THE AVAILABILITY OF USING SOLAR ENERGY IN SUDAN

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Abstract
Utilization of renewable energy resources not only generates useful energy but also aids in climate change mitigation. Energy development in Sudan has always been slow and the current generation only covers less than half of the total demand. Although multiple renewable energy resources are available, but due to the low economy all the types of energy systems cannot be developed together. The government seems to be perplexed in choosing the best among the alternatives as all the alternatives seems to be important and feasible. It becomes very important to prioritize them based on the population needs, resource availability, technical capability and environmental friendliness. Furthermore, it is also crucial to identify all the influencing actors that have major impacts on the development of energy systems in Sudan. This research identifies the most important actors, factors for exploitation of solar energy which could be guidelines for the policy makers and researchers during the development of energy systems not only in Sudan but also applicable to other developing countries. Present huge energy demands particularly from the residential and agricultural sectors are causing more pressure on Sudan already crippling economy. For a country like Sudan, solar energy according to the study acquires a huge potential in terms of contributing to the energy sector and development of the country altogether. However, the study also identifies how solar energy potential is being challenged by country lack of incentives and current policies. With present circumstances, off-grid solar energy systems (e.g. Stand-alone Photo-Voltaic systems), could play a large role in making a positive change to the country and its development. Many successful solar projects implemented in neighboring countries should be encouraging Sudan to follow the same experience. With having supporting policies along with various mechanisms of securing financing under a transparent cooperative context between various stakeholders could serve as a roadmap in promoting such a valuable technology in which Sudan is in desperate need of it.

Keywords: Sustainable Development, Historical background, Sudan, Influencing factors, Solar energy, Present parameters, Off-grid systems, Stand-alone PV systems, Discussions

1. Introduction

Sudan is in the midst of an energy transition. After losing its oil rich South the country is now seeking for alternatives. Alternatives that can secure its energy needs and yet meet Sudan action plan in combatting climate change. There are many types of renewables which provide clean environmental friendly energies. These range from biomass, hydropower, solar, wind energies and others. With a country like The Sudan that has vast areas of fertile land, abundance of minerals, water, winds and sunshine, many types of these energies become a valid option. However, in this research, the focus shall only be concerning one type of renewable energy that is the solar energy.

There are several reasons for the choice of solar energy over other types of renewable energies. First and foremost there are limited studies conducted over solar technology in the country. This is rather reflected in its current magnitude of contribution into Sudan energy sector. While hydropower dominates the country power supply sector with 70% share, solar energy at the bottom of the list poorly provides less than 0.1% share [1].

Abundance of the prime natural source in the country (i.e. solar radiation) enhancing solar energy, justifies too the urge of exploring such a technology. Sudan has been considered as one of the best countries for exploiting solar energy since its average sunshine duration ranges from 8.5 to 11 hours a day. It is also worth noting that the technology prime source (i.e. sun light) is free and requires no foreign permission, involvement or sharing., unlike the most invested in renewable energy in the country (i.e. hydropower), which usually requires permissions and approvals from many stakeholders and even neighboring countries at times (e.g. hydropower and Nile river).

Sudan huge loss in crude oil export revenues post South Sudan independence in 2011 obliges the country seek more cost effective energy solutions to avoid putting more pressure on the economy.

Solar energy could provide such alternative during this transition, especially since it offers a wide range of appliances under its umbrella. This rather unique feature from an energy perspective could also help address different needs at different locations (especially remote areas). For a large country like Sudan with varying terrains, landscapes and many communities living in remote areas without access to electricity, exploring such technology becomes vital.

Apart from providing energy, solar technology could play a key role in helping Sudan achieve its national goals in contributing to sustainable development, reducing poverty and long term negative impacts of climate change. The International Energy Agency (IEA) expects that by year 2050, 30 GT of CO_2 emissions could be avoided just by using Photovoltaic Solar technology alone [2].

There are many available successful stories in the region (e.g. African and Arabian Gulf countries) which entail solar energy adoption. Some involve huge investments and others that are relatively small, both in strong and weak economy states. Such experiences would inevitably help Sudan address its present transition and plans for its future.

The potential of using renewable energies depends primarily on the available resources and associated costs [3]. Being more specific however, the term potential in essence could be identified in different ways. Depending on the discussed topic and context, single, multiple or even various combinations of the terms given below could be used:

A. Theoretical Potential: Where the general physical parameters are taken into account (e.g. based on the determination of the energy flow resulting from a certain energy resource within the investigated region). It represents the upper limit of what could be produced from a certain energy resource from a theoretical point of view, based on current scientific knowledge. [3].

B. Technical Potential: Where technical boundary conditions are considered (i.e. efficiencies of conversion technologies, overall technical limitations) [3].

C. Realizable Potential: This represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active [3]. Thereby, general parameters as e.g. market growth rates, planning constraints are taken into account. It is important to mention that this potential term must be seen in a dynamic context i.e. the realizable potential has to refer to a certain year.

D. Long-term Potential: Involves a set time-frame (for e.g. year 2050) where achievable potential can be realized [3]. This is closely linked (among other constraining factors) to infrastructural prerequisites.

In our study for Sudan Solar energy potential, we shall be using a combination of all above terms, especially since the magnitude of possible solar energy projects could be quite broad in such a large country like Sudan. We should also be aware and consider the present physical parameters of Sudan as noted in the Theoretical potential definition yet still understand the rewards of Solar energy should all existing barriers be removed. In order to gain a more comprehensive understanding of how reliable and to what extent would Solar energy be beneficial for the country as a whole, solar energy implications in terms of economy, physical and environmental typical features will be highlighted and studied. For a country like Sudan that has gone through a number of wars and political instability, speaking of long-term potential could be certainly difficult, however we could always hint into how solar energy could positively contribute into Sudan environment and development altogether.

Aspects of sustainability represented by its three main pillars (i.e. economy, environment and society) shall also be an integral part of the study.

2. Historical Background

Sudan is endowed with abundance of resources. In fact the country main source of wealth lies in its natural resources. These represent fertile areas of land, abundance of water from the Nile rivers and ground water or other resources such as livestock, gold, uranium and other numerous embedded minerals. Unfortunately, Sudan resources have not to this very date been properly employed to bring the country and its people the success and prosperity they are in desperate need of. On the contrary, many of the country conflicts today, are attributed to the control and distribution of these resources.

The agriculture sector remains Sudan largest and influential sector in terms of the country economy. It contributes about 41 per cent of GDP and 80 percent of exports; it employs more than 65 per cent of the labor force and provides 50 per cent of raw materials for the industrial sector [4]. Though the contributions seem to be ample, these are considered small when compared to the potential of the sector. Reasons for such limitation are attributed to inadequate policies and investments within the sector along with weather conditions [4].

The country has experienced several armed conflicts since its independence in 1956. The two civil wars fought between the Northern Sudanese government in Sudan (1955-1972) and the government in Southern Sudan (1983-2005), were the longest conflicts in the unified Sudan back then. It was in 2005 when the second civil war ended with the two parties signing of the Comprehensive Peace Agreement (CPA). This consequently led to a referendum in 2011 which resulted in South Sudan independence. Prior to the split and in 2010, the unified Sudan was the second-largest oil producer in Africa outside of the Organization of the Petroleum Exporting Countries (OPEC). However, South Sudan gained control of about three quarters of the oil production when it became independent in July 2011. According to the International Monetary Fund (IMF), Sudan crude oil export revenues fell from almost $11 billion in 2010 to just under $1.8 billion in 2012. Hence, it is no surprise that South Sudan independence has left a great negative impact on Sudan economy.

Today, Sudan still has majority of the original area, with it now being 1,861,484 square kilometers [5]. The country still enjoys variety of landscapes across its area. While there are extensive swamps found in the southern part of the country, vast deserts cover up the north. In the far south and west of the Red Sea coast, low mountains exist. Highland mountains (the Nuba mountains) lie in the middle region of the country. Yet, running across the country from South to North flows the two strategic rivers (the White and Blue Niles) which join at the capital Khartoum to become The One Great Nile - which continues downstream all the way to Egypt [5].

Varying climate is quite indicative in The Sudan. While northern part of the country exhibits higher temperatures and rare or occasional rainfalls, southern Sudan, typically tropical, has relatively abundant and frequent rainy seasons which can go up to six to nine months. Dust storms are quite common in the central and northern part of the country [5].

Sudan like many other African states suffers from impacts of climate change. The country major economic sector (agriculture) has been and continues to be heavily affected by this. Several long devastating droughts and nearly annual floods have already caused huge detrimental effects on the population, livestock and land. Sudan First National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) and National Adaptation Programmes of Action (NAPA) identified the three sectors most vulnerable to climate change: water resources; agriculture (food production and economic livelihoods); and human health [4].

According to the World bank (2017), Sudan population reached 40.23 million year 2015, with most of the population living within 300 to 500 kilometers of Khartoum [5]. The country has hundreds of ethnic, tribal divisions and language groups. In fact, Sudan is considered to be one of the most ethnically and linguistically diverse nations in the world [5]. Two prevailing cultures noted include one that is of an African descent and another, which is Arab.

In terms of human development, the UN 2013 Human Development Index (HDI) report, ranked Sudan at the 171st place (from a total list of 187 countries) [6]. Even neighboring Arab countries with similar populations achieved better results than the Sudan. The HDI measurement which basically reflects achievements within three basic dimensions of human development, including a long healthy life, attainment of knowledge and a decent standard of living, indicated Sudan weak performances in many aspects altogether.

Today, with still many ethnic minorities forming Sudan, enmities and conflicts between and amongst various tribes and the government in Khartoum are still being evident. Key present conflict is the one between the various armed factions in the western province of Darfur and the Sudanese government. A conflict, which resulted in The International Criminal Court (ICC) issuing an arrest warrant for war crimes and crimes against humanity against the Sudanese president in March of 2009 [7].

Clashes between various opposition forces and successive Sudanese governments across the country have been quite common since Sudan independence in 1956. Sudan governance today is widely recognized as an authoritarian state. The political structure of the country changed following a military coup led by the current president Omar Al Bashir in 1989 [8]. Back then and for many years, all effective political powers were literally seized by the president. It was only recently in 2010, when Sudan held its first presidential elections since the military coup. Despite the international arrest warrant by the ICC in 2009, the Sudanese president was re-elected twice, once in 2010 and a second time in 2015 [8].

In addition to the wars and conflicts, the country suffered further from U.S. sanctions since 1997.

Sanctions, that involved a comprehensive trade embargo and blocked assets of the Sudanese government (Department of the Treasury OFAC [9]). However, just recently, mid-January 2017, the U.S. Department of the Treasury Office of Foreign Assets Control OFAC) issued a general license to suspend the OFAC-administered embargo on Sudan and conditionally terminate most U.S. sanctions on the country within a six months' time frame [10]. Another rather transformation in Sudan foreign relations is its recent announcement, in April 2017, of a strategic partnership with the oil rich Arab Gulf countries. Agreements including financial aid, investments, security and military cooperation are expected to be forming the yet to be signed partnership. (Sudanese Media Center [11]). Sudan too like many conflict torn countries suffers from widespread corruption. According to the 2011 Transparency International Corruption Perceptions Index (177 out of the 183 assessed countries) Sudan ranked among the most corrupt countries with a score of 1,6 on a 0 (highly corrupt) to 10 (highly clean) scale [12].

The country performed extremely poorly on the 2010 World Bank Worldwide Governance Indicators, scoring well below 10 (on a scale of 0 to 100) in all areas of governance assessed, and to date still showing no signs of improvement [12]. The country scored only 0.9 in political stability, 6.2 in rule of law, 7.2 in regulatory quality, 6.7 in government effectiveness, and 4.3 in control of corruption [12].

One key parameter to indicate and promote a development of a nation lies in the availability of energy. Not only is energy a prerequisite to any economic development but it enables basic human needs such as food, shelter, education and health services be met (Energy and Development, 2004).

More than 70% of Sudan population lives in rural and isolated communities. Unavailability and extreme shortages of conventional energy supply in these areas forced people use biomass as their ultimate source of energy [13]. As is the case with many developing countries, direct burning of fuel-wood and crop residues, constitute the main usage of Sudan biomass [13]. Sudan indicative high dependence on biomass woody fuels (firewood and charcoal) reflects the poor situation of the conventional energy in the country. A recent conducted study, which aimed in preparing an energy Sankey diagram, first of its kind for Sudan in 2014, concluded the following: a. Sudan main sources of primary energy included: Oil, hydroelectricity, biomass and renewable energy [1]; b. Main transformation and conversion processes were electric power generation, oil refinery and wood-to-charcoal conversion [1]; c. Most consumed primary energy source was Biomass with 56%, followed by Oil with 39%, Hydroelectricity with 5%; d. Imports compromised of 1427 ktoe (kilo ton of oil equivalent) of fuel oils and 40 ktoe of electricity from neighboring Ethiopia [1]. Table 1 below, concluded from the same study, indicates Sudan energy balance as of year 2012.

Table 1 Sudan Energy balance 2012

Demand Sectors	Power		Oil		Biomass		Total	
	ktoe	%	Ktoe	%	Ktoe	%	ktoe	%
Residential	401	54.3	298	7.9	3088	62.2	3911	40.0
Transportation			2994	79.2			3073	31.4
Services	181	24.5	43	1.1	1303	26.2	1579	16.1
Industry	120	16.3	400	10.6	575	11.6	1133	11.6
Agriculture	36	4.9	43	1.1			85	0.9
Total	738	100	3778	100	4966	100	9781	100
Share of Energy supply	7.5		38.6		50.8		100	
Share of Energy supply	7.5		38.6		50.8		100	

Looking at the table, it is rather clear that the residential sector had the highest energy demand amongst all other listed sectors with 40% share and 3911 ktoe. It is also indicative that the biomass energy contribution was the largest with 62.2% worth of share in fulfilling the energy demands for the residential sector.

Altogether and according to the study which has been collected from several local official reports (listed below), the biomass sector clearly dominates Sudan energy supply scene.

Official reports forming the study included: Annual report of Sudan Central Bank, Annual reports from the Ministry of Oil and Gas, Annual report from the Directorate of Agriculture and Forestry, Annual report from Sudanese thermal power generation corporation.

The study also looked in depth into the power supply, the respective producers and demands by several sectors in the country. Table 2 below summarizes the electric power supply and consumption in base year 2014 [1].

Above data clearly indicates the dominance of hydropower within the power supply sector in Sudan. A strong 70% share of hydropower is followed by the thermal power with nearly 26% share. Least of all, in terms of power supply stems photovoltaic with only 0.03% share. Not surprisingly, yet again the residential sector represented the largest sector in terms of power demand (with nearly 50% share).

Table 2 Electric power supply and consumption in base year 2014

	Power Supply (ktoe)					Power Demand by Sectors (ktoe)					Total
	Hydro	Thermal	IC	Import	PV	Residential	Industrial	Agriculture	Service	Transport	
Public sector	767	677	17	40	0	534	151	52	283	0	1019
Oil industry	0	54	0	0	0	0	29	0	0	0	29
Sugar industry	0	61	0	0	0	0	61	0	0	0	61
Renewable	0	0	0	0	0.4	0	0	0	0.4	0	0
Total	767	285	17	40	0	534	240	52	283	0	1109
%	69.11	25.65	1.57	3.63	0.03	48.12	21.68	4.67	25.53	0	100

It was back in 1991, when Sudan created the Ministry of Higher Education and Scientific Research (MHESR) to take the responsibility of all matters concerning renewable energies. To date, the ministry role covers all aspects from policymaking, planning and promoting along with management and coordination between the various parties [13].

Recently numerous and broad base of technologies from biogas plants, wind turbines, micro hydropower all the way to solar thermal and PV systems, are all managed by Sudan Energy Research Institute (ERI)-National Centre for Research (NCR) [13].

According to Energy Research Institute in Nottingham, although Sudan renewable energy strategy is well integrated in the National Energy Plan and clearly spelled out in the National Energy Policy, more is yet to be done.

With an average sunshine duration of about 9 hours a day, Sudan solar energy achievements so far appear to be very poor. Most of the solar technology installations in the country are Photovoltaic (PV) with a total installed capacity of about 2 MW [1]. Approximately half of the installed capacity is associated with the telecommunication industry (e.g. remote off-grid antennas and satellites). Table 3 below indicates the country total solar energy technology achievements as of 2010 [13].

Table 3 Sudan total solar energy technology achievements as of 2010

Source System	Status (unit)
Industrial solar heaters ($16m^2$-$80m^2$)	150
Solar cookers	2,000
Solar stills ($1m^2$-$10m^2$)	100
Solar dryers	10
PV solar refrigerators (120W-250W)	200
PV communication systems	30
PV solar water pumps (1.5kW-5.5kW)	120
PV solar lighting systems (40W-1.5kW)	1,000

The country, represented by its Ministry of Higher Education and Scientific Research (MHESR), does realize the importance of renewable energy and solar energy in particular in solving essential live problems especially in rural parts of the country. As part of this, few solar energy plans listed hereunder have been initiated: installation of 200 solar pumps in the rural areas every year to achieve self-satisfaction of drinking water in areas suitable for solar applications; lighting of rural areas at a level of 2 MW every year starting with 50 kW (8 MW for 10 years of the program); popularize the use of solar refrigerators by the installation of 300 units per year for vaccines and medicines preservation for human beings and animals; solar water heating in hotels, hospitals, and relevant industries through the installation of 500 units every year; disseminate the use of solar cookers in the northern states for household use through the production of 1000 units every year [13].

3. Availability of Solar Energy

The idea of using power from the sun for heating and lighting routes all the way to the 5th century B.C.; where back then the ancient Greeks designed their homes to capture the sun heat during winter. It was not until the 19th century where entrepreneurs from both the U.S. and Europe formed and concluded the basis of solar energy modern designs [14].

Two French inventors (Edmund Becquerel, an experimental physicist and August Mouchet, a mathematician) played key roles into the development of modern solar energy. While Edmund in 1839 found that certain materials produce small amounts of electric current when exposed to light; few decades later and in 1878, it was Mouchet, his fellow citizen, who first invented a solar-powered steam engine.

Since then there was huge interests in the potential of solar energy. It was estimated that between years 1880 and 1914, there were almost 50 articles on solar energy published in the popular influential science magazine back then the Scientific American [14]. During the same period, there were many attempts by various newly launched companies in adopting the solar energy business. For instance, during the 1890, many solar water heater companies opened in California. Failures, challenges and commercial interests were also quite common at the time. With both coal and fossil fuels widely available and cheap, it was quite difficult to see a solar energy boom.

However, more ambitious schemes were launched in the developing countries. The first attempt of such kind was initiated by William Adams in the 1870s; an engineer who served as deputy registrar of the High Court at Bombay. He came up with plans to use concentrated sunlight to make the high pressure steam needed to run modern steam engines. Although the colonial government in India was extremely skeptical about his plans, local engineers from other British colonies like Aden in Yemen, adapted Adam apparatus successfully in producing drinking water [14].Greatest progress noted in the region during that time was in Egypt. Thanks to an American entrepreneur Frank Shuman who was attracted to Egypt due to the abundance of sunlight and to the irrigation projects near the river Nile. After leasing a farm adjacent to the Nile, Shuman successfully launched a cost effective solar plant which over time upgraded the entire Egyptian irrigation system. Shuman success thrilled the British administration to an extent that they offered him 30,000 acre cotton plantation in British Sudan in order to build a larger version of the solar plant. However this project along with other several ambitious solar plans he had planned were all brought to an end by the outbreak of World War I [14]. Presently two main large scale methods or forms of solar energy exist by which sunlight is converted into usable energy: Solar Thermal energy by conversion of warmth to either thermal, heating application or electricity generation ; and Photovoltaic (PV) energy by conversion of radiant light quanta into electricity.

A. Solar Thermal Energy: This form of energy, in simple terms, involves absorption of sunlight by a blackened surface which accordingly warms up. By passing either air or water through this warmed surface these can be consequently warmed and then later either stored or transported to wherever they are needed.

There are two categories that form Solar thermal energy: Solar thermal non-electric which includes applications as agricultural drying, solar water heaters, solar air heaters, solar cooling systems, solar cookers [15] and Solar thermal electric which entails heat to produce steam for electricity generation, also known as Concentrated Solar Power (CSP). Four types of CSP technologies are currently available in the market as Parabolic Trough, Fresnel Mirror, Power Tower and Solar Dish Collector [15]. Typical examples of today use of solar thermal technology systems include: Heating water in commercial buildings, swimming pools, apartment and houses; Space heating/cooling of buildings and Supplying power for absorption heat pumps [16].

B. Solar Photovoltaic Energy: Here the conversion occurs whenever sunlight falls onto a solar cell. This accordingly, induces an electric tension in which with several cells combined in a panel, enables the generation of enough current to drive for instance an electric pump or charge a battery.

Depending on how the system is installed and set, there can be a wide variety of photovoltaic applications. These can range from large scale energy production in power plants all the way to small sized energy required by calculators. Different ways of setting up photovoltaic systems include:

Grid connection: In this setup electrical energy from the PV system is transferred directly to the national power grid. Using inverters connected to the network, voltage and frequency of electrical energy produced can be adjusted to meet the required parameters of the national power grid [16]. (Fig. 1) below illustrates a typical setup for a grid connected PV system.

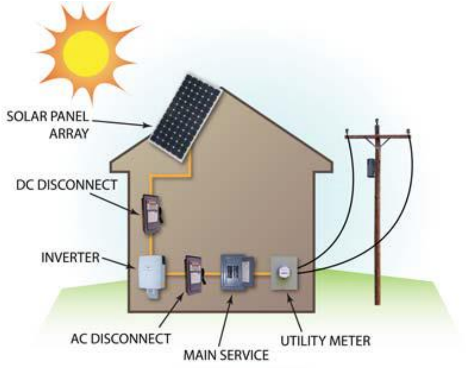

Fig. 1 Typical setup for a grid connected PV system

Stand-alone PV system: This is generally used for generating power in areas lacking electricity network. In fact, this type of system contributes significantly to the world off-grid power generation [16]. Typical applications where such system is used includes providing energy for rural areas, remote villages, residential houses and telecommunications. (Fig. 2) below illustrates a typical setup for stand-alone PV system.

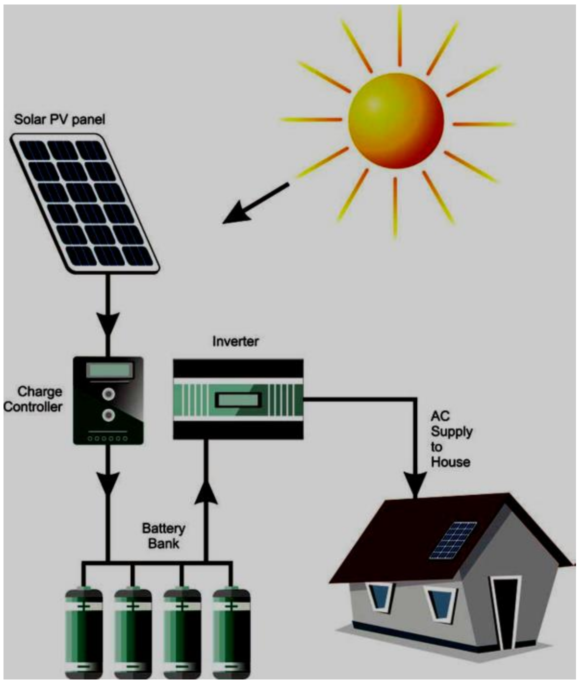

Fig. 2 Typical setup for stand-alone PV system

In addition to power generation, PV can be used in many other ways. The following are common examples:

Solar lighting: Used in residential areas, schools, parking lots, road stations and tunnels; Portable Solar generators: Most common examples include solar vehicles and solar calculators; Water pumping: Increasing demands in this sector reflects both the capabilities and the functionality of such system; Applications range from domestic use to irrigation and livestock watering; and Cathodic protection: Protective electric current that prevents underground pipelines and tanks from corrosion.

C. Present Global Markets and Shares of Solar Energy: Installations of solar energy technologies grew exponentially over the last decade. Sustained policy support in countries such as China, Germany, Italy, Japan along with U.S. were the reason behind this recent growth of solar technologies [15]. (Fig. 3a) below indicates the trend of global PV (both grid and off-grid) installed capacity from years 2000 to 2010, whereas (Fig. 3b) highlights the countries share in global installation as of year 2010.

An indicative exponential increase is exhibited between years 2000 to 2010. The World Bank states that an average annual growth rate of around 49% has been achieved during the 10 years period.

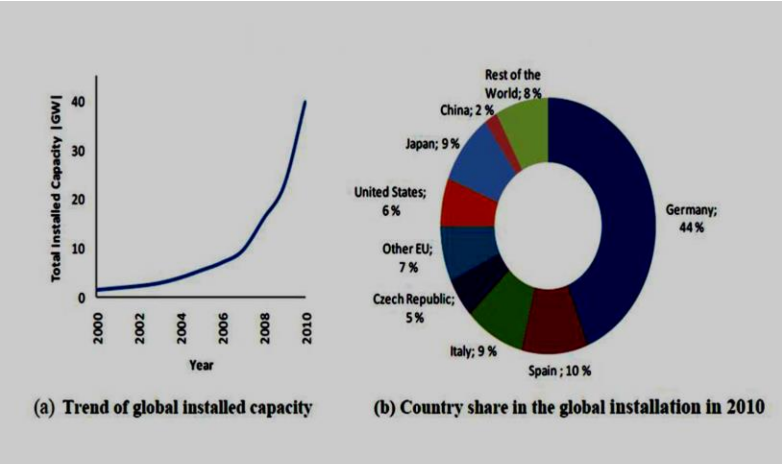

Fig. 3 (a) Trend of global PV (both grid and off-grid) installed capacity from years 2000 to 2010, whereas and Fig. 3 (b) Countries share in global installation as of year 2010

Solar thermal energy represented by CSP has also grown rapidly. Installed capacity of CSP more than doubled over the last decade to reach 1,095MW by the end of 2010. Non-electric solar thermal technology increased almost 5 times from 40 GWth in 2000 to 185 GWth in 2010 [15].

In 2010, a total of 185 GWth amounted for the installed solar collectors (i.e. non-electric solar thermal) worldwide with only four countries, namely China, Germany, Turkey and India all contributing to over 86% of the world solar collectors installed share.

4. Solar Energy Influencing Factors

There is no doubt that the prime source forming solar energy (i.e. solar radiation) is free and abundant, however when we wish to analyze and discuss the success or failure of putting such renewable energy into practice then a closer look into solar energy influencing factors need be considered. The following section looks closer into these critical factors and highlights their significance in promoting solar energy plans and projects altogether.

A. Natural Resource and Environment: The efficiency of solar panels (consequently the solar energy output) depends on three factors: The intensity of the solar radiation flux, The quality and the operating temperature of the semiconductor in use and The operating temperature of the semiconductor cell [17].

Though the two latter factors may somehow, in one way or the other, be altered and improved; the intensity of the solar radiation flux however, to a great extent, is simply a given natural resource. The actual level of solar irradiance depends on the latitude and local climatic conditions. Annual solar irradiance, for instance in northern Europe is different from that noted within the sub-Saharan region. It is however also, worth noting that anthropogenic effects such as generation of aerosols and greenhouse gases, have direct impacts onto the amount of solar radiation reaching the earth surface. Generation of anthropogenic gases within a given environment, do cause considerable reductions on the intensity of the solar radiation flux.

Solar energy system efficiency is rated according to their performance under a standard test irradiance of 1000 W/m^2 [2]. This, which corresponds to the maximum irradiance expected in summer on a clear day at moderate latitudes. As shown in (Fig. 4) below, most regions in the world exhibit annual average solar energy density in a range from 100 to 250 W/m^2 .

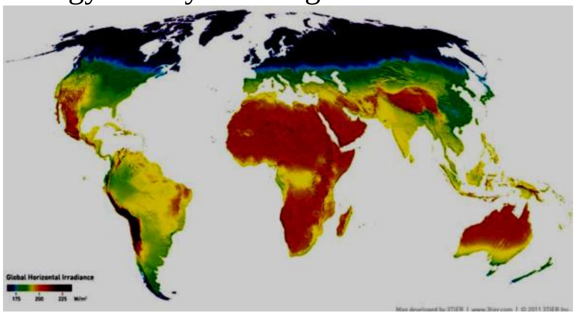

Fig. 4 Solar radiance over the globe

(Fig. 4) above indicates the solar irradiance over the globe. Looking at the figure, it can be easily noted that the sub-Saharan region, the Arabian peninsula and northern regions of India and Australia, are amongst the regions with the highest solar irradiance values.

In summary, high radiation intensity values greatly contribute to the solar system efficiency. Ideally, having more number of sunny days throughout the year, with clear skies and unpolluted atmosphere provides the optimum environment for any potential solar system.

B. Technology and Infrastructure: An admirable key characteristic of solar energy is that it can be commissioned in a wide range of sizes, costs and for a relatively large social spectrum.

Applications of solar energy can range from solar drying, water heating and irrigation, solar cooking, powering a calculator or an entire village. With every application, different infrastructures and size of investments, if any, will be required. The following section represented by several tables shall look closely at key solar energy technologies used today, briefly discuss the concept behind the technology and in which context it would work best and under what level of cost.

Table 4 Key characteristics of Solar Drying technology

No.	Solar Technology	Type	Concept	Advantages	Limitations
1	**Solar Drying:** Used for drying crops (e.g. cocoa, coffee beans etc.)	Sunlight directly employed	Warmth absorption occurs primarily by the product itself (e.g. covered racks, drying boxes with insulation and absorptive material and traditional drying racks in open air) (Vanderhulst, P., et al., 1990, p.11).	*Requires minimal financial investment *Constructed from ordinary locally available materials (i.e. well suited for domestic manufacture) *Low running costs *Not dependent on fuel *Very short drying time for some products	*Sensitive products can be overheated and eventually charred *Commercially available driers often appear to be economically unfeasible. (Vanderhulst, P., et al., 1990, p.11).
		Sunlight indirectly employed	Here drying air is warmed in a space other than that where the product is stacked.	*Risk of charring is reduced as product is exposed to less high temperatures *Product not exposed to ultraviolet radiation which would otherwise reduce the chlorophyll levels of the vegetables. (Vanderhulst, P., et al., 1990, p.12) *During hottest hours of the day, excess heat can be stored by passing the air through, for example, a container full of stones. This storage helps the drying during the night. (Vanderhulst, P., et al., 1990, p.12).	*Demands extra care *Higher costs than direct sunlight method

Although there are numerous disadvantages surrounding solar cookers, it still without doubt remains a fuel-saving technique which helps during fuel-scarcity situations. More Research and

Development (R&D) is required to improve current designs and costs of solar cookers to enable these meet wider sections of the rural population.

Table 5 Key characteristics of Solar Collector technology

No.	Solar Technology	Type	Concept	Advantages	Limitations
2	**Solar Collector:** Used in many applications	Water Distillation	The solar distiller purifies water by first evaporating and then condensing it to produce potable water.	*Simple and can be locally constructed *Suited for areas with ample water but polluted or salty	*Produces 4 litres of distilled water per day per square meter of working surface (Vanderhulst, P., et al., 1990, p.17)
		Water Boiler	Basically a water heater which is widely used in hospitals, kitchens, laundries, showers etc.	* No pump required *With proper insulation, water remains warm into the evening and early morning	*Requires more skilled work than distillers (Vanderhulst, P., et al., 1990, p.20)
		Disinfector and Sterlizer	Used in sterilizing and deactivating even most resistant bacteria (e.g. Clostridium tetani, virus for Hepatitus B). Widely used in hospitals, laboratories etc.	*Possible to reach higher temperatures than solar boiler	* Apparatus and construction is quite complex and not suited to local construction (Vanderhulst, P., et al., 1990, p.20).

Table 6 Key characteristics of Solar Cooker technology

No.	Solar Technology	Type	Concept	Advantages	Limitations
3	**Solar Cooker:** Without the use of wood, just sun light, cooking is made feasible. There are several types of solar cooking.	Parabolic solar cooker	Reflects sun's rays in a way that are further reflected and converged onto a small area. In this area a dark metal cooking pot is fixed (Vanderhulst, P., et al., 1990, p.11).	* No need for any fuel, fire or wood to enable the cooking process.	*Available room for only one pot at a time *Cannot be used during night, dusk or dawn when many people tend to cook their meals. *Reflector needs to be realigned frequently (typically every 10 minutes due to sun's movement *Apparatus is sensitive to wind *Apparatus requires extreme precision during construction *Extreme high temperatures at times may result in burnt food. (Vanderhulst, P., et al., 1990, p.24).
		Cooking Box	Works on the principle of the retention of warmth (Vanderhulst, P., et al., 1990,	*No need for any fuel, fire or wood to enable the cooking process.	*Box cannot be opened during cooking otherwise heat loss would result, hence slowing down the cooking process *Box must be aimed at the sun more frequently *Reflector makes the cooker more expensive *Cooker is less stable. (Vanderhulst, P., et al., 1990, p.25).

Hereunder, key characteristics of PV technology are discussed: PV: Though used mostly for small appliances (e.g. telecommunication, refrigerators etc.), it can also be used in large scale projects such as feeding grids.

Typical applications today include:

Vaccine Refrigeration (Stand-Alone PV system): Power supply for the refrigerator comprises photovoltaic array and a battery for storage. These refrigerators play an important role in vaccination Programmes especially in developing countries where the performance of the grid is poor or nonexistent.

Currently the demand for one type of vaccine refrigerators-Solar Direct Drive Refrigeration Systems (SDD) has been growing since 2010 (UNICEF [18]). Procurement through UNICEF increased from 230 units a year in 2011 to approximately 3,000 units in 2014 and even higher off takes in 2015, with revised needs of just over 9,800 units (UNICEF[18]).

Telecommunication (Stand-Alone PV system): PV powered telecommunication system comprises a PV array, a power conditioning unit, a battery storage unit and the telecommunication apparatus. These are found in a wide range, from as small as health care communication projects, all the way to large systems operated by governments, public and private companies.

Battery Charges (Stand-Alone PV system): PV charging stations, in several countries, have proven to be a profitable option for local traders. These play significant role especially in developing countries where most people use non-rechargeable batteries for their appliances (e.g. radios, flashlights, cassettes etc.)

Lighting (Stand-Alone PV system): The use of PV as an energy source can be of great help, especially since lighting does not need a lot of energy and because extending the grid is a too costly project in itself. The uses of such technology are immense and of great importance in terms of improving the quality of life, especially in areas where kerosene lights are being used. PV-lighting can be used for domestic and community buildings and nevertheless in street and tunnel lighting.

Water pumping (Stand-Alone PV system): In the past, many problems were encountered in applying solar pumps in developing countries, however these have been overcome lately. Today submersible pumps can pump up to 200m heads as well as larger volumes of water. For instance, at 100m and 50m, about 10,000 liters and 20,000 liters of water respectively can be pumped out per day [19]. Due to wide range of different types of pumps, proper design of the whole pumping system is quite complex, however, key satisfactory performances depend mainly in attaining reliable data on insolation, water resources, water demand and well characteristics.

Grid connected system: Grid interconnection of PV systems is achieved through the inverter, which converts dc power generated from PV modules to ac power used for ordinary power supply to electric equipment [20]. Technical reliability in connecting PV systems with existing grids and their corresponding costs play the significant role in incorporating such a technology. PV for electricity generation is growing worldwide, in fact it is one of the highest in terms of the renewable energies [20]. The following table highlights typical factors that affect PV systems costs and feasibility: [21].

Table 7 Key factors that affect PV systems costs and feasibility

Factors	Stand-Alone System	Grid-connected System	General PV System
Size of PV arrays		For a comparable load these are smaller than stand-alone systems	
Distance to nearest utility grid	More feasible in locations which are far from electrical distribution networks	Grid extensions can cost thousands of dollars per mile of transmission line	
Solar resource			Solar resource will not affect capital costs but the availability of solar energy does affect the cost of producing energy,
Type of installation, mounting, size and space	Due to capital cost restrictions, these tend to be smaller or used for smaller loads	Tend to be larger because they provide lower capital costs and energy costs for larger loads	
Operation and Maintenance (O&M)	Battery assisted systems may require acid refills when valve regulated batteries are not used	Do not have notable O&M costs. Mostly no moving parts and therefore maintenance is minimal	Some arrays will require regular cleaning. This could represent additional costs especially for large scale systems
Energy use and cost			PV systems can be cost competitive in locations with high energy prices and Net metering programs. The assumption that PV is expensive is therefore relative to the solar resource and utility energy prices in a location
Indirect benefits			Emissions reductions provide a wide range of economic, environmental and health benefits. These are difficult to quantify, yet they cannot be ignored

C. Economy: The economics of renewable energy installation in general depends primarily on the potential availability of the subject resource of concern for energy production (i.e. for e.g. solar radiation). The more potential there is for energy production, the faster the payback period is for the initial investment in the renewable system and the larger potential savings over the life of the system [22].

Although the resource (sunlight) is quite abundant and the cost of producing photovoltaic devices has continued to fall over the years, according to the Science for Environment Policy EU commission, (2016), [23] solar energy adoption has not been growing to the level of expectations. Recent researches made by the commission concluded that the economic factor and lack of financing was one of the barriers that influenced decisions to discourage adopting solar energy. High initial costs of solar PV modules and high installation, maintenance and repair costs along with uncertainties in the funding process and inadequate government subsidies along with unwillingness of banks to fund medium or long term investments in shrinking economies, all these served as barriers in the diffusion of solar energy (Science for Environment Policy, 2016, [23]).

According to the Institute of Political Economy at Utah State University (2013) [24], traditional sources. of energy such as coal or natural gas are largely less expensive than solar energy. The institute provides further details of such comparison using the Leveled Cost of Electricity (LCOE), which measures a power plant average costs over its lifetime, including its construction, fuel, operations, maintenance and efficiency.

While conventional coal plants cost $95.1 per megawatt-hour, natural gas combined cycle plants cost $75.2 per megawatt-hour, and advanced nuclear plants cost $95.2 per megawatt-hour; solar power on the other hand costs $125.3 per megawatt-hour for a PV plant and $239.7 per megawatt-hour for solar thermal plants [22].

Lack of economic support for solar energy is without doubt one of the key barriers in its deployment and diffusion worldwide. However on the contrary, application of certain economic policy instruments and strategies would inevitably not only promote the use of this renewable energy but indeed raises its competitiveness amongst other conventional energy resources.

Few economic policies that may, if implemented properly, positively influence solar energy adoption for both electric and direct heating applications include: Feed in tariffs, Direct subsidies, Mandatory access and purchase, Public investment [15].

D. Policies: Implementing a change or coming with a new policy or strategy is always driven by either an inspiration or desperation. Within the energy sphere, the International Energy Agency (IEA) (2011) sees that change can be driven by concerns about energy security and the negative impacts of unstable energy prices and long term energy access (desperation).

Change according to the agency (IEA) (2011) can also be stimulated by a willingness to support actions to improve the global and local environment, or to provide stimulation for innovation and economic development (inspiration).

A study made by The American National Renewable Energy Laboratory (NREL) [25] concluded the important role of policy in renewable energy development. Results of the study identified how there is a quantifiable connection between state-level policy and renewable energy development. However it further stated, that this connection is made more complex by the contextual factors within which policies are set, factors such as resource availability, technology cost, economic context, public acceptance, and ownership and financing structures.

Most, if not all, of the renewable supporting policies launched today are in one way or the other economically related. These aim at directly altering the balance of supply and demand in a way that increases the total market volume for renewable energies [26].Support mechanisms as such, share the characteristic that they create an additional revenue stream for renewable energy, or oblige market participants to use certain technologies.

Presently and according to the IEA [26] the most widely used mechanism for generating additional revenues for renewable lies within the feed in tariff system.

Today key policy instruments, which are being implemented to increase power supplies from Solar PV and CSP include: Feed-in-tariffs, Direct subsidies, Mandatory access and purchase, Renewable energy portfolio standards, Public investment [15].

Key target goals behind adopting the above listed policies include: Encouraging the use of low carbon technology especially in the absence of a more comprehensive policy for greenhouse gas mitigation, like a carbon tax; Expanding investments in order to drive down the costs of solar technologies; and Subsidization of small-scale, off-grid PV to bring electricity to remote and poor areas [15].

Discussed below is a brief description of various policies and examples of how are these widely being adopted:

Feed in tariffs (FiT): Is a premium payment to renewable energy technologies. The tariff pays producers of solar electricity a pre-determined, premium rate for each kWh supplied over a long term time period (commonly 20 years), starting from the moment the system is connected to the grid [2].This simultaneously gives investment security and encourages early adoption, as the tariff is reduced each year in line with anticipated improvements in the technology [2]. FiT policy has been implemented in more than 75 jurisdictions around the world as of early 2010, and is believed to have played a major role in boosting solar energy in countries like Germany and Italy, which are currently leading the world in solar energy market growth [15].

Direct subsidies: A primary instrument to support solar energy development in most countries. This involves a direct support payment which can be in various forms such as investment grants, soft loans or output/production based payments. In the United States, the Section 1603 grant scheme works in this way: renewable energy project developers get back 30% of the investment costs in cash [26]). Subsidies lower the effective price that project developers see and therefore makes the technology more competitive.

Renewable Portfolio Standard (RPS): A mechanism which obliges electricity supply companies to produce a minimum specified fraction of their electricity from renewable energy sources. Many countries, particularly developed countries, have set penetration targets for renewable energy in total electricity supply mix at the national or state/provincial levels [15]. In the United States, 31 out of 50 States have introduced RPS. The standards range from 10% to 40% [15].

Public Investment: This has been one of the main drivers of solar energy development in the developing countries. Mutual local and national level programs in a number of developing countries led to the success of many rural electrification programs. China for instance, had a great success in this regard with the accomplishment of the supporting PV program which launched in 2000 with plans to provide electricity to 23 million people in remote areas using 2,300 MW of wind, solar PV, wind/PV hybrid and wind/PV/diesel hybrid systems [15].

Climate change mitigation: Many incentives and mandates formed to trigger Green House Gases (GHG) mitigation, have helped promote solar energy in industrialized countries. The Clean Development Mechanism (CDM) under the Kyoto Protocol has been the main scheme to promote solar energy under the climate change regime in the developing countries [15]. The mechanism allowed industrialized countries to purchase GHG reductions achieved from projects in developing countries. As a result of this and as of July 2011, there were 6,416 projects already registered or in the process of registration under the CDM [15]. 109 projects of these were solar energy projects mostly in China with an annual emission reduction of 3,570,000 tons of CO_2 [15].

E. Public Support: In addition to all above factors, the level of public support or opposition is also quite significant and could be crucial at times in any decision involving introducing any new forms of energy. Potential concerns which may trigger pro or anti solar energy adoption and development may be around issues such as aesthetics, effects on wildlife, habitat, land/water use and economic interests or even climate change concerns.

Public involvement with other project stakeholders at an early stage within a democratic decision making process context may help address any raised concerns and issues for communities, hence creating solid grounds for positive communications and accordingly raising the chances for social acceptance.

One key factor, which does play a role in public acceptance is the level of general knowledge of the population. A study carried out by the German Ecological Economy Research institute (Institut für ökologische Wirtschaftsforschung (IÖW) GmbH) (2005) [27] clearly showed that knowledge is an important acceptance factor for the distribution of a new technology like PV. The study further concluded that more effort needs to be made in order to increase education about solar technologies and renewable energies in general. Recommendations in achieving this included: Increasing basic knowledge in schools, Information campaigns (Media, leaflets, workshops etc.), and Information provided by consultants, planners etc. [27].

5. Discussion

The need to act against climate change is definitely critical. The consequences of the rapidly rising temperatures will be detrimental for both humans and the entire planet. In 2012, the energy sector alone attributed to about 72% of the global Green House Gas emissions. It is projected that climate variability and change will adversely affect agricultural systems and access to food in many African countries and regions [4].

Sudan like many other countries understands the important role in which renewable energies play in combatting climate change. In fact according to the key pillar of several countries mitigation strategies at COP 19 was the de-carbonization of the energy sector through renewable energy deployment.

Renewable energy already contributes to emission reductions in the power sector. In 2012, an estimated 3.1 GT CO_2 equivalent of emissions was avoided through renewable energy use, compared to the emissions that would otherwise have occurred from fossil fuel-based power. With electricity production from wind, solar and bioenergy seeing a large increase over the past decade this has helped further reduce the global emissions. It is believed that without renewable-based power generation, total emissions from the power sector would have been 20% higher. Energy and water security too can be improved through renewable energies. Conventional energy relies heavily on water for energy extraction and production (15% of water withdrawals globally). In today world where access to water is becoming scarce, risk for conventional energy security becomes greater. It is not the case with renewable energy. For instance both wind and solar PV consume up to 200 times less water than conventional options including coal, nuclear and natural gas .

On the job creation front, renewable energy made a huge success. On average these technologies create more jobs than fossil fuel technologies which estimate that the renewable energy sector (excluding large hydro) created around 7.7 million direct and indirect jobs in 2014, an 18% increase over last year count. Solar PV was the largest employer with 2.5 million jobs worldwide.

As discussed in earlier chapters both Sudan economy and majority of the population rely primarily on the agriculture sector. A sector, which is currently being adversely affected by climate change and suffers from poor infrastructures and ever since failing policies and strategies.

The residential sector too which represented the largest sector in terms of both power and energy demands in the country (see Tables 1 and 2) certainly requires serious attention. The continuing direct burning of fuel-wood and crop residues, constituting Sudan largest energy contributor (through biomass) will do nothing but deteriorate the country environment further and weaken its battle against climate change.

Once again renewable energy provides a great opportunity in tackling Sudan current energy sector issues. Securing clean energy in a sustainable fashion for both residential and industrial sectors (primarily agriculture) is what Sudan seems wanting to achieve through renewable energy.

So the question is no longer whether renewable technology provides reliable solutions to Sudan energy and development goals but rather what sort of renewable energy needs to be adopted and how.

Presently, Sudan largest dominating renewable energy lies in hydropower. As discussed earlier, (see Table 1) it contributes to 70% of the country total power. Although Sudan has invested largely and for many years in this type of renewable technology, the country still, to date, fails to provide power to the most of its population and key economic sectors. Other than poor technical designs of the already installed projects, lack of trans boundary cooperation amongst other Nile riparian countries just makes the situation more complex. Other factors such as environmental, social considerations along with leading times and financing issues act as additional inevitable barriers in making the most out of this technology.

On the other hand, in terms of the least power supply source in the country stems the photovoltaic with only 0.03% share. Whereas a country like Germany PV-generated power covers 7.4% of the country net electricity consumption [28].

Sudan presented its intention to invest in several renewable energies including solar. This which included: Solar PV energy 1000 MW (on and off grid) to be installed in different states within Sudan; Solar CSP technology 100 MW (grid connected) to be installed especially in the northern part of Sudan; and Solar rural electrification through installation of 1.1 million Solar Home Systems (SHSs) up to 2030.

It is definitely a small step in the right direction, however after having looked at Sudan parameters in terms of solar energy adoption, it becomes quite clear to the observer that there is yet a lot of work to be done before we could sense a success story of putting this rather valuable energy into practice.

It becomes also clear that having high levels of solar radiation is not the only key or crucial factor in identifying the make or break of such technology in a given context. Being gifted with a natural resource should never mean a guarantee of a successful exploitation or adoption. Oil wealthy states Iraq, Nigeria or even present South Sudan still struggle to date to secure their own energy demands mind having any accomplishments within any other fields.

In the this section we shall discuss how solar energy exceptionally enhances several key factors that would be of great importance to present Sudan and its strategic plans. Also discussed is how Sudan with its present parameters affects the solar energy diffusion and adoption.

A. Energy Point of View: Sudan loss of its oil-rich South and its present desperate need for affordable yet environmental friendly source of energy is definitely a challenging task but still achievable should the state seriously consider solar energy. With the industrialization of its agriculture, now being Sudan focus in terms of economy, Sudan recognizes the importance of increasing its energy service levels. Needs not only to satisfy its agriculture but also to address and meet the needs of about 80% of the population that largely depend on this sector. Not to mention that Sudan population current high dependence on primitive inefficient biomass for energy surely requires a drastic change.

Solar energy with its vast range of appliances (i.e. particularly in Stand-Alone PV systems) definitely presents a strong energy candidate. Perhaps even stronger than the present installed hydropower, which currently dominates Sudan power supply sector and yet still fails to acknowledge 70% of the population who have no access to electricity. Unlike hydropower, solar energy represented by many of its standalone PV systems may be able to reach the most remote habitats and yet provide a varying range of services from lighting up a house/village, pumping water for drinking or irrigation all the way to charging batteries and other more vital services. Services which many would align with the typical needs of a rural farming village in The Sudan.

In terms of energy security Solar energy is also a better resort than hydropower since it requires no permission from neighboring countries and has no potential effects whatsoever across the borders, unlike as in Sudan hydropower case where water resources (i.e. Blue, White Niles and the joint Nile) are shared.

The manufacturing of solar panels and technology as a whole is also not exclusively limited to the U.S. or the west. In fact today world largest manufacturers come from China [29]; a country in which Sudan has very close ties with [30].

B. Sustainability and Environmental Point of View: In 1983, the UN secretary general at the time requested Brundtland (Norway Prime Minister) to create an organization in order to address and raise awareness to the world development and negative impacts associated along with it, and provide suggestions on solutions. The organization, which is also known as Brundtland commission, concluded to Our Common Future report in 1987. It was in this report that today widely used term Sustainable Development has emerged for the first time. The definition stated: Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs [31].

Sudan national sustainable development process, which also aims in having a low carbon and a resilient development, should actually serve as a driver in promoting solar energy technology. A technology that strongly promotes these 17 UN adopted Sustainable Development Goals to be accomplished by year 2030.

Today, where more than 70% of Sudan population is forced in one way or the other to resort to inefficient biomass, such as firewood and charcoal, solar technology could be the optimum solution. A solution, not only to change the current economically inefficient and environmentally devastating practices, but also one that can transform lives of many for the better. Various stand-alone PV appliances, solar driers and collectors could play an important role and in many aspects, in promoting better standards of living for the most poor and vulnerable people of Sudan. From PV supported vaccine refrigerators, battery chargers, lighting systems, all the way to telecommunications and water pumping schemes, improved health, wellbeing, education and safety levels could be easily achieved.

C. Economic Point of View: It is rather clear from earlier discussion (see Tables 5 and 6), that Sudan present tax policy just makes solar energy (represented by PV systems) less economically competitive and consequently a less attractive option for the rural regions. Although Sudan appears to want to adopt renewable energies altogether, actions on the ground seems to be just doing the opposite at least as far as solar energy concerned. In order to be able to make solar energy an affordable, more competitive option amongst other energy sources, fundamental changes in present policies need to be made. Provisions of soft loans from banks and subsidization from the government shall inevitably help promote the technology.

Sudan, a developing country, which apparently plans to diversify its energy sources through renewable energies may well be able to secure international funds in doing so. This is particularly the case when it comes to promoting solar energy. Solar power ability in promoting both a clean power source and yet focus in improving the basic living standards makes it a major attraction for international funding especially in developing countries [32].

Funding for developing countries like Sudan is available through various venues. Developmental aid funding from several multi-lateral and bi-lateral aid agencies specifically include solar activities. Major projects worth tens of millions of U.S. dollars have installed PV systems in remote villages in countries such as Indonesia and the Philippines [32].

An increasing trend is the funding of sustainable, locally-based enterprises that can provide PV systems in an affordable way through micro-finance [32]. Lately this mean of financing is becoming more of a focus towards assisting PV systems affordability [32]. Perhaps NGOs in Sudan could also play a key role in providing micro finance to the most poor and needy.

D. Agricultural Energy Requirements Point of View: Solar energy can supply and or supplement many agricultural energy requirements. It offers farmers an opportunity to cut down their energy expenses. In addition to this, it is also a predictable energy source, which means that farms need not be concerned about potential power outages [33]. Following are few applications:

Solar dryers: Used for drying crop and grains.

Solar air/space heaters: Can be installed in farm building to preheat incoming fresh air. These systems can also be used to supplement natural ventilation levels during summer months depending on the region and weather. Solar water heating can provide hot water for equipment cleaning or for preheating water going into a conventional water heater. Water heating can account for as much as 25 percent of a typical family energy costs and up to 40 percent of the energy used in a typical dairy operation [34]. A properly-sized solar water heating system could cut those costs in half.

Solar greenhouses: Passive ones typically used for small growers since they provide a cost efficient way for farmers to extend the growing season. On the other hand, Active Solar greenhouses use supplemental energy to move solar heated water or air from storage areas to other areas of the greenhouse.

Off-grid PV systems: Provides power for many uses such as lighting, small motors, aeration, irrigation valve switches, sprinkler irrigation systems, water pumping for livestock in remote pasture etc. [34]. This kind of system allows farmers to become less reliant on electric grids especially for those ones who live in remote locations where installing new utility lines can be very expensive or inaccessible. It also requires much less maintenance than other traditional farm energy sources.

This section shall discuss few successful stories of how solar energy contributed to both energy and development in various countries.

6. Conclusion

The motivation that led to the writing of the present study is the necessity to exploit the high potential solar energy and other renewable energies like hydraulic, wind, biomass etc.. Therefore, a suitable energy converter is needed to utilize this abundant energy [35].

Sudan recent loss of its oil rich South along with its commitment in Green House Gas emissions reduction made it realize the significance of renewable energies. The choice between renewables and how these could be incorporated into the energy sector is definitely not an easy task. Many influencing factors need be considered and addressed. Key ones such as the availability of the natural resource, economies of the technology, country infrastructure, state policies and nevertheless the target population and sectors; all these could shift preferences between one renewable technology over another [36].

Solar energy is definitely one significant energy source holding huge potentials for a country like Sudan. Sudan current energy status, effects of climate change and development levels should be a strong driver for considering solar energy. Apart from providing clean energy, it proved in many parts of the world to have contributed largely towards sustainable development. With only 30% of the Sudanese population having access to electricity, off-grid systems in general and stand-alone PV systems in particular stand a great chance in making progress in this regard. The country agriculture sector (i.e. backbone of the economy) too could greatly benefit from adopting such technology.

It is never late for Sudan to explore the benefits of this energy source. With the apparent strong support of the population to this technology and the existing high solar radiance across the country, Sudan, primarily represented by the government, needs to grasp this rather invaluable opportunity. The government present tax policies and lack of incentives act as a large barrier against solar energy diffusion. Success stories from neighboring and regional countries are definitely worth studying and learning from.

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