UTILIZATION OF SOLAR ENERGY IN SUDAN

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Abstract
Sudan loss of its oil rich south in 2011 made it realize the significance of renewable energy. 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 path and work on the influencing factors standing against solar energy diffusion.
With having supporting policies along with various mechanisms of securing financing under a transparent cooperative context between various stakeholders could serve as the roadmap in promoting such a valuable technology in which Sudan is in desperate need of.
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 (bioenergy), hydropower, solar, wind energies and more 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-The Solar Energy.

A. Choice of Solar Energy

One may question the choice behind wanting to explore the solar technology in the Sudan over other types of renewable energies. There are several reasons for the choice and of which all have been influenced by the country present transition, past experience and future goals.
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 (Rabah, A.A., et al., 2016).
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. According to Abdeen M.O.(2009) 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 (revenue fell from almost $11 billion in 2010 to just under $1.8 billion in 2012) (U.S. Energy Information Administration, 2014) 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 (Intended Nationally Determined Contributions, No Date). 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 (Ekins-Daukes, N.J., 2009).

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.

Along with above-mentioned justifications for exploring solar technology, one should also understand what is meant by the term potential within this context.

B. Potentiality of Using Renewable Energies

The potential of using renewable energies depends primarily on the available resources and associated costs (Hoefnagels, R., et al., 2011). 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. (Hoefnagels, R., et al., 2011).

b. Technical Potential: Where technical boundary conditions are considered (i.e. efficiencies of conversion technologies, overall technical limitations) (Hoefnagels, R., et al., 2011).

c. Realizable Potential: This represents the maximal achievable potential assuming that all existing barriers can be overcome and all driving forces are active (Hoefnagels, R., et al., 2011). 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 (Hoefnagels, R., et al., 2011). 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.

C. Aim of the Research

The basic aim of the research lies in identifying the present magnitude of solar energy in Sudan and any possible challenges that may hinder its use and diffusion. This, in accordance requires that we identify and understand the technology adoption influencing factors as well how these are exhibited within Sudan environment. The research also aims to identify how solar technology could contribute into the country energy sector and what would be the practical steps and policies in achieving optimum results. Whether or not there are negative impacts in adopting such a technology shall also be highlighted.

2. Historical Background

A. Sudan in Brief

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, root to the control and distribution of these resources (Simmons M. & Dixon P., 2006). As stated in US Institute of Peace-Special Report (2010) "Sudan main source of wealth, its natural resources are a focal point for competition and conflict".

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 (Mahgoub, F., 2014). 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 (Mahgoub, F., 2014).

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. According to the United Nations Development Programme (2013), since South Sudan independence, the Sudanese government has continued to seek strategic partnerships with local and foreign investors to diversify and increase its agricultural exports.

Today, Sudan still has majority of the original area, with it now being 1,861,484 square kilometers (Berry, La V., 2015). 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 (Berry, La V., 2015).

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. (Berry, La V., 2015).

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 (Mahgoub, F., 2014).
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 (Berry, La V., 2015). 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 (Berry, La V., 2015). 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) (Sudan tribune, 2013). 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 (UN News center, 2009).
Clashes between various opposition forces and successive Sudanese governments across the country have been quite common since Sudan independence in 1956. According to the United Nations Development Programme (2013), most of these conflicts were linked with struggles over natural resources.
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 (History World, No date). 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 (History World, No date).
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, 2013). 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 (Mortlock, D., et al., 2017).
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, 2017).
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 (Martini, M., 2012).
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 (Martini, M., 2012). 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 (Martini, M., 2012).

B. Sudan Energy Sector

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 (Omer, A.M., 2015).
As is the case with many developing countries, direct burning of fuel-wood and crop residues, constitute the main usage of Sudan biomass (Omer, A.M., 2015). 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 (Rabah, A.A., et al., 2016).
b. Main transformation and conversion processes were electric power generation, oil refinery and wood-to-charcoal conversion (Rabah, A.A., et al., 2016).
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 (Rabah, A.A., et al., 2016). 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 collated 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 (Rabah, A.A., et al., 2016).
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

C. Sudan Renewable Energy Sector

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 (Omer, A.M., 2015).

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) (Omer, A.M., 2015).

According to Abdeen Omer (2015) from the 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.

The following sections provide a brief insight into some key renewable resources in The Sudan:

a. Biomass Resources

The main usage of Sudan biomass entails the direct burning of fuel-wood and crop residues (Omer, A.M., 2015). As discussed earlier, biomass resources contributed significantly into the energy supply of the Sudan, however with the present approach, not only is the process inefficient but it has proved to cause detrimental effects to both the environment and human health. Exhibited damage to the environment was quite obvious and alarming to an extent, which led the Sudanese government start a reforestation Programme of 1.05×10^6 hectares (Omer, A.M., 2015).

Approximately 13×10^6 m^3 of dedicated biomass resources (e.g. firewood and charcoal) are consumed per year (Omer, A.M., 2015).

Other types that constitute the biomass used for energy in The Sudan include: agriculture residue, bagasse (sugar cane by product), bioethanol, and animal waste.

b. Hydropower

Sudan, like many tropical countries, has ample water resources that can be efficiently exploited in a manner that is both profitable and sustainable. Major hydro plants presently operating in the country include the following 5 dams: Merowe Dam: 1250 MW, Roseires Dam: 280 MW, Sinnar Dam:15 MW, Jebel Aulia Dam: 30 MW, and Khasm El Girba Dam: 10 MW.

The latest achievement was Merowe dam with total installed capacity of 1585 MW which was inaugurated in 2010. (Rabah, A.A., et al., 2016).

As shown in Table 2 earlier, the hydropower sector dominated Sudan power supply with 767 ktoe in 2014. This corresponded to nearly 70% worth of power supply to the entire country.

Experts believe that for most Nile riparian countries (including Sudan), hydropower would be the preferred source of energy for meeting the power needs of the region (State of the river Nile basin, 2012). However, there are many constraints that hinder the full exploitation of the vast hydropower potential in the region. Few of these include: Trans-boundary context, damage to global environment assets, land and resettlement issues, lead times and financing.

c. Thermal Energy

Sudan present installed thermal power, 1400 MW, comes from a total of 8 power plants. Two more power plants (Al Fula and the Red Sea) are under construction with a planned power of 405 MW and 600 MW respectively. Prime movers in thermal generation include steam turbine (ST), gas turbine (GT), combined cycle of gas turbine (CCGT), and internal combustion (IC) engines. IC engines are used in remote areas that are not covered by the national grid. The installed thermal power generation is about 46% of the total installed public power generation (hydro + thermal). (Rabah, A.A., et al., 2016).

d. Wind Power

Although Sudan is rich in wind, with mean wind speeds of 4.5m/s across 50% of the country, wind energy has not been significantly exploited for power generation (Omer, A.M., 2015). The first experience with wind energy routes to the 1950s when the Australian government back then installed 250 wind pumps in El Gezira Agricultural Scheme, these, which have been neglected overtime (Omer, A.M., 2015).

Around fifteen years ago, in an attempt to revive the wind pumps industry, the local Energy Research Institute (ERI) in collaboration with Consultancy Services Wind Energy Developing Countries (CWD); installed 15 Nos. of 5,000 mm diameter wind pumps around the capital area and neighboring northern and eastern states (Omer, A.M., 2015). Unfortunately, due to lack of financial support not much progress has been made since then.

Recently, in December of 2014, both parties, the United Nations Development Programme (UNDP) and the Sudanese Ministry of Water Resources and Electricity agreed on funding and implementation of a five-year project on Promoting Utility Scale Power Generation from Wind Energy. The estimated total budget of the project is 217 million US$, with more than 98% of financing ought to be secured by the Sudanese government (UNDP, 2014).

e. Solar Energy

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 (Rabah, A.A., et al., 2016). 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 (Omer, A.M., 2015):

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. (Omer, A.M., 2015).

3. Insight into 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 (Jones, G., and Bouamane, L., 2012).

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 (Jones, G., and Bouamane, L., 2012). 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. (Jones, G., and Bouamane, L., 2012).

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. (Jones, G., and Bouamane, L., 2012).

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 (Vanderhulst, P., et al., 1990).

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 (R. Timilsina, G., et al., 2011) 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. (R. Timilsina, G., et al., 2011).

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. (Aghaei, P., and Meisen, P., 2014).

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. (Vanderhulst, P., et al., 1990).

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:

a. **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 (Aghaei, P., and Meisen, P., 2014). (Fig. 1) below illustrates a typical setup for a grid connected PV system.

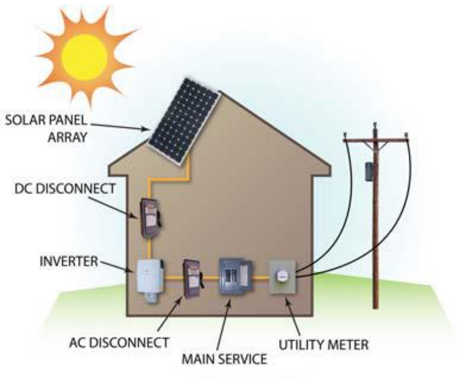

Fig. 1 Typical setup for a grid connected PV system

b. 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 (Aghaei, P., and Meisen, P., 2014). 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.

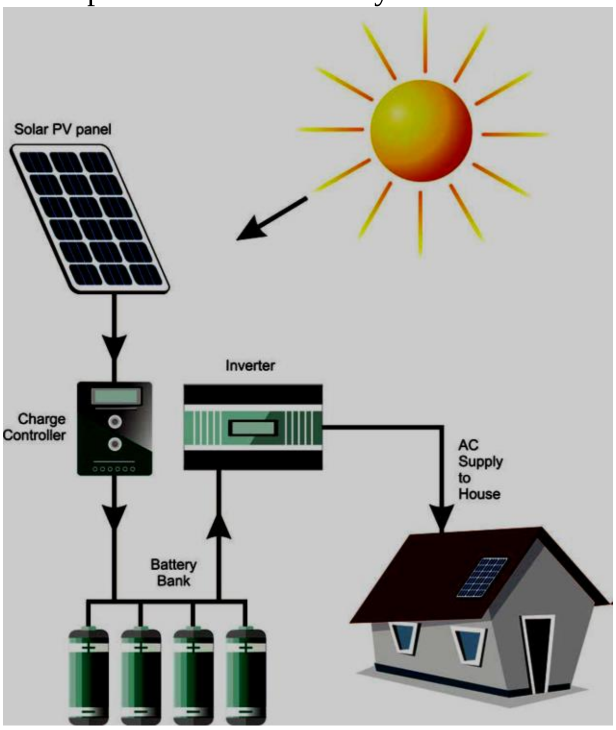

Fig. 2 Typical setup for stand-alone PV system

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 (R. Timilsina, G., et al., 2011). (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.

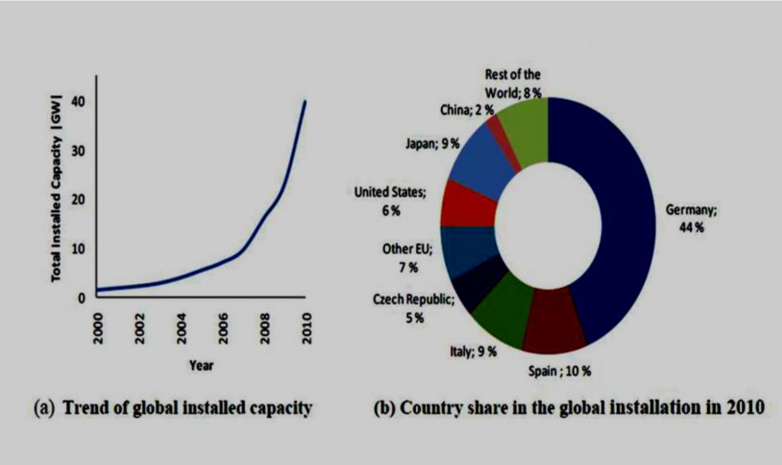

Fig. 3 (a) Trend of global PV (both grid and off-grid) installed capacity from years 2000 to 2010, whereas and Fig. 3 (b) Countries share in global installation as of year 2010

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.(R. Timilsina, G., et al., 2011).

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. (Biwole, P., et al., 2011).

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/m2 (Ekins-Daukes, N.J., 2009). 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 (Sustainable Energies, No Date).

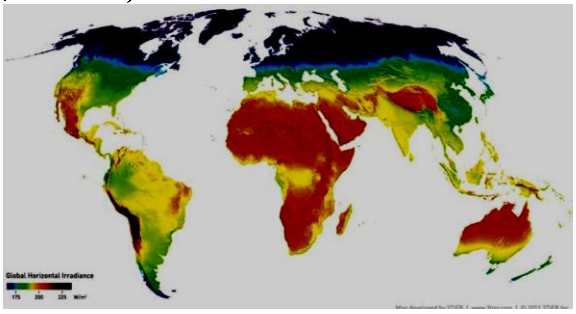

Fig. 4 Solar radiance over the globe

(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. (Vandedulst, P., et al., 1990, p.24).
		Cooking Box	Works on the principle of the retention of warmth (Vandedulst, 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. (Vandedulst, 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:

a. 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, 2015). 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, 2015).

b. 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 (Vanderhulst, P., et al., 1990). 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.

c. Battery Charges (Stand-Alone PV system): PV charging stations, in several countries, have proven to be a profitable option for local traders (Vanderhulst, P., et al., 1990). These play significant role especially in developing countries where most people use non-rechargeable batteries for their appliances (e.g. radios, flashlights, cassettes etc.)

d. 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.

e. 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 (Nath Maurya,V., et al., 2015). 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.

f. 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 (A. El Tawil, M., and Zhao, Z., 2010). 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 (A. El Tawil, M., and Zhao, Z., 2010). The following table highlights typical factors that affect PV systems costs and feasibility: (Sumathi, S., et al., 2015, p.66)

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 (M. Xiarchos, I., and Lazarus, W., 2013).

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), 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).

According to the Institute of Political Economy at Utah State University (2013), 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 (M. Xiarchos, I., and Lazarus, W., 2013).

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 (see below) 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. (R. Timilsina, G., et al., 2011).

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) (2009) 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 (Müller, S., et al., 2011).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 (Müller, S., et al., 2011) 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. (R. Timilsina, G., et al., 2011).

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. (R. Timilsina, G., et al., 2011).

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

a. 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 (Ekins-Daukes, N.J., 2009).This simultaneously gives investment security and encourages early adoption, as the tariff is reduced each year in line with anticipated improvements in the technology (Ekins-Daukes, N.J., 2009). 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 (R. Timilsina, G., et al., 2011).

b. 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 Müller, S., et al., 2011). Subsidies lower the effective price that project developers see and therefore makes the technology more competitive.

c. 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 (R. Timilsina, G., et al., 2011). In the United States, 31 out of 50 States have introduced RPS. The standards range from 10% to 40% (R. Timilsina, G., et al., 2011).

d. 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 (R. Timilsina, G., et al., 2011).

e. 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 (R. Timilsina, G., et al., 2011). 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 (R. Timilsina, G., et al., 2011,). 109 projects of these were solar energy projects mostly in China with an annual emission reduction of 3,570,000 tons of CO2 (R. Timilsina, G., et al., 2011).

E. Public Awareness and Acceptance

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) 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. (Hirschl, B., et al., 2005).

5. Sudan Present Parameters

This section presents Sudan current status with regards to the influencing factors discussed in previous section and how these translate in terms of promoting solar energy adoption.

A. Natural Resource and Environment

As mentioned earlier, Sudan has abundance of sunshine with an average duration ranging between 8.5 to 11 hours per day. Where most regions in the world exhibit annual average solar energy density ranging between 100 to 250 W/m^2 (Sustainable Energies, No Date) ; Sudan solar energy density ranges between 436-639 W/m2 (Omer, A.M., 2015).

The map below (Fig. 5) reflects Sudan Global Horizontal Irradiation. It is quite indicative that both the northern and western regions acquire relatively higher irradiance than remaining areas of the country. (GeoSun Africa, 2017).

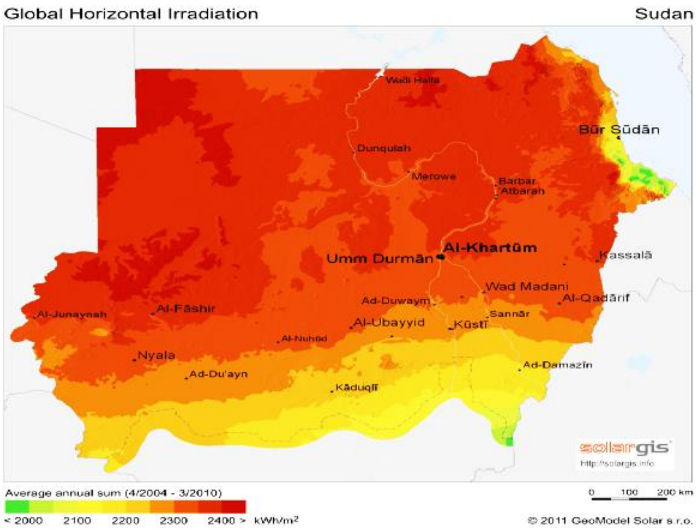

Fig. 5 Sudan Global Horizontal radiance map

Though altogether, the radiance figures are quite promising, it is worth noting that Sudan like many developing countries suffers from air pollution. This as discussed earlier can have negative impacts onto the amount of solar radiation reaching the earth surface. According to a UNICEF air pollution report (2016), Sudan still and as of 2016 did not have any air quality laws and regulations.

The country present levels of air pollution which lay between above moderate and high per the particulate matter PM2.5 reference are attributed to many factors. Few of these presented by UNICEF report include: The country poor access to non-solid fuels and lack of Programmes to promote efficient cooking and heating stoves; The country lack of low sulfur fuels (550ppm) and advanced vehicle emission standards; Burning of both agricultural and municipal waste is not regulated and being commonly practiced; and Absence of air quality laws and regulations (e.g. Ambient Air Quality Standards-AAQS).

Sudan high radiation intensity values is definitely a great asset and may well greatly contribute to the efficiency of any installed solar system, however and in order to achieve ideal results pollution issues need to be addressed. (Fig. 6) below shows a typical farmland along the sides of the river Nile. (El Zein, I., 2015).

Fig. 6 Farmland in Khartoum State (Omdurman-Al Sururab)

B. Technology and Infrastructure

The Sudanese government allocates a limited budget for Science and Technology. For instance in year 2006, only 0.2% of the country GDP was allotted to Research and Development (R&D) (Sudan Tribune, 2013).

Similarly, Sudan energy infrastructure too is suffering, with currently only 30% of the population mainly in urban areas having access to electricity (Omer, A., 2013). Consequently, the national development and existing services are also being negatively affected. Inadequate supply of power for lighting, heating, cooking, cooling, water pumping, radio or TV communications and security services is quite common in many rural areas of the country of where about 70% of Sudan population lives (Omer, A.M., 2015).

The industrial sector is not doing any better with having medium, small and even large industries often exhibiting power outages (Omer, A., 2013).

Lately and after South Sudan independence, it appears that Sudan has recognized renewable energies potential role in making significant positive changes to its present crumbling infrastructure. Perhaps Sudan hydropower domination (70%) of power supply in year 2014 (see Table 2) reflects that new era and recognition of renewable energy altogether.

Adoption of solar technology was also incorporated in the country new energy strategies with the Ministry of Higher Education and Scientific Research putting plans to promote and deploy stand-alone PV systems in rural areas (see Table 3 earlier). However, neither the magnitude of the initiative nor the adopted roadmap appears to have succeeded so far in meeting the demands of the vast majority of the affected population or their surrounding environment and infrastructures.

Unlike other renewable energies, solar energy in particular has a vast variety of technologies within itself which as mentioned earlier can be commissioned in a wide range of sizes, costs and for a relatively large social spectrum.

Sudan energy deprived population (more than 70%) could definitely find optimum solutions through the various solar technologies. From solar driers for crops, collectors for water applications, cookers for food along with the various stand-alone PV systems (e.g. vaccine refrigerators, battery charging and lighting), all these could serve as viable energy replacements to the present bad practices (e.g. fuel wood burning) which have proved to cause detrimental effects not only to the environment but also to human health.

Typical low energy demands in Sudan villages (e.g. lighting schools, mosques, clubs and clinics) should inevitably increase the popularity of using stand-alone PV systems, as they do not need fuel and regular maintenance).

Extending or installing new PV grids or PV power stations could also be worth studying. In fact these could be cost effective in the long term. However with Sudan present poor electric grid distribution and the sparsely populated rural communities (e.g. northern state , 2 persons/km^2) (ElZubeir A.O., 2016) such mega projects may well require a large initial investment and a longer construction time.

A comparison study concerning PV stand-alone systems conducted year 2006 in two areas of the country, Northern Kordofan (Southwestern Sudan) and Dongola (North Sudan) concluded the significance of both supporting Policy-making and Economy in promoting the technology across the country. In the following two subsections outcome of the conducted study with respect to policy making and economy shall be discussed further.

C. Economy

Just like many other countries, the economy in Sudan plays a crucial role in the decision-making and energy adoption. Renewable energy in general and solar technology in particular too face these economic challenges. With the absence of subsidies to solar technology other energy sources become more economically competitive and hence more attractive to the common consumer.

An economic comparison between three types of electricity generators; stand-alone PV modules (50 Wp), two imported gen-sets (0.5, 2.4 kW) and a small mini-grid system (313kW peak) conducted in two locations in Sudan (Dongola and Northern Kordofan) proved the difficulty in adopting PV systems.

The comparison results included two sets of calculations, one with and another without subsidies and taxes. Following tables present the outcome: (Croxford, B., and Rizig, M., No Date).

Table 8 Indicates system costs with subsidies and taxes at the time (year 2006)

System	Generated Electricity (kWh/year)	Initial cost (USD)	Annual running cost (USD)	Net Present Cost-NPC (USD)	Levelized Cost-LEC (USD/kWh)
PV(A)	129	865	29	1,141	1.63
PV(B)	257	1,250	29	1,526	1.09
PV(C)	5,661	22,692	721	29,940	0.96
Gen-set (0.5kWh)	548	446	192	2,260	0.76
Gen-set (2.4kWh)	4,380	1,396	989	10,717	0.45
Mini-Grid (Max)	1,370,940	208,797	115,631	1,298,966	0.17
Mini-Grid (50%)	766,500	208,797	115,631	1,298,966	0.31

Table 9 Indicates systems costs considering no subsidies or taxes at the time (year 2006)

System	Generated Electricity (kWh/year)	Initial cost (USD)	Annual running cost (USD)	Net Present Cost-NPC (USD)	Levelized Cost-LEC (USD/kWh)
PV(A)	129	540	21	733	1.05
PV(B)	257	775	21	968	0.69
PV(C)	5,661	14,250	505	19,009	0.62
Gen-set (0.5kWh)	548	338	178	2,012	0.67
Gen-set (2.4kWh)	4,380	1,058	937	9,895	0.41
Mini-Grid (Max)	1,370,940	208,797	194,266	2,040,338	0.27
Mini-Grid (50%)	766,500	208,797	159,450	1,712,095	0.41

Table 10 The three load levels for the PV systems indicated in earlier tables (i.e. Tables 5 and 6)

System Level	Equipment	Operation time hours	Daily type load (W)	System total load kWh/day	System total load kWh/year
Low (A)	3 DC lamps (20W)	3	60	0.18	65.7
Med (B)	2 DC lamps (20W), 1 Tv (60W)	3	100	0.3	109.5
High (C)	1 Refrigerator (160W), 1 Fan (40W), 5 DC lamps (20W), 1 Airconditioner (1,040W)	5	1,340	6.7	2,445.5

Table 11 The loads for Gen-sets indicated in earlier tables (i.e. Tables XX and XX)

Generator Type	Operation time (hours)	Total daily load (kWh)	Total yearly load (kWh)
0.5 kW	3	1.5	547.5
2.4 kW	5	1.2	4,380

Other than reflecting the significance of subsidies and taxes in shaping the final costs of a system, the study also concluded that the PV technology under the presented conditions was simply the least adequate electricity supplier while the best economic choice went to the subsidized mini-grid category. The study further added and identified how the Sudanese customs and tax policy adds a significant cost to PV, making diesel generators the best power choice for rural and nomadic regions in Sudan. With lack of soft loans from banks and subsidization from the government, adoption of solar energy may well be quite economically challenging, especially when we speak about incorporating these within the most poor and vulnerable population in Sudan (i.e. rural areas).

D. Policies

In the wake of the Conference of the Parties (COP 19 and 20) to the United Nations Framework on Climate Change (UNFCCC), Sudan communicated its share of responsibility and contribution in the global Green House Gas emissions (GHG) reduction. The intended mitigation contributions involved actions within three sectors, namely the Energy, Forestry and Waste (Intended Nationally Determined Contributions, No Date). The following table (Table 12) shall present only the intended program of action within the energy sector. As stated in the Intended Nationally Determined Contributions (INDC) report (No Date), Sudan intended mitigation contributions are in line with its national sustainable development process which also aims at having a low carbon and a resilient development. Looking at the objectives and sets of actions it appears that Sudan truly intends to promote the renewable energy sector. Solar energy too had a great share in this road map with an intention of having a total of 1000 MW from Solar PV system and another 100 MW from Concentrated Solar Power (Intended Nationally Determined Contributions, No Date). However interestingly enough, the same report does state that Sudan intended mitigation contributions are considered fair yet ambitious given its present national circumstances, development objectives and priorities (Intended Nationally Determined Contributions, No Date). Sudan may well be aware of the huge benefits that could be achieved by adopting renewable energies in general and solar energy in particular. However to date, it seems that there are not any clear institutional policies and practical strategies to support this. In fact present tax policies which implement high duties on imported goods and technologies such as PV for instance does nothing other than discourage the adoption of the technology. Similarly, when the Sudanese government subsidizes fuel, renewable technologies such as solar become less economically attractive.

Table 12 Sudan action plan for the energy sector

Action	Description	Objectives of Actions	Cost (USD)
Integration of renewable energy in the power system	**Objective:** Integration of renewable energy in the power system of the Sudan, target of 20% by 2030 1. **Wind energy:** 1000 MW (grid connected) will be applicable in strong wind regime areas. 2. **Solar PV energy:** 1000 MW (on - and off - grid) will be applicable in different states within Sudan. 3. **Solar CSP technology:** 100 MW (grid connected) will be applicable, especially in the northern part of Sudan 4. **Waste to Energy:** 80 MW (grid connected) will be applicable in several intended sites 5. **Biomass Potential:** 80 MW (grid connected); e.g. the sugar industry. 6. **Geothermal Potential:** 300 MW in different states of Sudan. 7. **Small Hydro Plants:** 50 MW (grid connected)/ especially in combination with irrigation-sites, small hydro plant projects; 8. **Solar rural electrification** through installation of 1.1 million Solar Home Systems (SHSs) up to 2030	1. Utilization of the different renewable energy resources potential in Sudan to avail the electric energy all over the country; 2. To achieve a competitive price of energy from renewable sources which will lead to fuel saving; 3. Diversify the energy supply sources and ensuring the energy security and saving the environment; 4. To be part of the global energy development which is expected to lower the prices in the future; 5. Supporting the national economy by technology and knowledge transfer and capacities building and promoting local Renewable energy industry; 6. Contribute to the development of the different regions of the Sudan; 7. Provides access to electric energy supply to rural areas far from the national or the isolated grids for which the grid extension is not a feasible solution. Energy	4,300,000,000
Energy efficiency	GHG mitigation is achieved through energy efficiency according to: 1. Reduction of loss in transmission and distribution networks; 2. Rehabilitation of the cooling system in Hydroelectric stations; 3. Increase the readiness of the power station – matrix turbines. 4. Reduction of the costs of producing electricity and auxiliary consumption from thermal power plants; 5. Improvement of specific fuel consumption in thermal power plants; 6. Replacement of incandescent lamps by CFL and LED lamps in residential sector; 7. Establishment of the labeling system for electrical appliances.	The indicative target of the energy efficiency reflecting the rate or the value of savings in electrical energy consumed in 2016 up to 2030, which resulted from measures to improve electric power efficiency and the rationalization of electricity consumption. These contributions are estimated to result in energy saving in the order of 6500 GWh.	350,000,000
Electricity thermal generation using Natural Gas	Production of 2300 MW using natural gas in different areas in the country	GHG emission reduction, fuel cost reduction and enhancement of social and economic development in the country.	2,900,000,000

E. Public Awareness and Acceptance

There is no solid data or trace of any conducted wide range national survey on either the public awareness or acceptance on renewable energy let alone one concerning solar technology . With the knowledge, that more than 70% of the population live in rural areas, one may only assume that the level of awareness would be quite low. However, the earlier mentioned study conducted in Dongola and Northern Kordofan (Croxford, B., and Rizig, M., No Date) advised that the public awareness in these two areas was found to be very good and especially among women who happened to be benefitting from the installed PV systems. Apparently, according to the study, knowledge of PV spreads effectively through word of mouth. (Fig. 7) below shows the varying population densities within The Sudan. (World Population Review, 2017)

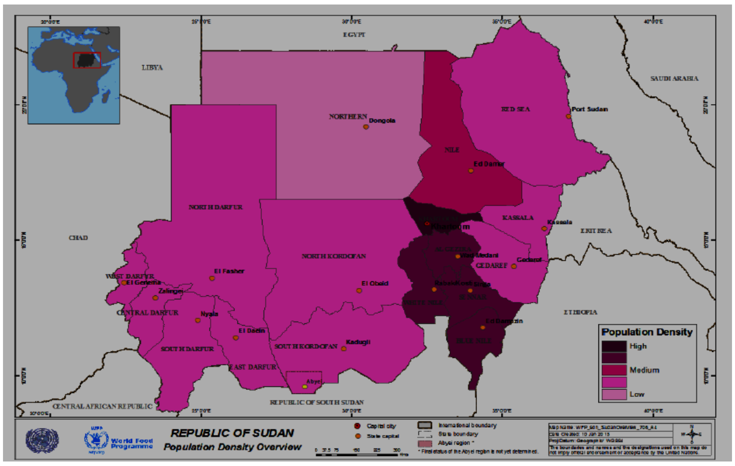

Fig. 7 Sudan population densities

Asim Osman ElZubeir (2016) who investigated the solar energy in Sudan northern state saw that the low awareness among both consumers and decision makers was one of the key factors in constraining the diffusion of the technology in the state. His recommendations to change this, was through having a viable institutional plan for commercializing the system via demonstration seminars and workshops not only to potential users but also to distributors and the public at large.

Abdeen Omer (2015) who looked closely into Sudan sustainable development and the use of environmental friendly energy systems signified the importance of launching of public awareness campaigns at all levels (investors, small-scale entrepreneurs and end users of renewable energy technologies). In his investigation, Abdeen Omer tied the public acceptance to economic supporting schemes.

It appears that more work need to be done in terms of raising public awareness about solar technology and its benefits. Public acceptance however yet needs to be addressed through various schemes. In a country like Sudan where majority of the population lives under the poverty line, providing incentives may well be the key factor in securing public acceptance and consequently the diffusion of solar energy across the country.

6. 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 (RENA, 2015). It is projected that climate variability and change will adversely affect agricultural systems and access to food in many African countries and regions (Mahgoub, F., 2014).

Sudan like many other countries understands the important role in which renewable energies play in combatting climate change. In fact according to IRENA (2015) 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. (RENA, 2015).

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 (RENA, 2015).

On the job creation front, renewable energy made a huge success. On average these technologies create more jobs than fossil fuel technologies (RENA, 2015). IRENA (2015) estimates 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 (Wirth, H., 2017).

In its Intended Nationally Determined Contributions report, 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. From an Energy perspective

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.

There may be a realization from the state for the need to change through renewable energies, however and I totally agree with Abdeen Omer from the Energy Research Institute in Nottingham, that yet more needs to be done.

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 (Fortune, 2015); a country in which Sudan has very close ties with (Nelsen Moro, L., 2012).

B. From a Sustainability and Environmental Perspectives

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. (Hopwood, B., et al., 2005).

In accordance with this definition and over many years of various initiatives, the United Nations Development Programme (UNDP) in 2015 launched a new set of 17 measurable Sustainable Development Goals (SDGs)**,** ranging from ending world poverty to achieving gender equality and empowering women and girls by 2030 (United World Schools, No Date).

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 (listed below).

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.

Few live and general examples of how using solar energy and its appliances could in one way or the other promote and align with the 17 UN adopted Sustainable Development Goals is given below.

a. No Poverty: Access to solar energy could bring along huge opportunities for both the local consumers and producers in terms of creating jobs and business revenue. Reducing the amount of purchased energy (typically costly fuel) would also be of great help in avoiding huge economic burdens particularly for the most poor and vulnerable.

b. Zero hunger: PV water pumping helps attain drinking water and supports irrigation.

c. Good health and well-being: PV vaccine refrigerators used in preserving lifesaving vaccines especially in regions where access to power is a challenge.

d. Quality education: PV telecommunication systems providing access to the outside world information and knowledge.

e. Gender equality: Generally, providing easy access to electricity makes home life more convenient and housework easier (Clancy, J., et al., 2004). A study conducted in rural areas of Sri Lanka found that the major benefit of electricity is the time that women save. Eighty percent of the interviewees in the study reported saving between one and two hours through avoided journeys (such as going to the city to buy kerosene and vaccinations) and on household activities (such as firewood collection, cooking, ironing, boiling water etc.) (Clancy, J., et al., 2004). In accordance, the study saw the possibility in an indirect gender equity when households tasks are made simpler and exert less effort. At these circumstances the probability of sharing household duties between men and women becomes greater with men wanting to contribute more while enjoy the use of modern appliances.

f. Clean water and sanitation: PV water pumping helps attain drinking water and supports irrigation whilst solar collectors via water distillation help purify waters.

g. Affordable and clean energy: According to the Organization for Economic Co-operation and Development-OECD (No Date) ; renewable energy helps reduce the fuel poverty in remote and rural regions, by allowing isolated communities produce their own energy instead of importing expensive conventional fuels. Not only this, the organization also acknowledges the replacement of the costly rare fuel with a cleaner environmental friendly source of energy instead.

h. Decent work and economic growth: A Food Agriculture Organization (FAO)/UNDP postharvest Programme in Uganda, recommended small-scale solar dryers for long-term storage and eventual household consumption of fruit and vegetables. However rural women groups became more interested in solar dryers for income generation than for food security. Subsequently, the Fruits of the Nile company was formed in 1992 to link rural producers with the market for dried fruit in Europe. Within three years, more than 50 women groups had taken up the solar drier technology, and in 1995 the company exported more than 50 tons of dried fruit. (Clancy, J., et al., 2004).

i. Industry, innovation and infrastructure: Rural areas hosting renewable energy installations actively contribute to the development of new technologies, products, and also new policy approaches. The OECD (No Date) stated that it is in rural areas that new renewable technologies are tested, challenges first appear, and new policy approaches are tried. An example of such is the new innovation of solar powered boats that was founded in Fryslân, in the Netherlands (OECD, No Date, p. 8).

j. Reduced inequalities: Diffusion of solar technology has helped at many events and through many partnerships and Programmes in empowering women especially in the rural areas. A prime success example in this regard would be the story of four women from remote corners of Honduras who have been actively involved in installing, maintaining and repairing solar energy equipment in their communities. So far, these inspiring women have installed more than 200 panels, each generating 85 watts of power (United Nations Development Programme, 2016).
k. Sustainable cities and communities: Solar energy represented by its wide range of appliances can be captured for both household and institutional uses in urban settings where biomass fuels are not available. The technology not only helps reduce the reliance on expensive and unsustainable fossil fuels but also reduces the competition and conflict for energy, especially in high density settings.
l. Responsible consumption and production: Solar PV consume less water than conventional energy options such as coal, natural gas and nuclear.
m. Climate action: Solar energy like many other renewable energies contributes in reducing climate change forcing agents (e.g. greenhouse gases).
n. Life below water: Solar energy could also indirectly help conserve and sustain the use of oceans, seas and marine resources for sustainable development. With solar energy for instance replacing biomass combustion fires for energy, preservation of forests could be achieved. Subsequently, land ability to absorb water is maximized and accordingly runoff-containing pollutants reaching any marine resources is reduced.
o. Life on land: Employing solar energy through its various appliances helps avert the need to bring down forests for energy. Thus, wildlife and its corresponding environment could be protected.
p. Peace, justice and strong institutions: As mentioned earlier, reducing competition for energy by employing solar energy would inevitably contribute in conflict reduction.
q. Partnerships for the goal: With a goal to empower women worldwide, a six month solar engineers study Programme was made possible through a partnership between the Government of India and the Small Grants Programme (SGP) (a Programme supported by the Global Environment Fund and UNDP). The initiative, which has expanded to 18 countries, resulted in training 71 women as solar engineers, these whom have electrified 3,778 households in 52 villages. (United Nations Development Programme, 2016).

C. From an Economic perspective

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 (D. Foroudastan, S., 2006).

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 (D. Foroudastan, S., 2006, p.5).

An increasing trend is the funding of sustainable, locally-based enterprises that can provide PV systems in an affordable way through micro-finance (D. Foroudastan, S., 2006, p.5). Lately this mean of financing is becoming more of a focus towards assisting PV systems affordability (D.

Foroudastan, S., 2006). Perhaps NGOs in Sudan could also play a key role in providing micro finance to the most poor and needy.

D. Appliances Supporting Agriculture

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 (Intermountain Wind & Solar, 2015).

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 (Chikaire, J., et al., 2010). 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. (Chikaire, J., et al., 2010). 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.

E. Respondent Views

Responses from both the Ministry of Water Resources & Electricity along with Dr. Shamboul (Dean college of Engineering) from Mughtaribeen University reflected rather positive prospects about solar energy in Sudan. Both respondents advised that the population was very positive in favoring solar energy adoption.

In terms of main concerns and whether there were any foreseen obstacles in adopting solar energy, Dr. Shamboul was quite over optimistic by saying that there were none. However the Ministry did point out what we in earlier discussions touched upon and concluded (i.e. lack of supporting policies, financing and Sudan poor grid infrastructure).

With regards to the ongoing solar projects in the country the Ministry did provide very brief details on three projects (two actual and one being a feasibility study). Dr. Shamboul too provided very little data on the subject. Lack of sufficient details and any project supporting documents or studies made it extremely difficult to track and confirm these ongoing solar projects.

Two varying responses were noted concerning the areas where projects are being or have been developed and whether there were any issues with inhabitants or environments being affected on site. While the Ministry advised that there were cases where relocation of inhabitants occurred and compensations have been made, Dr. Shamboul on the other hand expressed his concerns on public ownership and land property. He stressed that these issues need to be resolved by the government.

With regards to the question about areas of improvement and who shoulders the most responsibility, the Ministry yet again pin pointed the source of issues that need be addressed. Legal infrastructure (in terms of policies and laws) along with planning is what the Ministry saw still requiring improvement. The Ministry did acknowledge that the government shoulders the most responsibility in making positive changes towards solar energy adoption.

There is no doubt that both respondents understood the significance of adopting solar energy though I would have expected the mention of Sudan action plan for renewable energies provided in its INDC report and perhaps any suggested practical solutions to overcome the present barriers in terms of financing and policies. Perhaps a mention of other players such as role of NGOs and international organizations would have been an interesting aspect to discuss and learn more from.

F. Successful Stories

There are many live examples of how solar energy in many countries and in many fronts has helped make positive changes. The following are few successful stories and plans in which Sudan represented by the government could learn from:

Kenya: A local review report (Innovation and Renewable Electrification in Kenya-IREK) estimated that over 320,000 rural households (representing 4.4% of rural people in Kenya) have had solar home systems as of 2010. The report also suggests that between 25,000 to 30,000 PV systems are sold annually in the local markets. (Innovation and Renewable Electrification in Kenya-IREK, 2015) Total installed solar power capacity is estimated at about 16 MWp as of 2012 where vast majority is contributed by solar home systems installed at individual homes (Innovation and Renewable Electrification in Kenya-IREK, 2015).

Enabling institutional environment (from policies and incentives) is believed to have the key role in solar PV technology diffusion and solar energy altogether.

Tunisia: Supporting policies and Programmes in the country have succeeded in promoting solar water heaters. Both the Tunisian government and the United Nations Environment Programme (UNEP) worked together to provide subsidies and concessional loans to facilitate the uptake of solar water heaters, whose high initial cost constituted a substantial market barrier when compared to less capital-intensive alternatives such as gas water heaters (IRENA, 2015). Results of the mutual work paid off, with Programme Solaire (PROSOL-Solar water heater Programme) installed capacity rising from around 7 000 m^2 in 2004 to over 80 000 m^2 in 2010. At the end of 2010, the total installed collector surface area had reached around 490 000 m^2 compared to just 120 000 m^2 in 2004, creating a genuine market for over 50 suppliers, including seven manufacturers, and over 1 200 small installation businesses (IRENA, 2015).

Morocco: The country has focused recently in rapid deployment of mini-grids in order to help expand electricity access and stimulate socio-economic development. According to IRENA (2015) 3,633 villages have been electrified with solar power, benefitting nearly 52,000 households.

Senegal: Rural electrification agency in the country installed 35 hybrid (solar PV, battery and diesel) mini-grid systems and yet there are plans to install 41 more (IRENA, 2015).

U.S.A.: According to the U.S. solar foundation and as of 2016, more than 260,000 workers nationwide have been employed within the industry with California state alone having just over 100,000 solar jobs (Think Progress, 2012). The U.S. Energy Information Administration (EIA) reported that California solar share of demand actually topped 50% for a few hours on March of 2011 (Think Progress, 2012).

Saudi Arabia: A recent report published by Orient Planet revealed that solar energy will take up to 76% of Saudi Arabia sustainable energy plans by year 2040 (Al Arabiya English, 2017). According to the report, shifting to eco-friendly energies will save up to 87 billion U.S. dollars and will reduce up to 1 gigaton of carbon emissions by 2030 (Al Arabiya English, 2017).

United Arab Emirates: Dubai Electricity and Water Authority net-metering Programme creates a regulatory environment for solar PV plants to be connected to the electricity network and to be compensated for the surplus electricity fed to the grid (IRENA, 2016). The Authority received many applications for solar PV installations from both private and government entities. Dubai Ports too expressed their interest and announced that they will be adding between 30 to 40 MW of capacity on their premises under the Programme (IRENA, 2016).

The given above examples are only few of many other successful projects of utilizing solar energy. Economically poor or rich, many countries worldwide see in solar energy a valuable opportunity for a better change.

7. Optimum Approach

Sudan action plan incorporated in its INDC report does reflect huge, ambitious and rather costly (7,550,000,000 USD) plans for its energy sector. For a developing country like Sudan which had just recently lost its oil-rich South part and where the country is still seeking means of reviving its crippling economy, a mention of several billion dollars investments up until year 2030, just appears to be unrealistic.

Sudan must understand to prioritize its actions according to its present weak economy and limited budgets. This should be even valid when we consider the type of renewables to adopt and within each type which specific method works best for a given circumstance and cause. For instance, there would be no point in building more costly hydropower dams and yet the country grid infrastructure is in critical condition. Similarly, investing millions of U.S. dollars in grid-connected solar projects targeting urban areas, whilst rural regions where majority of the population lives and country strategic agriculture lies with no access to electricity would definitely be a wrong decision.

There are definitely huge potentials (theoretically, technically, realizable and long term) should solar energy be adopted in The Sudan. The present transition phase requires a serious practical focused strategy to make positive contributions to its energy sector and development altogether.

Hereunder are few action plans (with ones derived from the International Renewable Energy Agency, IRENA) that Sudan should consider during its current energy transition and long-term vision:

A. Adoption of investment promotion measures to attract both domestic and foreign investors to support solar energy diffusion through: Improvement of the availability of local financing by raising awareness of local commercial banks and financial intermediaries about solar energy applications in both grid-connected and off-grid market segments; The use of public financing to reduce perceived risks, in order to attract investments (either foreign direct investment, local or official development assistance); and Establishment of Public Private Partnerships for cost and risk sharing to attract private sector participation and financing. (IRENA, 2015).

B. Promotion of off-grid systems solutions (e.g. stand-alone PV systems, solar collectors etc.) which play significant role in improving access to modern energy and consequently poverty reduction: By introducing dedicated policy and regulatory frameworks that incentivize the private sector, foster innovation in business and financing models, and create enabling conditions for scale-up and replication; By shifting the focus away from a project-by-project approach towards one that supports the development of a sustainable market in the long-term; and Establishment of an institutional framework that enhances dialogue and coordination between different stakeholders involved, in order to improve clarity and define roles and responsibilities for off-grid electrification initiatives. (IRENA, 2015).

C. Promotion of cooperation between the locals, the government and Non-Governmental Organizations (NGOs): By holding regular meetings between the parties to address any raised issues concerning potential/ongoing projects or post installation services and maintenance; By holding regular workshops and trainings to ensure adequate levels of education are being achieved; and By introducing renewable energy science with emphasis on solar energy into institutional systems (e.g. schools, government news and media etc.).

A rather long-term action would be:

D. Creation of an enabling policy and a regulatory framework that can catalyze investments into renewables in general and solar in particular in order to maximize socio-economic benefits: By establishing national energy plans and renewable energy targets translated into supportive policy and investment frameworks; By fostering stable and long-term market development while adapting to changing technological and market conditions; Implementation of deployment policies as part of a broad range of cross-cutting policy instruments. A policy mix tailored to meet Sudan conditions and the level of maturity of its varying sectors, aimed at strengthening firm-level capabilities, building a domestic industry, promoting education and research and facilitating investment and technology transfer; By broadening of financing sources to support expansion in capacity and transmission and infrastructure distribution through regional cooperation (e.g. utilizing the strategic partnership with the oil-rich Arab Gulf countries to support large grid-connected solar projects); and By expanding regional grid integration and power trade through regional planning, harmonization of standards and procedures, equitable commercial terms and coordination at power pool level. (IRENA, 2015).

Apart from above recommended action plans, the Sudanese government needs first and foremost to realize that corruption must be eliminated. Negligence of such detrimental factor will do nothing but plunge the country into economic uncertainty and lead to further waste and loss of its immense natural and human resources.

8. Conclusion

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.

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.

Acknowledgement

The author would like to acknowledge with deep thanks and profound gratitude Mr. Osama Mahmoud Mohammed Ali of Dania Center for Computer and Printing Services, Atbara, who spent many hours in editing, re – editing of the manuscript in compliance with the standard format of most Journals. Also, my appreciation is extended to Professor Mahmoud Yassin Osman for revising and correcting the manuscript several times.

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