker surfaces. For example, since permafrost has kept billion tons of organic (carbon-based) matter in the soil, melting permafrost due to heat will release large amounts of greenhouse gases. Consequently, various natural systems such as mangroves, coral reefs, boreal, tropical forests, arctic regions, alpine ecosystems, grasslands and prairie wetlands will struggle to survive. If these natural systems shrink, they won't have the capacity to trap as much carbon dioxide [59,60].

The world's people have to face the reality of climate change, because in many regions of the world, the consequences of climate change have increased. Bangladesh, Honduras, Myanmar, the Philippines, Haiti and Nicaragua were the country's most influenced via extreme weather events during 1995–2014, according to the German watch Global Climate Risk Index (CRI). Table 1 demonstrates ten countries that are impacted by climate change in recent two decades with their average weighted ranking (CRI score) and the determined results related to the four indicators analyzed [61].

Table 1
The Long-Term Climate Risk Index (CRI): The 10 countries most affected from 1995 to 2014 (annual average) [61].

Country	CRI score	Deaths per 100,000 inhabitants	Total losses in million US $ in Purchasing Power Parities (PPP)	Losses per unit GDP in %	Number of events (total 1995–2014)
Honduras	11.33	4.41	570.35	2.23	73
Myanmar	14.17	14.75	1140.29	0.74	41
Haiti	17.83	2.76	223.29	1.55	63
Philippines	19.00	1.10	2 757.30	0.68	337
Nicaragua	19.00	2.97	227.18	1.23	51
Bangladesh	22.67	0.52	2438.33	0.86	222
Vietnam	27.17	0.44	2205.98	0.70	225
Pakistan	31.17	0.32	3931.40	0.70	143
Thailand	32.33	0.25	7480.76	1.05	217
Guatemala	32.50	0.66	407.76	0.50	88

According to the statistics published via the World Health Organization (WHO), between 2030 and 2050, the negative direct and indirect impact of climate change is expected to cause nearly 250,000 additional deaths worldwide per annum because of some diseases mainly malaria, malnutrition, diarrhea and heat stress [62]. Also, as a matter of fact, climate change is reportedly responsible for global economic losses of between 4% and 20% of the gross domestic product (GDP) all over the world [63]. If the external costs of conventional fuels are considered, non-renewable energy technologies would appear to be more expensive than renewable energies. Reduction of greenhouse gas emissions and mitigation of climate change are the main strategies of the global climate policy. Increase in renewable energies utilization is an essential measure in achieving these goals.

5. Renewable energy sources

Renewable energy technologies (RETs) produce considerable and marketable energy through converting natural phenomena (e.g. sunlight, water flows and the wind energy) into useful energy forms. Nowadays, solar energy systems are the most economical solution for the mini-grid and off-grid electrification in rural or remote areas and isolated communities and also for grid expansion in some cases of centralized grid supply with excellent renewable resources. According to the statistics published by the National Renewable Energy Laboratory (NREL), global demand for renewable energy continued to rise during 2010–2015, as shown in Table 2. The potential of solar power to provide an increasing share of future energy growth without increasing GHG emissions is making many countries to consider the role of solar energy technologies in for meeting the energy needs of the future. As illustrated in Table 2, in recent years, the use of renewables, particularly PV has increased very rapidly in the world [64].

Rapid growth, especially in the power sector is driven by different factors, including the enhancing cost-competitiveness of renewable technologies, appropriate policy initiatives, easier access to financing, energy security and environmental matters, increase demand for energy in emerging economies and developing countries and the requirement for access to modern energy [65].

With the new adoption of the Paris agreement to decrease GHG emissions, renewable energy technologies have appeared as a significant part of any global solution to address the threat of climate change and its impacts [66]. The increase of renewable technologies utilization for energy supply will reduce GHG emissions. Every 1 GW of extra renewable energy capacity has vast potential to reduce carbon dioxide emissions, on average, by 3.3 million tons each year. For

Table 2
Renewable electricity as a percentage of total installed global electricity capacity during 2010–2015 [64].

Year	Hydropower %	PV%	CSP%	Wind%	Geothermal%	Biomass %	All Renewables%	Renewable Capacity (GW)
2010	18.4	0.8	0.0	3.9	0.2	1.3	24.6	1253
2011	18.0	1.3	0.0	4.5	0.2	1.4	25.4	1356
2012	17.8	1.8	0.0	5.1	0.2	1.5	26.5	1470
2013	17.6	2.4	0.1	5.5	0.2	1.5	27.3	1579
2014	17.5	2.9	0.1	6.1	0.2	1.5	28.5	1712
2015	17.0	3.6	0.1	6.9	0.2	1.7	29.5	1848

example, in India, nearly 4–5% of total energy-related emissions reduced through existing renewable energies portfolio [67]. The share of renewable energy (RE) employment in the future will depend mainly on climate change mitigation objectives, the level of requested energy services and resulting energy needs as well as their relative merit within the portfolio of zero- or low-carbon technologies [68].

6. Solar energy technologies

Solar energy is a kind of renewable energy and also the most abundant renewable energy source that is accessible and free to all countries. Solar power is energy from the sun that is harnessed and converted into two common applications, electrical and thermal energy. Overall, solar energy technology has two main categories that could convert solar energy into electrical energy [11,69]. One application is concentrating solar power (CSP) systems that produce heat or electricity by hundreds of mirrors which concentrate the sunlight to a temperature commonly between 400 and 1000 °C. In addition, CSP as a solar energy technology can operate either through storing heat or through combination with fossil-fueled power plants such as natural gas and oil power plants, making power available at times when the sun is not shining [57].

CSP is a large-scale and commercially usable and viable way to make electricity. This technology will require a direct normal irradiance (DNI) of 5 $kWh/m^2/day$ in order to concentrate the sun's energy to drive traditional steam turbines or engines that produce heat and electricity and also be economic [70]. It is best suited to those regions of the globe that receive the large amount of sunlight like the Middle East, Northern Africa, China, parts of India, Southern Europe, Southern USA and Australia and also many areas where people are suffering from peak electricity problems, power blackout, and rising electricity costs. Concentrating solar power system does not contribute to climate change and it is an endless source of energy. For CSP systems, each square meter of concentrator surface is enough to save 200–300 kg (kg) of carbon dioxide each year, depending on its location on the Earth. It is expected that annual saving in CO_2 through concentrated solar power would be 148 million tons of CO_2 each year in 2020, increasing to 2.1 billion tons worldwide in 2050 [57].

The second application of solar energy is photovoltaic (PV) power. Electricity can be produced via solar energy systems such as photovoltaics. PV cells convert the radiant energy from the sun directly into electricity. There are several different PV technologies and types of installed system. Nowadays, the photovoltaic (PV) modules in the market are monocrystalline silicon solar cells, polycrystalline silicon (or multi-crystalline), microcrystalline silicon as well as cadmium telluride and copper-indium-gallium-diselenide (CIGS) solar cells [71,72]. These systems can provide clean power for small or large utilization. They are installed and generating energy across the world on commercial buildings, residential homes, offices, housing developments and public buildings [59].

As mentioned earlier, solar photovoltaic (PV) as a typical type of renewable electricity source can reduce fossil fuels consumption and their related emissions such as CO_2, SO_2, and NO_x. PV systems can save 0.53 kg CO_2 emission for each Kilowatt-hour of electricity generated. Utilization 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. As a result, due to reductions of NO_x and SO_2, many serious diseases will be reduced. Heart attacks and various types of Asthma will reduce 490–720 and 320–470 each year, respectively, by 2030 [13].

7. Solar energy potential around the world

The earth's surface receives much energy from the sun which is enough to provide 7900 times as much energy as the world's population currently uses. On the global average, each square meter of land that received enough sunlight can generate 1700 kW-h (kWh) of power each year [59,73]. Almost all places on the earth receive 4380 daylight hours per annum (i.e. half the total duration of one year). Global horizontal irradiance (GHI) is the measure of the quantity of the available solar resource per surface area. Various areas receive different annual average amounts of the solar energy from the sunlight. The average solar energy received in the Middle East that is measured in global horizontal irradiance varies approximately between 1800 kW-h per square meter per year ($kWh/m^2/y$) to 2300 $kWh/m^2/y$, while in Europe, it is about 1200 $kWh/m^2/y$. The United States, most of Latin America, Africa, Australia, most of India and parts of China and other Asian countries also have an excellent solar energy source; these are the main regions where energy demand is expected to rise considerably in the coming decades. Alaska, Canada, Russia, Northern Europe and Southeast China receive less solar energy than other areas around the world. But tilting equator-facing collectors towards the sun can reduce disparities and raise the annual energy received on solar photovoltaic systems, particularly at high latitudes; however, this varies with meteorological patterns and the ratio of diffuse versus direct light [73–75]. As also shown in Fig. 2, developing countries have high potential to receive enough solar radiation as a result of their geographical location in comparison to developed countries. This comparison gives us an idea regarding the abundance of solar energy, which seems to be an inexhaustible source. In many countries, in particular in developing countries, solar radiation that reaches to the land is enough in the quantity which makes it beneficial to each developing country's utility [76]. Since solar energy has been known as an important clean energy source among other renewables, realizing its potential and the benefits that solar energy can bring in addressing consequences of climate change and energy security issues.

8. Sustainability indicators of renewable energy technologies

Renewable energy technologies (RETs) can play a crucial role in providing clean energy for global sustainable development. The widespread use of renewable energy sources (e.g. solar, wind, hydroelectric power, geothermal and biomass) would not only help to avoid the negative environmental and social impacts relating to fossil fuel energies, but also they have great potentials to create remarkable extra socio-economic benefits such as reducing local air pollution and safety risks, increasing energy access and improving security of energy supply.

8.1. Greenhouse gas emissions

As mentioned earlier, reduction of GHG emissions and mitigating

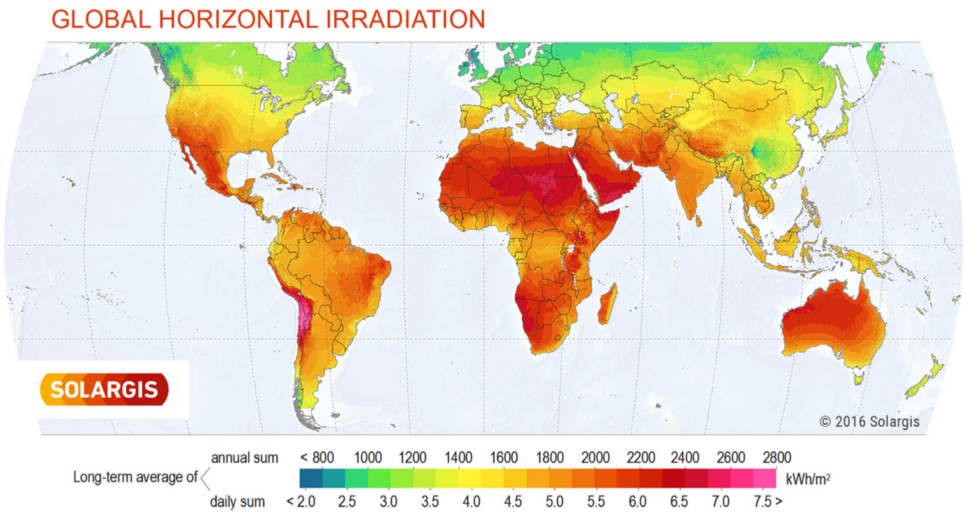

Fig. 2. Global Horizontal Irradiation (GHI) [76].

Table 3
Lifecycle greenhouse gas emissions intensity of electricity generation methods [77].

Energy source	gCO_2e/kWh range
Coal	756–1310
Gas	362–891
Oil	547–935
Nuclear	2–130
Photovoltaic	13–731
Wind	6–124
Hydro	2–237
Biomass	10–101

climate change are the main aims of the global climate policy. As discussed earlier, electricity production sector is the major source of GHG emissions. Table 3 gives CO_2 emissions (g/kWh) of the major forms of electric power generation. The total greenhouse gas emissions are expressed as grams of CO_2 equivalent per one kWh of energy produced. From this table, it is obvious that CO_2 emissions from fossil-fueled power sectors (i.e. conventional coal, oil and natural gas) far exceed those of the renewable energy technologies and nuclear power stations. According to the data provided by the World Nuclear Association (WNA) [77], a remarkable fraction of CO_2 emissions produces by coal-fired electricity plants. This type of power station emits between 756 and 1310 g of CO_2/kWh. For an oil-fired power, CO_2 emissions per unit of electricity range between 547 and 935 g of CO_2/kWh. In comparison to coal and oil, gas-fired power plants are known to have the lowest relative carbon dioxide emissions per Kilowatt-hour, which ranged from 362 to 891 g of CO_2/kWh. Compared to fossil-fueled power plants, nuclear power stations do not emit greenhouse gases when they generate electricity, which ranged from 2 to 130 g of CO_2/kWh. Accordingly, a solar PV system emits ranged low from around 13 to a high of 731 g of CO_2/kWh. While a wind power plant emits between 6 and 124 g of CO_2/kWh. A hydropower plant produces between 2 and 237 g of CO_2/kWh. Between 10 and 101 g of CO_2/kWh of electricity generated come from biomass use [77].

For fossil fuel power stations, the largest part of emissions arises during the operation of the power plant. Nuclear power plants and some renewable energy sources (i.e. solar and wind) do not directly emit CO_2 emissions [28,31,78]. The GHG emissions by a nuclear fuel cycle are mainly due to the fossil fuel-based energy and also electricity needed to uranium mining, processing the fuel and for the construction, waste byproducts, materials of fuel cycle facilities and decommissioning as well [31,79]. The construction of hydropower, wind turbines and PV panels account for approximately 70–80% of total emissions. For hydroelectric power plants, CO_2 emissions result from the production of steel, cement and concrete for the foundations [80]. The amount of CO_2 produced by a wind power plant depends largely on the amount of material and work needed to construct the wind turbines [81]. Emissions from any type of solar systems are lower than those from fossil fuels because solar energy technologies do not require fuel to operate. For photovoltaics power, the most of the emissions are the result of electricity use during the manufacturing stages of PV cells [80,81]. Thus, renewable technologies have very low lifecycle GHG emissions compared to fossil energy sources. Replacing carbon-intensive fuels with various sources of renewable energy can mitigate greenhouse gas emissions.

8.2. Price of renewable electricity generation

In recent years, because of improvement of technologies and increase in manufacturing scale, the costs of some technologies has declined sharply in order to deliver distributed clean energy. Since the first solar cells were made, the price of PV solar cells has declined steadily [82]. Since 2009, the price of solar panels has dropped by 80% and their efficiency has improved considerably as well, which reflected in the pricing of energy. Recent decreases in the cost of solar PV technologies coupled with countries requires a decarbonized energy system to meet climate change objectives have led to a 20% increase in PV installations in the year 2015 worldwide [83]. Fig. 3 illustrates the price for electricity generation through the use of renewable sources. This figure compares the range of costs for electricity generation from 2010 to 2015 in dollars per Kilowatt-hour ($/kWh) for renewable energies. According to data from the International Renewable Resources Agency (IRENA), solar PV and solar thermal are the largest remaining cost-reduction potential among other renewable technologies, which make solar PV attractive to project developers, particularly in areas with the excellent solar resource. Between 2010 and the end of 2015, the prices of solar photovoltaics (PV), solar thermal and onshore wind power have dropped significantly and markets have grown substantially. From 2010–2015, the costs of solar PV have declined by $0.285 per Kilowatt-hour and $0.126 per Kilowatt-hour, respectively. Also, the cost of solar thermal energy has decreased from almost $0.331 per Kilowatt-hour in 2010 to $0.245 per Kilowatt-hour in 2015 [84].

As the cost of the onshore wind and solar energy technologies continues to decline, more and more people are choosing to purchase renewable energy technologies. Various businesses are also choosing to utilize renewable energies and combined heat and power at their buildings to save their money, reduce their negative impacts on the

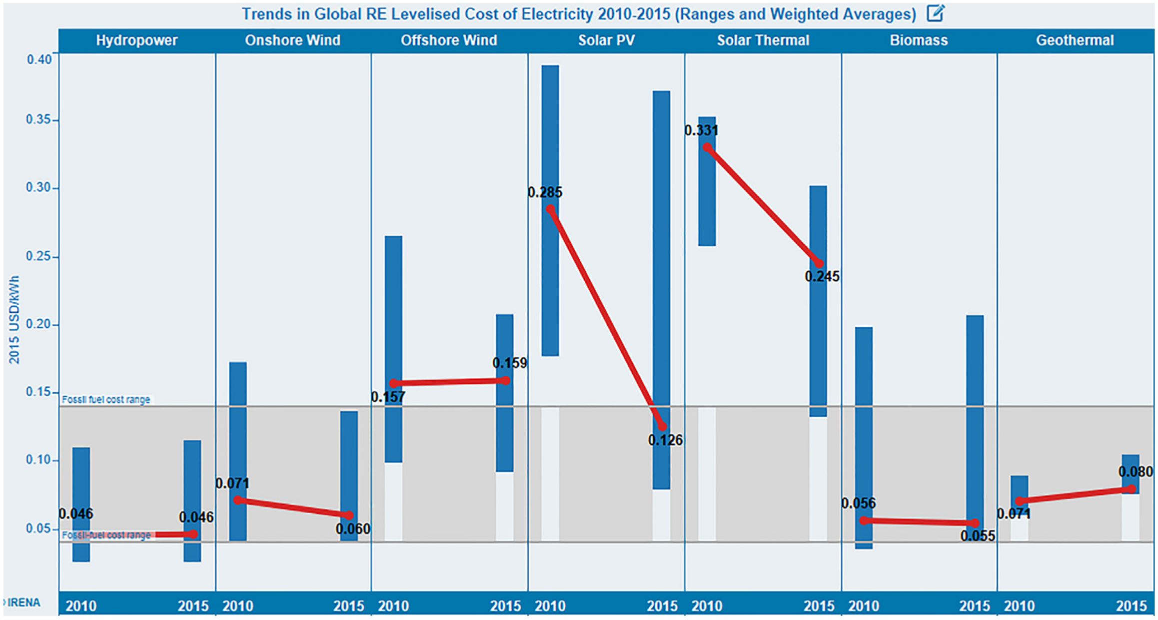

Fig. 3. Global renewable energy levelized costs of electricity (LCOE) (USD/kWh) in the time period from 2010 until 2015 [84]. Source: This plot is provided by the International Renewable Resources Agency (IRENA).

environment and provide greater control of their energy consumption [85]. The global weighted average installed cost of utility-scale solar photovoltaic could decline by higher than half (57%) during 2015–2025, driven by continued technological improvements, competitive pressures, and economies of scale. Presently, solar PV is a mainstream technology among other renewable technologies [86]. Solar energy technologies, particularly PV is one of the fastest growing renewable energy technologies and is projected to play an important role in the future electricity production worldwide. It is estimated that solar power could produce 22% of the global electricity by 2050. This would eliminate a remarkable portion of the increasing global carbon dioxide emissions [87].

One of the main advantages of using solar energy technologies is remarkable reduction in capital investment. Therefore, solar energy technologies have better acceptance in the market among other energy producing sources. Despite the recent cost reductions of PV electricity, more transitional policy support mechanisms will be required in many markets as long as electricity prices do not consider climate change or other environmental factors in order to enable the price of photovoltaic electricity to attain competitive levels compared with fossil fuels. The key target is to enhance the performance of solar energy technologies and reduce solar panel costs in order to accomplish the competitiveness needed for extensive necessary investments.

9. Environmental impacts of fossil fuels and renewable energies

The exploitation of energy sources (i.e. fossil fuels, renewable energies and nuclear) have some negative impacts on the environment. Table 4 shows the main negative environmental impacts of fossil fuels, renewable energy resources, and nuclear energy. Some negative effects may arise during fuel production, others could arise during plant construction and some others arise as a result of power production. Combustion power systems emit several types of substances such as carbon dioxide, carbon monoxide, sulfur dioxide, nitrogen oxides, hydrocarbons, primary and secondary aerosols and so on. The level and pollutant mixtures depend on the fuel and the specific technology used and other factors [31].

Table 4
The most significant environmental impacts of energy production forms [31].

Type of impact	Combustion based				Nuclear	Hydro	Wind	Solar
	Coal	Oil	Gas	Biomass				
Resource depletion	✓	✓	✓		✓			
Land use, visual impact	✓			✓		✓	✓	✓
Watercourse Regulation						✓		
Thermal releases	✓	✓	✓	✓				
Noise							✓	
Radiation					✓			
Air pollution	✓	✓	✓	✓				
Acidification	✓	✓	✓	✓				
Greenhouse effect	✓	✓	✓	✓				
Thermal releases	✓	✓	✓	✓	✓			

9.1. Coal

Coal-fired electricity-generating plants are the main source of Sulfur dioxide (SO_2) emissions (about 70%). SO_2 is the primary cause of acid precipitation [56]. Burning conventional coal is also the second largest source of nitrogen oxides (NO_x) (which contribute to smog and asthma attacks). Moreover, coal combustion emits other common air pollutants like particulate matter (fine soot particles), which contribute to thousands of premature deaths from heart and lung diseases annually [88]. Coal-fired power stations also place notable demands on groundwater and surface water supplies, affecting both water quantity and quality, which are becoming serious problems in hot or dry areas. Coal combustion creates large amounts of solid and liquid wastes that can leach heavy metals and different toxic substances into ground and surface waters [89–93]. Available knowledge regarding coal shows that it needs a lot of less land than any renewable supply of energy, however, this is often direct land requirements for coal power plants solely (by power plants and mining activities). Indirect use of land, involving fallout of region emissions or involving the impacts of temperature change does not seem to be enclosed within the knowledge. These areas are large and may multiply the land use factors of fossil fuels [94].

9.2. Oil

Burning oil releases high amounts of harmful emissions, including a high proportion of sulfur dioxide (SO_2), depending on the sulfur content of the fuel [95], nitrogen oxides (NO_x), carbon emissions (mainly CO_2 and CO), volatile organic compounds (VOC) and ash particles into the atmosphere. These emissions are harmful to the environment and public health as well. As mentioned above, both sulfur dioxide (SO_2) and nitrogen oxides (NO_x)contribute to acid precipitation. Acid rain causes respiratory and heart diseases especially in kids and the elderly people and it has also negative impacts on plants and animals, which live in the water (i.e. aquatic species) [91,95].

9.3. Natural gas

Natural gas extraction typically begins by drilling the wells. After that the natural gas is extracted, it transports via pipelines. These activities have harmful environmental effects. One of the major current environmental consequences occurs from uncontrolled methane (CH_4) leakage. Natural gas transportation in pipelines results in the leakage of CH_4. Methane is a potent greenhouse gas, which is 34 times stronger at trapping heat than CO_2 after 100 years, and it is also 86 times more potent after 20 years [96]. Pipelines are needed in order to transport the natural gas from the wells, which generally require clearing lands to bury the pipes and also require a road for delivery to a variety of locations [96,97]. Groundwater sources can become contaminated with natural gas production processes. The combustion of natural gas releases toxic pollutants or global warming emissions. Large amounts of carbon dioxide, hydrogen sulfide, sulfur dioxide, nitrogen oxides, carbon monoxide and many other compounds typically release into the environment due to gas flaring. The amount of pollution depends largely on the chemical composition of the natural gas and also how natural gas is flared or burned at well sites [94,97]. Burning natural gas emits a negligible amount of gaseous air pollutants like oxides of sulfur and nitrogen, virtually no particulate matters or soot and also lower levels of carbon dioxide (CO_2) and carbon monoxide (CO) compared with conventional coal and oil. Natural gas is the cleanest of all the fossil fuel sources [98]. In general, thermal power plants using fossil fuels produce particulates, oxides of sulfur, nitrogen, and carbon and also toxic elements such as arsenic, mercury in trace concentrations.

9.4. Biomass

Biomass may not be naturally carbon neutral, it may release global warming emissions like methane during the production of biofuels, landscape change and deterioration of soil productivity and produces hazardous waste as well [99]. Traditional biomass power plants release large amounts of atmospheric pollutant such as carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x) and particulate matter (PM). Biomass has a low emissions factor for SO_2 but a very high factor for NO_x [100]. It is, therefore, an important source of acid precipitation. Also, nitrogen oxides are one of the most significant factors in ozone depletion, which is produced from fossil fuel and biomass combustion processes [3]. Biomass plantation is the system that needs the most land per unit of energy production [94].

9.5. Nuclear

Nuclear power stations produce radioactive materials and small amounts of gaseous or particulate pollutants. The risk associated with nuclear radiation is probabilistic. Emissions from nuclear power plants are significantly lower than fossil fuels, but the dumping of the radioactive substances leads to increasing damage to the surroundings [72]. If land use requirements are not taken into account for long-term waste disposal, nuclear power plants will have the lowest land use requirements. The extra land for disposal would seriously raise the land requirements because a small area of land is required, but for long periods.

9.6. Hydropower

Large hydropower plants generate electricity via storing vast quantities of water in the reservoir behind a retaining wall or a massive dam. The hydropower generators do not directly release gaseous air pollutants. Hydropower dam operations have some negative impacts on the environment. A reservoir and a dam can change river flow characteristics, water chemistry, natural water temperatures and silt loads. Furthermore, the construction of a dam can affect land use, homes and natural habitats in the dam area. A reservoir and the operation of the dam may result in the relocation of people [101,102]. Renewable energy resources (e.g. hydropower, wind and solar power) have high land requirements, which can vary considerably according to site-specific conditions. Data on hydropower is based on the total area of reservoirs, not the flooded areas which would essentially be smaller [94].

9.7. Solar

Solar energy utilization like other sources of energy (i.e. renewable energy and fossil fuel sources) have some environmental concerns. Solar and wind energies are non-thermal renewables, which do not use water for dry-cooling systems, therefore, they have very low operational water-use intensities. Some PV systems need a relatively small amount of water for washing panels. CSP facilities can utilize dry-cooling systems to reduce water usage; wet and hybrid cooling require higher amount of water [103].

Solar farms require significantly enormous amounts of land. This is not an issue for roof-mounted PV systems and solar thermal, but it can be an issue for large-scale PV and CSP. For CSP plants, sensitive lands may be a specific challenge. Land-use impacts of installed PV systems will vary for centralized and decentralized applications. Photovoltaic modules as small or intermediate residential or commercial decentralized devices can be used as cladding on the south-facing walls or on roofs of residential buildings and commercial buildings as well. Therefore, no additional land is required. PV systems land requirements for large central electric power generation depend on several identified factors, including system energy efficiency and insolation. Providing much of society's electricity by solar PV would require a remarkable amount of space. [104].

For small and large photovoltaic power plants, the area needed ranges from 2.2 to 12.2 acres per megawatt (MW), with a capacity-weighted average of 6.9 acres per megawatt (MW), while concentrating solar power plants (CSP) need land from 2.0 to 13.9 acres per megawatt (MW), with a capacity-weighted average of 7.7 acres per megawatt (MW). Land-use intensity will decrease with increasing solar panel efficiency [105]. Large PV arrays could certainly have negative visual impacts if installed within a sensitive ecosystem or in areas of natural beauty or other sites of scientific interest. As land-use impacts, visual impacts will also differ by application type (centralized and decentralized PV systems) [104]. Since solar PV systems do not produce greenhouse gases (GHGs) during operation and do not emit other pollutants such as oxides of sulfur and nitrogen, therefore, 4600 GW of installed PV capacity would avoid more than 4 gigatons (Gt) of carbon dioxide emissions annually by 2050 [106]. Solar energy as a renewable energy provides multiple environmental benefits when compared to the fossil fuel sources.

9.8. Wind

A wind farm is a group of wind turbines to generate electricity.

These turbines can be located on open land, on mountain ranges or also in bodies of water, typically in lakes or in the oceans. The main environmental impacts of wind turbines are biodiversity and landscape impacts and noise produced by the rotor blades during operational work [107]. Wind turbines rotor blades kill birds that fly into the rotors in the area [98]. The land use impact of wind power turbines varies substantially depending on the site: in the flat areas, wind turbines typically use more land than those located in hilly areas. On average, they use between 30 and 141 acres of land per one MW of power capacity. However, wind turbines may occupy only a fraction of this land, they must be typically spaced between 5 and 10 rotor diameters apart. The rest of the land can be used for a variety of other productive purposes, including farming and livestock grazing [108]. Moreover, modern wind turbines are large machines and they have a visual impact on the landscape [109].

As mentioned above, fossil fuels have several externalities are not considered in the retail price, including associated unfavorable human health problems, future costs due to climate change and other environmental negative impacts [26]. It is estimated that the indicative external cost range associated with human health impacts is $325-$825 billion per year in the world. This includes the effects of emissions of particulate matter ($PM_{2.5}$), mono-nitrogen oxides and sulfur dioxide from fossil power generation as well as $PM_{2.5}$ and NO_x emissions from light-duty vehicles and indoor air pollution associated with domestic use of conventional coal and traditional biomass [70].

10. Benefits of solar energy utilization in developing countries

Although fossil fuel sources still control the global economy's energy balance, there are still various reasons for deployment and use of solar energy technologies. Its sustainability means that it is among the most secure sources of energy available to any nation, in comparison with other renewable energy sources. As mentioned earlier, it also produces little or no pollution and least contribution to global warming emissions. Along with other renewable energies, it can reduce energy-related GHG emissions in the next few decades to help mitigate the effects of climate change. Solar energy is infinite and sustainable and has a great potential to support communities against fossil fuels price volatility. The absence of reliable power and energy supply is an established challenge to the quality of life for human beings. This is because most activities are dependent on affordable and sufficient energy for productive processes [110]. Solar energy technologies such as applications of solar PV, off-grid electrification, and solar water heating are cost-competitive with traditional energy sources [111]. Due to the global energy shortage and control of negative environmental impacts, utilization of solar energy has received much attention around the world. Solar energy technologies can bring many benefits to the society in many ways.

10.1. Solar energy for electricity production

Solar energy applications are gradually developing in various fields. One of the most prominent of these applications is electricity production. Electrical energy is the most popular kind of energy because it can be used for a variety of applications. It is also very easy to transform into a variety of forms of energy that are beneficial to human lives. Electricity and other modern sources of energy play a key role in economic and social development in all countries. Its relative importance rises in relation to technical advancement, industrialization and the need for modern means of comforts. Electricity has also brought information, education, entertainment and other benefits to communities. The increase in its production translates into better quality of life and creation of wealth. Yet, nearly 1.3 billion people do not have access to electric power and approximately 85% live in low-income, rural or remote areas in developing nations [70,112–114]. For example, 40% of Nigerian people have no access to electric power [115] and use kerosene lamps or candles for lighting. A kerosene lamp produces between 3 to about 40 times more carbon dioxide (CO_2) emissions than a grid-connected compact fluorescent lamp (depending on the power mix) [19]. It is estimated that just India produces almost 6.5 million tons of CO_2 annually due to the use of kerosene in rural households [116]. Providing electricity access to replace kerosene lamps could save an estimated 35 Mt CO_2 per annum [19]. Electricity increases access to information, communication and entertainment services such as mobile phones, the internet, television and radio which cannot be quantified by evaluation.

10.2. Off-grid solar electrification

Nowadays, fully functioning solar photovoltaic installations operate in either built environments or isolated locations where connection to the grid is very difficult or there is no energy infrastructure. It has a large potential to remarkably improve the quality of life of rural people. Solar off-grid systems can provide a better way of life in rural areas through providing lighting and electricity to basic health care centers and educational institutions [113,116]. For example, in India, 3600 remote villages were electrified by solar energy technologies [67]. By the year 2050, although the vast majority of people will live in cities, millions of people will still live in remote and rural areas where off-grid solar systems would likely be the most appropriate solution for minimum electrification [106]. In the Sub-Saharan Africa, off-grid solar lighting is growing at a breakneck pace. By the end of 2012, approximately 4.4 million cumulative solar lighting products were sold, with 90–95% annual sales growth since the year 2009 [83]. The importance of solar lamps is also growing as shown in Table 5. According to the trade information provided by the International Renewable Energy Agency (IRENA), there has been a notable increase in its imports over the past five years resulting in a decrease in the trend of utilizing oil or kerosene-powered lamps [23].

Household energy use accounts for a significant proportion of the total energy consumption in rural areas. They need energy largely for lighting, cooking, water heating, and space heating. Proper lighting in the villages increases community safety as well as the residents' productivity during nighttime. Nowadays, 89 million people in the developing world own a solar lighting product in their home [83]. Therefore, for rural areas where grid connectivity would not be possible or not cost-effective, off-grid solutions based on freestanding or stand-alone solar power systems may be taken up for the supply of electricity for those areas. Providing a primary level of electricity access via solar energy is more economically achievable. For example, the cost of kerosene lighting systems is more than 4–15 USD every month, while the cost of running a solar lighting system is 2.00 USD every month [117].

The solar home systems (SHSs) are recommended as a cost-effective form of providing power for lighting and devices in off-grid remote rural areas. In these areas, SHSs can be used for supplying household's energy demand. Around the world, SHSs provide power to millions of households in remote locations where electric power supply through the grid is not possible [118,119]. Bangladesh is the major market for SHSs worldwide and other developing nations such as China, India, and Nepal in Asia; Brazil and Guyana in Latin America; Kenya, Uganda, and Tanzania in Africa that are seeing rapid development of small-scale

Table 5
Trade data for solar lamps in selected countries, 2010 and 2014 [23].

Country	Imports (USD) 2010	2014
Ethiopia	0	9757
India	2632	24,207
Jordan	53	376
Mauritius	15	52
Zimbabwe	0	2183

renewable energy technologies, including renewables-based mini-grids to provide electric power for people who are far from the national transmission network [53]. In Bangladesh's solar home systems (SHSs) program commenced in 2003 with a target installation of 50000 SHSs over a five-year project period. The program far surpassed its objective and is currently installing more than 65,000 systems monthly, making it one of the fastest growing SHSs programs worldwide. Today, the program reaches a total of 13 million people or 9% of Bangladesh's population and has driven the development of a strong domestic industry that has employed approximately 100,000 people. The SHSs program is now targeting 6 million SHSs by 2017, with an estimated capacity of 220 MW of electricity [120].

Also, in Fiji, SHSs user's satisfaction with the systems installed was high and that the SHSs were accounted to be reliable and to be financially attractive choice compared to kerosene, benzine lamps, dry cell batteries or small petrol generators. Users revealed that they derived many benefits from the establishment of their SHSs apart from increased comfort, which included improved capacity for children to study at home, a cleaner indoor environment, the facilitation of social gatherings and capability to undertake activities at nights that couldn't be attempted using kerosene or benzine lamps [121]. Reduction of kerosene usage had the most significant impact of the utilization of SHSs, therefore SHSs were observed to yield less air pollution, less hassle of kerosene lamps and a better and sure light in off-grid rural areas. Solar energy utilization for supplying clean energy for a million homes would reduce CO_2 emissions by 4.3 million tons annually [122].

10.3. Solar energy for cooking

As described above, 2.7 billion people are still without clean cooking facilities and depending on the traditional utilization of biomass for cooking. The majority of people, which do not have access to modern energy services live in sub-Saharan Africa and developing countries in Asia [6,112,123,124]. Traditional and inefficient stoves are extremely toxic when burned and create indoor smoke pollution leading to serious health damage such as respiratory diseases, obstetrical problems, blindness and heart diseases [4,31,49], and inhalation of smoke inside the houses increases the risk of pneumonia and other acute lower respiratory tract infections in kids under five years old [125]. Women exposed to smoke suffer from chronic bronchitis three times more than women that cook with much cleaner fuels like electricity or gas. Similarly, the utilization of inefficient charcoal increases the risk of lung cancer among women in particular [30].

Solar cooking helps to decrease the use of fossil fuels and is the most direct and useful way of the application of solar energy. A typical hot box-type solar oven would save approximately 16.8 million tons of firewood and also reduces 38.4 million tons of CO_2 emission per annum [126]. The diffusion of solar cookers, for instance, for all its potential benefits, unquestionably requires local people to alter their traditional cooking habits [127]. Therefore, the use of inefficient traditional fuel for cooking is a widespread problem, which requires essential solutions to avoid serious health and environmental implications (i.e. indoor air pollution and deforestation). Renewable energy-based solutions to improve cooking practices are beneficial in reducing polluting fumes.

10.4. PV-refrigeration system

The solar-powered refrigeration systems harness an already-available resource (sunlight) and use it to run a cooling system with no reliance on the local electric grid. Photovoltaic power provides the energy required for the refrigerator [128]. PV-refrigerator systems increase food freshness and avoid wastage. Clinics with electricity can sterilize instruments and safely save medicines through refrigeration [4]. The solar-powered refrigeration systems do not have negative impacts on the environment. The utilization of PV-refrigerator systems is suitable for an alone system that can suitably be used in many remote areas without reliable electrical supply, however, refrigeration is continuously crucial [128].

10.5. Solar water heater

The solar water heaters (SWHs) use the solar energy from the sun to generate heat, which can provide hot water at temperatures ranging from 40 to 80 °C for domestic (showering, space heating) or industrial utilization [129]. A traditional hot water system operates through a hot water cylinder powered either by electricity or by diesel oil through the central heating boiler, which produces CO_2 emissions [48], while the solar hot water is a very reliable and practical. A 50-collector solar hot water system can reduce more than 50 t of carbon dioxide each year and also a 100-collector pool-heating system can reduce above 80 t of CO_2 each year or 5000 t over the life of the system [130]. On average, about 3.74 $TgCO_2$ (teragrams of CO_2 equivalent) can be saved per year, based on 2010 with the application of solar water heaters, which represents a remarkable reduction of emissions released into the environment [131].

10.6. Solar air collectors

The solar air collectors have been in particular developed in India for crop drying, food processing, and textile manufacturing sectors. Crop drying is a useful alternative to cooling for conservation, especially in a country where large amounts of agriculture products are lost through the absence of conservation techniques [75].

10.7. Solar powered water pump

The solar-powered submersible pumps are utilized for wells, boreholes, water transfer and irrigation and for livestock watering in particular. Nowadays, the price of solar PV modules has declined dramatically all over the world, making solar-powered pumping systems increasingly affordable. Solar pumping systems allow essential water resources to be accessed in the remote rural areas. The solar water pumps require no fuel and their maintenance is very minimal [132]. The solar-powered pump is a labor-saving technology and can reduce hours of labor daily workload in rural off-grid areas, where women and children have responsibility for water hauling. These pumps are durable and resistant to fuel shortages. In the medium term, they are not expensive as much as diesel-powered generators [4]. Compared to using fossil fuel-powered pumps, solar-powered water pumps do not emit gases associated with atmospheric pollution or global warming and also there is no fuel or oil to spill.

10.8. Solar desalination units

The introduction of renewable energy-driven desalination would be an environmental-friendly solution used to resolve the scarcity of fresh water resources. Moreover, renewable energy-powered desalination is mostly the only possibility of a secure fresh water supply in developing nations, especially in rural and remote areas where no electricity grid is available [133]. For instance, solar distillation of brackish waters is used to supply drinkable water for many of inhabitants in remote arid lands of South Algeria. Yet, solar desalination units are used to produce fresh water from brackish water through directly using the sunshine. These stills seem the best technical solution to supply in the remote rural areas in South Algeria with fresh water without relying upon high-tech and skills [134]. Solar-driven desalination is attractive as a method of conserving fossil fuel resources and reducing the carbon footprint of desalination [135].

10.9. Greenhouse heating

The solar greenhouses naturally rely on solar energy for heating and also lighting. A solar greenhouse equipped with thermal mass can be utilized for collecting and storing solar heat energy to maintain the temperatures necessary to grow plants in the colder conditions. In addition, the greenhouse can be insulated to maintain this heat for utilizing during the night and on overcast days. This will enormously reduce the need to utilize conventional fuels for heating [63].

10.10. Solar drying and dehydration systems

The solar drying and dehydration systems utilize solar irradiance for sustainable power supply to heat the air and as a complementary energy source. Solar dryers can widely be utilized in food and agriculture industry in order to increase quality and quantity of products while reducing the wastes and the environmental issues. A traditional drying system utilizes fossil fuels for their performance, while a solar dryer exploits the sun irradiation for drying and dehydration processes in industries such as fruits, bricks, plants, coffee, wood, green malt, textiles, leather and sewage sludge [136]. A solar-energy drying system is a potential decentralized thermal application of solar energy in the world, especially in developing countries. The solar dryers reduce the drying time significantly and basically provide better product quality in comparison to the traditional sun-drying systems. The roof-integrated solar dryer payback period is approximately 5 years [53]. Moreover, the use of solar dryer systems for drying agricultural products has enormous potential for energy conservation in developing countries.

As a result, solar energy is the best choice for generating electricity, cooking, heating, and large and small-scale applications. It is the source of energy that humankind can continue their daily tasks on the planet without depending on conventional fuels.

11. Identification of barriers to solar energy deployment

Although from among renewable technologies, solar technologies are highly reliable and mature, there are several limitations associated with them. While a few barriers are specific to solar technologies, others are specific to a region or a country. Many studies have been performed to identify the barriers to solar energy utilization in the developing countries. This part of the paper explains such barriers to solar energy implementation. The majority of barriers have been identified using exhaustive literature reviews.

11.1. Price of solar energy technologies

There are various barriers to the widespread deployment of solar energy technologies. The main challenge for the development of solar energy technologies that is seen in a vast majority of the literature reviews is the installation cost of these systems [65,71,82,98,110,115,116,127,136–143]. Many authors have identified the high cost and low efficiency of solar energy technologies as the most significant barrier in relation to solar energy utilization. For decades, solar panels manufacturers have struggled to become cost-competitive with manufacturers of other sources of electricity generation (i.e. fossil fuels and other renewable sources). Despite the reducing cost of installation of solar technologies in recent years, the cost of solar energy per unit of electricity produced is still higher than that of conventional energies. Cost reduction is vital for solar energy technologies to become widely accepted. In the future, higher prices for fossil fuels and also cost reduction in solar energy technologies make solar power economically competitive with power generation from conventional coal and natural gas despite the relatively high capital cost of solar power plants.

11.2. Low efficiency of solar technologies

Historically, one of the main concern about solar technologies has been the low efficiency and performance of solar systems [98,116,127,136,141,143,144]. The efficiency of energy conversion depends mostly on solar panels that produce electricity from sunlight. In general, practical solar energy systems have low efficiency. Power production from photovoltaic systems has the lowest efficiency that is far less than other renewables (e.g. wind and hydropower) and non-renewable technologies [81]. Single-crystalline silicon (sc-Si) solar cells have the maximum efficiency of above 25%. At the same time, the efficiency of multi-crystalline silicon (mc-Si) solar cells is about 21% [145]. Additionally, unlike fossil fuel technologies, location and weather conditions influence the power output of solar energy systems [65,82,98,139,143,146]. The efficiency of solar power systems generally depends on several environmental factors such as solar radiation, ambient temperature, relative humidity and wind speed at the site. In cloudy and rainy weather conditions, most solar systems such as photovoltaic modules do not operate under standard operating conditions.

11.3. Inadequate access to finances

Another barrier is the lack of access to finances. This has been highlighted by researchers as one of the main barriers to the development of renewable energy technologies, particularly solar energy [70,99,116,137,143,147]. Solar energy deployment is relatively capital intensive and this is a key risk to its success. Investment costs are generally higher in the developing countries than in the developed countries due to several factors such as poorly skilled work force, a need to bring qualified engineers from developed countries, and weak transportation infrastructure in these countries [148]. Financial institutions are reluctant to finance solar power projects. In many developing countries, it is difficult to get the long-term financing required for investment in solar projects and sometimes it is even impossible. This problem is due to regulatory or other significant restrictions on long-term bank loans. It is a risk that is associated with green energy sources for both private and public investment.

11.4. Inadequate government policy support

The lack of appropriate policies and regulations to encourage solar energy utilization in developing countries is another barrier to the development of solar energy technologies [110,115,137,139,140,148,149]. At the present, most developing countries, especially the poor ones, do not have a specific policy for solar energy utilization despite the possibility of using it. Poor national regulations almost hinder the adoption of solar energy systems in these countries. Policy frameworks must be well designed to reduce the capital cost of implementation for developers and regulatory risk for investors. For example, a feed-in tariff is the most effective tools for developing utilization of solar power technologies. This results in low-risk financing, which minimizes capital costs for renewables, particularly solar energy.

11.5. Lack of qualified engineers and skilled labors

Technical issues, shortage of skilled labors and qualified engineers are other barriers to solar energy utilization [82,115,116,127,137,140,142,143,149]. A common issue among the developing countries is the shortage of qualified engineering support to perform maintenance tasks and control failures. Developing countries suffer from a lack of technical expertise to implement these facilities. For example, in Mexico, a shortage in the indigenous human resource is a key barrier to make use of the high potential for development of solar technologies in this country [150]. In many developing countries, specific training for solar energy projects in universities, vocational centers, technical training centers and labor training centers is limited.

11.6. Lack of social awareness and acceptance of solar technologies

The acceptance of renewable energy technologies by communities is another challenge for solar energy development [98,115,116,137,142,143,151,152]. Public acceptance has been identified as a primary barrier that can significantly reduce the use of solar energy technologies in developing nations. In spite of the environmental benefits of renewable energies, renewable energy projects, particularly solar energy technologies lack widespread social acceptance in the developing nations, while it is an important aspect for successful implementation of solar energy technologies in these countries. Public acceptance is influenced by a number of factors, such as expected costs and benefits, social, economic and environmental risks, distance to the proposed power station and the regulatory setting [151].

11.7. Lack of consumer awareness of externalities of fossil fuels

The majority of the public in the developing world lacks enough knowledge about the externalities of fossil-fuel power generation and benefits of using renewable energies. Usually, in the majority of countries around the world, the externalities of fossil fuels combustion are not factored into the real cost. For instance, the largest damage to public health is caused by emissions of particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOC). Also, damages from climate change, associated with the high emissions of GHGs from conventional power plants have remarkable costs [153]. These costs are not borne via the energy suppliers or consumers, but the society has to pay in the form of medical bills and environmental cleanup.

11.8. Lack of appropriate physical infrastructure and logistics

Despite the fact that, rural and remote locations in developing countries are often rich in natural resources, they usually lack any preexisting energy or other appropriate physical infrastructure. There are a lot of road problems. In these countries, roads to access rural and remote areas, especially in rainy seasons, are very rare. Therefore, investors and engineers cannot access the communities that they target [137]. The lack of appropriate infrastructure will require a big initial investment to build infrastructure projects. These investments in infrastructure increase the cost of providing solar electricity, particularly during the initial years.

11.9. Need for back up or storage devices

The unpredictable availability of solar energy in solar systems makes storage devices a necessary component of solar generation systems [82,94,98,113,115,116,141,151,154]. For solar power systems, particularly off-grid, a storage device is required to provide electric power during cold or cloudy weather. The implemented storage technologies of solar electricity will alter the method of solar electric power generation on cloudy days or at night. As renewable generation increases and fossil generators curtail, renewable generation technologies themselves or the additional needed systems like storage devices will be essential to meet the increased need for energy services. Moreover, these devices will increase costs for owners of solar systems.

11.10. Low price of fossil fuels

In recent years, an extra barrier for deployment of solar energy has been the low crude oil and natural gas prices in global markets [138,155] The abundance of fossil fuel reserves (i.e. conventional coal, oil and natural gas) in many developing countries, particularly in the Middle East and the low price of these fossil fuels in global markets have posed the main challenge to the successful implementation of solar energy technologies in the world, especially in the developing world. In 2016, global crude oil prices were US$43.73 per barrel, while in 2011, crude oil prices were about US$118.71. This represents a 275% drop in crude oil prices from 2011 to 2016 [156]. The low oil price has caused renewable energies, particularly solar energy less attractive and less competitive compared with fossil fuels in many countries by continuing system payback periods [82,110,116,127,137,138,142].

11.11. Subsidies for fossil fuels

Fossil fuels receive many types of subsidy via both direct and indirect channels, which hinder investment in renewable energy technologies [16,72,149]. The subsidies paid by governments in the developing countries to the utilities for each kWh of electric energy produced from burning conventional fuels hinders massive adoption of solar energy systems in these countries. For example, the countries of the Gulf Cooperation Council (GCC) - Saudi Arabia, the United Arab Emirates, Kuwait, Bahrain, Qatar and Oman spend more than 100 billion USA dollars per year on energy subsidies [149]. The adverse effects of fossil fuel subsidies are that they damage the competitiveness of emission-free renewable sources.

11.12. Dust deposition on solar panels

In some regions around the world, dust deposition is a serious issue. In many desert areas, dust deposition rates are very high and have negative effects on solar system performance [67,143,157–159]. Dust deposition on solar cells or solar mirror surfaces is site-specific and it is modulated via several environmental factors such as soil parent material, local microclimate as well as frequency, intensity and duration of dust events [158]. The lands of many countries in the Middle East and North Africa region that are usually subject to strong winds are covered with a mixture of gravel, sand, silt, and clay. Dust and dust storms occur in all these countries almost during the whole year, particularly during the summer and the spring seasons. Deposition of dust decreases the amount of solar radiation reaching the surface of solar panels. Therefore, it can significantly reduce the efficiency of solar panels and the power output of solar energy systems. Technically, dust deposition reduces output power from photovoltaic systems from 2% to 50% in various areas [160]. Therefore, it is essential to maintain them by regular cleaning.

11.13. Environmental issues associated with solar energy technologies

PV manufacturers use some toxic compounds, explosive gases as well as corrosive liquids in their production lines. The presence and amount of these materials differ with the type of cell. Lead is often utilized in the cell metallization layer in silicon wafer-based modules by many manufacturers. Cadmium telluride (CdTe) thin-film modules contain cadmium (Cd), and copper indium selenide (CIS) solar cells contain selenium, which is toxic and harmful to the environment [65,72,82]. Therefore, it is essential to use quite rigorous control methods that reduce emission of hazardous elements in module production lines. As mentioned above, another form of environmental impact of solar energy systems is land use [72,126,139,140].

11.14. Unavailability of solar radiation data

Unavailability of enough solar radiation data at some locations is another barrier to large-scale development of solar energy [116,141]. Solar radiation resources are not distributed uniformly around the world. Unavailability of solar radiation data is a considerable barrier to solar energy utilization in many parts of the world. Solar radiation resources differ greatly depending on location and thus deliver different results depending on location factors. Therefore, the potential to derive a given specific percentage of electricity from solar energy will vary widely from location to location in many parts of the developing countries. Reliable and high-quality solar radiation data are required to establish solar energy projects in these countries. Awareness of such factors is important in developing effective policies in the developing countries to boost the use of solar energy for production of electricity.

11.15. Lack of research and development (R&D)

The lack of research centers has slowed the uptake of solar energy systems [115,116,127,141,142,144]. The high cost and low efficiency of solar panels are likely due to lack of R&D programs. The key focus of research institutes is to bring down the cost of solar PV panel while increasing solar systems efficiency. A lack of funding for primary stage research is slowing the deployment of solar energy technologies.

As a result, government policies in the developing countries have an important effect on development of solar energy technology since it is new and it is not close to its capacity in the world. Various supporting mechanisms are essential for the development of solar technology in these countries. Currently, there are several government-backed financial incentives to increase investment in clean energy sources worldwide. These supporting strategies could reduce the gap between the cost of electricity generation from solar energy and conventional fuels.

12. Recommendations

Finally, this study proposes some specific recommendations to overcome numerous barriers to the development of solar energy. In order to overcome the mentioned barriers and accelerate development of application of solar energy systems in the developing countries, there will be a need for positive approaches and strong political strategies from the governments at all levels. In the last decade, various forms of financing programs such as capital subsidies, feed-in tariffs (FITs), R&D work, taxes credits, low interest loans, net-metering and other incentive programs have been put into effect for increasing the deployment of solar energy technologies.

12.1. Capital subsidies

In order to increase the use of renewable energy sources, subsidies for conventional energy should be slowly removed or transferred to RETs or at least the same subsidies should be given to renewables RETs [161,162]. Subsidies to renewable energy technologies are beneficial to the environment, can increase incentives to invest in cleaner technologies and can improve the competitiveness of renewables by reducing their price relative to conventional fuels. In poor rural and remote communities, subsidies to local renewable power generation sources such as solar energy technologies can provide access to electricity to improve life of the people in these areas.

12.2. Feed-in tariffs

The governments of developing nations should adopt a decree and order on the price and subsidies for the purchased electricity from the qualified producers of electricity from solar energy systems. Feed-in tariffs (FITs) subsidize renewable electricity generation. Feed-in tariffs have been the primary policy mechanism utilized for supporting development of renewable energy technologies in industrialized countries. This mechanism has played a considerable role in promoting solar energy technologies in countries like Germany, Spain, Italy, France, Japan, China, and the USA. The feed-in tariff can easily be associated with other support programs like tax credits or capital subsidies [163]. FIT is considered to be the major drive for the recent growth of grid-connected photovoltaic (PV) and grid-connected concentrated solar power (CSP) [164]. Deployment of solar photovoltaic (PV) systems has strongly increased in Asia, especially in Japan and China. The Japanese expansion being supported via generous feed-in tariffs instrument [19]. Indeed, half of the global solar photovoltaic installations are due to this instrument [161,162].

12.3. Low interest loans

Low interest loans are essential in the developing countries for the purchase of solar energy systems. Many financial institutions should offer low interest loans to their customers to purchase solar systems. For example, many home owners in USA and Malaysia have financed their solar systems through low interest loans (4–5%). In New York, the government offered loans at low interest rate (4%) to home owners for installation of solar photovoltaic (PV) systems. As a result, many people were interested in solar photovoltaic (PV) installation. Each user can borrow more than 20,000 dollars for a period of 10 years [143]. In developing countries, governments should offer loans with reduced interest rates as incentive for the residents in those countries to install solar systems.

12.4. Net metering and self-consumption support scheme

Net-metering and self-consumption schemes allow a reduction of PV owners' electricity bills, taking benefits of compensation for electricity consumption and power produced by the PV system. The net-metering mechanism allows residential and small-scale commercial solar electric power producers to sell surplus electricity produced via their PV systems to a utility company at standard retail prices and receive credit on their utility bill. This credit offsets the customer's electricity consumption during off-peak times at a much lower rate, which reduces the amount of electric power the customers buy back from the utility. This scheme provides an extra financial benefit for consumer-owned solar PVs [154]. A net-metering mechanism exists in many countries, particularly in the USA and several EU countries like Italy, Belgium, Denmark, Greece and the Netherlands to provide an incentive for photovoltaic (PV). Self-consumption is another electricity compensation scheme in some countries like Germany. In this country, a PV owner can compensate for the electricity generated by the photovoltaic system via a self-consumption mechanism, therefore reducing their electricity bill [163].

12.5. International aid

Developing countries should be encouraged and greatly assisted for establishing developed renewable energy programs. Further cooperation between the industrialized and the developing world is needed for development of renewables. The World Bank (WB) and Global Environmental Facility (GEF) have been providing funds for RETs to developing countries since 1993. From 1997–2007, the World Bank and Global Environmental Facility supported China with 40 million USA dollars in the form of grants and loans. Due to that support, within those 10 years, China became one of the top manufacturers of solar modules and the balance of system (BOS) components worldwide [165].

12.6. Tax credits policy

In the USA, the tax credit policy is one of the main federal government incentive instrument to support the development of solar energy technologies. It is a 30% tax credit for solar energy systems on residential and commercial properties. In the USA, 24 states offer tax credits. For instance, the government of Hawaii offers a 35% tax credit for personal solar photovoltaic systems. This program reduces the cost of generating electric power using renewable energy sources [154]. Also, tax credits are used in many EU countries like Belgium, France, Italy, the United Kingdom and the Netherlands. Similar to capital subsidies, tax credits depend largely on government budgets and are extremely sensitive to political conditions [163]. In the EU countries, a large range of other initiatives in tax incentives (direct and indirect taxes) exist to promote the use of renewable energies. These direct taxes include personal income tax, corporate tax, property tax, and indirect taxes, including value added tax (VAT) and excise duty exemptions that can be found in [166].

12.7. Carbon tax or cap-and-trade

Introducing a price on emissions of carbon either by carbon taxes or top cap-and-trade schemes is essential to promote the use of non-polluting energy sources. Policy options include a carbon tax, under which electric power producers are required to pay a certain tax per ton of carbon dioxide released to the atmosphere, and a cap-and-trade scheme, in which the government issues permits and sets a cap on the total amount of carbon dioxide that may be emitted. Under a cap-and-trade system, emitters could be allocated permits or required to buy permits to cover their carbon emissions. Those who would need to increase their emissions might purchase credits either from those who have decreased their emissions or from other markets. This scheme can have positive impacts on the deployment of clean energy sources [154,167].

12.8. Skilled workforces

Skilled workers are one of the most significant factors in the development of solar energy technologies. From research to installation and maintenance, solar systems market needs skilled workforce. Highly skilled and well trained people are needed for technology development, customer's confidence in the quality of installation, reliability and cost reduction. To ensure all these factors, there should be educational institutions and training programs for specific target professional groups such as government planners, home builders and architectures [143]. Training and educational programs in installation and maintenance of solar technologies are crucial to any solar rural electrification scheme. In order to cope with this problem, some companies have been training local people to solve solar energy problems that can happen post-installation [137]. It is very important to employ skilled labor to operate and maintain solar systems already installed and to be installed in the future.

12.9. Technological and R&D incentives

Increasing durable long-term support for research and development (R&D) is essential to fully exploit the potential for further technology improvements and reduce the cost of solar technologies. Research and development programs are being carried out for further improvement in solar technology efficiency and reduction in manufacturing cost of PV modules [72]. In developed countries, many institutes are working on solar technologies to increase the quality of solar equipment and components. Experts can provide essential services to solar energy projects. Since high cost is the main barrier to RETs penetration, R&D programs have been set up to make it more competitive with other renewables and conventional fuels. Long-term RETs costs can be reduced through increasing research activities [111]. A practical and usually useful way is to provide a larger budget for research work regarding solar energy. Governments in the developing countries should increase funding for renewable energies research.

12.10. Increasing awareness about environmental impact of conventional fuels

Increasing awareness about the environmental impact of carbon dioxide (CO_2) and other harmful emissions and also increasing awareness of benefits of renewable energy sources is an appropriate response to questions about consequences of climate change and energy security. Therefore, it triggered further interest in environmental friendly technologies. People also may have insufficient knowledge about non-renewable resources that they use and their environmental implications. In fact, community awareness about the negative environmental impacts of conventional sources of energy and acceptance of renewable technologies are important factors for successful implementation of these technologies in the developing countries. The governments should take initiatives to make customers aware of renewable technologies and their benefits. As many consumers become more aware of environmental issues related to fossil fuels use, they become more willing to switch to green energy technologies. Finally, it is necessary to take into account the various environmental externalities of conventional fuels such as air pollution, healthcare costs, future costs of climate change, reduced life expectancy and premature deaths. To overcome cost barriers, global warming emissions and related negative externality costs need to be accounted for to increase the price of carbon-emitting fuels relative to non-carbon energy resources. In this way, non-polluting energy sources could fulfill their large potential contributions to climate change mitigation, energy security and economic development.

13. Conclusion

Ensuring access to reliable and sustainable modern energy services is vital for development. The most important environmental issue relating to energy production and utilization is the greenhouse gases and their harmful effects. The high potential of renewable energies to provide an increasing share of future energy growth without increasing greenhouse gas emissions has been making countries to consider the role of renewables in meeting future energy needs.

Solar energy technologies have a great potential for overcoming energy poverty issues for growing population and raising the living standards. Since solar energy is zero air pollution during power generation, thus it provides excellent environmental benefits when compared to the conventional energy sources; it reduces CO_2 emissions and other pollutants, slows down the global temperature trend and suggests a workable model for sustainable energy strategies.

Solar energy as a renewable energy can play a crucial role in achieving safe and secure energy future with diversification. Solar electric power systems and solar cookers are the most direct and useful applications of solar energy technologies. The solar cookers provide better kitchen environment to rural women in the developing countries and as a healthy option can improve their health standards. Off-grid solar system solutions can be deployed rapidly and customized to local needs and are often the only option for electrification in areas where grid extensions are financially or technically infeasible. Although solar energy has many advantages for the environment, economy, and society at large, there are some barriers impeding the solar energies diffusion such as the installed cost of solar panels, which is an important challenging aspect.

In order to promote and ensure the rapid, effective and smooth development of solar energy, the governments of developing countries have to formulate a series of policies on solar energy development and reducing dependence on fossil fuels and biomass resources, including laws, regulations, economic encouragement, tax incentives as well as technical research and development. Removing or reducing inefficient fossil fuel subsidies or introducing a significant support program could make investments in solar energy profitable.

As a result, replacing the carbon-intensive energy sources with renewable or other lower-emission energy sources will reduce dramatically greenhouse gas and other harmful emissions associated with energy production and consumption in future. Since the potential of solar energy is substantial in many developing countries, it is enough to replace conventional fuels and therefore it will reduce energy related-emissions in these countries.

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