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Harnessing solar energy: from past to present

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$$Min \sum_{i=1}^{n} w_i . x_i$$
$$s.t \ A_{(n+w)\times n} X_{n\times 1} \geq b_{(n+w)\times 1}$$

$$Min \sum_{i=1}^{n} w_i x_i$$
$$s.t \ y = A_{n\times n} X_{n\times 1} \geq b$$

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ABSTRACT

For over a decade now attention is critically focused on the exploitation of environmentally sustainable and renewable energy sources, particularly due to the depletable, expensive and pollution characteristics of fossil fuels. In this regard, solar energy has strong potentials to play a great future role, especially in the global areas around the equator. Substantial effort has therefore been made to cover numerous issues associated with harnessing solar power. Hargreaves equation and its derivatives as assessment models, wide range of literature studies documented across the globe with emphasis to African countries and the key green areas were substantially covered. Necessary recommendations were also offered in line with international energy demand and strategies.

Introduction

Various books have been written on the history of solar technology (Butti and Perlin, 1980). This history began when early civilizations discovered that buildings with openings facing the Sun were warmer and brighter, even in cold weather. During the late 1800s, solar collectors for heating water and other fluids were invented and put into practical use for domestic water heating and solar industrial applications, for example, large-scale solar desalination. Later, mirrors were used (by Augustin Mouchot in 1875) to boost the available fluid temperature, so that heat engines driven by the Sun could develop motive power, and hence, electrical power. Also, the late 1800s brought the discovery of a device for converting sunlight directly into electricity called the photovoltaic (PV) cell; this device bypassed the need for a heat engine. The modern silicon solar cell, attributed to Russell Ohl working at American Telephone and Telegraph's (AT&T) Bell Labs, was discovered around 1940. The modern age of solar research began in the 1950s with the establishment of the International Solar Energy Society (ISES) and increased research and development (R&D) efforts in many industries. For example, advances in the solar hot water heater by companies such as Miromit in Israel and the efforts of Harry Tabor at the National Physical Laboratory in Jerusalem helped to make solar energy the standard method for providing hot water for homes in Israel by the early 1960s (Arvizu, 2011). At about the same time, national and international networks of solar irradiance measurements were beginning to be established. With the oil crisis of the 1970s, most countries in the world developed programs for solar energy R&D, and this involved efforts in industry, government labs and universities. These policies support efforts, which have, for the most part, continued up to the present, have borne fruit: now one of the fastest growing renewable energy (RE) technologies, solar energy is poised to play a much larger role on the world energy stage.

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Objectives

The objective of this paper is to re-examine the widely accepted methods of evaluating solar radiation potentials and critically report previous and recent progress on harnessing solar energy documented in the literature. Possible recommendations would also be offered taking in to account other renewable energy sources.

Estimating Solar Radiation

Solar radiation (R_s) reaching the earth's surface varies significantly with location, atmospheric conditions including cloud cover, aerosol content, and ozone layer condition, and time of day, earth/sun distance, solar rotation and activity. Thus it can be stated that solar spectra at a particular location depend on so many variables. Solar radiation is a primary driver of the evapotranspiration (ET) process and R_s data are integral part of many ET estimation procedures. For example, the Penman and Penman-Monteith equations (Wright 1982; Jensen *et.al.*1990) require net radiation data, which are commonly estimated using measured R_s (Jensen *et.al.* 1990; Shuttle worth 1992). Solar radiation is not routinely measured at many weather stations and may need to be estimated when a Penman-type ET equation is applied. The common and most recommended alternative is to use empirically based ET methods, such as the Hargreaves *et.al.* (1985) method, which requires only maximum and minimum daily air temperatures.

The equation that is applicable in both urban and rural areas according to Chineke (2007) is $R_s = k_r R_a Td^{0.5}$. (1.1)

Where, kr = Empirical coefficient, Ra = Extraterrestrial solar radiation, Td = (T_{max} - T_{min})

The most important parameters in estimating the solar potential are temperatures and solar radiation. According to Jensen (1985), at least 80 percent of solar potential can be explained by temperatures and solar radiation. Hargreaves and Samani (1982) recommended a simple equation to estimate solar radiation (R_s);

$$R_s = (KT)(R_a)(TD)^{0.5} \qquad (1.2)$$

Where, TD = Maximum daily temperature minus minimum daily temperature (^oC) for weekly or monthly periods.(T_{max} - $T_{min,} {}^{O}C$)

R_a= Extraterrestrial radiation (MJ/m^2/day); and requires that the latitude of the site be input in decimals of degree;

KT=Empirical coefficient. Combining equation (1.2) with the original Hargreaves equation (Hansen *et al*, 1979) resulted in a simplified equation which requires only temperatures and latitude (Hargreaves and Samani, 1982, 1985). The simplified equation is;

$ET_0 = 0.0135\ (KT)\ (R_a)\ (TD)^{1/2}(TC+17.8)$. (1.3)

TC is the average daily temperature (^oC). Equation (1.3) explicitly accounts for solar radiation and temperature. Although relative humidity is not explicitly contained in the equation, it is implicitly present in the difference in maximum and minimum temperature. The temperature difference (TD) is linearly related to relative humidity (Hargreaves and Samani, 1982). Equation (1.3) has been successfully used in some locations for estimating solar potential where sufficient data were not available to use other methods (Orang *et al* 1995). Though the equation does not account for advection, it has been successfully used even in advective conditions when calibrated against wind data (Salazar, 1987). Hargreaves (1994) recommended using KT =0.162 for 'interior' regions and KT=0.19 for coastal regions.

There is an implicit assumption in both equations (1.2) and (1.3) which could result in significant errors in some conditions. Both equations assumed that the difference in maximum and minimum temperatures is directly related to the fraction of extraterrestrials radiation received at the ground level. However, there are factors other than solar radiation, cloudiness, and humidity that can influence the difference in temperatures of a given location. These factors include; latitude, elevation, topography, storm pattern, advection and proximity to a large body of water. For example, at low latitudes, the temperature difference becomes negligible and consequently equation (1.2) and (1.3) becomes insensitive and could significantly under estimate both solar radiation and solar potential as demonstrated by Jagtap (1991).

Solar radiation as a source of energy

Solar energy is an abundant energy resource. Indeed, in just one hour, the solar energy intercepted by the earth exceeds the world's energy consumption for the entire year. Solar energy's potential to mitigate climate change is equally impressive. Except for the modest amount of carbon dioxide (CO_2) emissions produced in the manufacture of conversion devices, the direct use of solar energy produces very little greenhouse gases, and it has the potential to displace large quantities of non-renewable fuels (Tsilingiridis *et al.*, 2004). Solar energy conversion is manifest in a family of technologies having a broad range of energy service applications: lighting, comfort heating, hot water for buildings and industry, high-temperature solar heat for electric power and industry, photovoltaic conversion for electrical power, and production of solar fuels, for example, hydrogen or synthetic gas (syngas). Several solar technologies, such as domestic hot water and pool heating are already competitive and used in locales where they offer the least-cost option. And in jurisdictions where governments have taken steps to actively support solar energy, very large solar electricity (both PV and CSP) installations, approaching 100MW of power, have been realized, in addition to large numbers of rooftop PV installations.

Other applications, such as solar fuels, require additional R&D before achieving significant levels of adoption. In pursuing any of the solar technologies, there is the need to deal with the variability and the cyclic nature of the Sun. One option is to store excess collected energy until it is needed. This is particularly effective for handling the lack of sunshine at night. For example, a 0.1m thick slab of concrete in the floor of a home can store much of the solar energy absorbed during the day and releases it to the room at night. When totaled over a long period of time such as one year, or over a large geographical area such as a continent, solar energy can offer much greater service. The use of both these concepts of time and space, together with energy storage, has enabled designers to produced more effective solar systems. But much more work is required to capture the full value of solar energy's contribution. Because of its inherent variability, solar energy is most useful when integrated with another energy source, to be used when solar energy is not available. In the past, that source has generally been a non-renewable one. But there is great potential for integrating direct solar energy with other renewable energy technologies (Arvizu, 2011).

The solar irradiance reaching the Earth's surface (Figure 1) is divided into two primary components: beam solar irradiance on a horizontal surface, which comes directly from the Sun's disk, and diffuse irradiance, which comes from the whole of the sky except the Sun's disk. The term 'global solar irradiance' refers to the sum of the beam and the diffuse components (Arvizu, 2011).

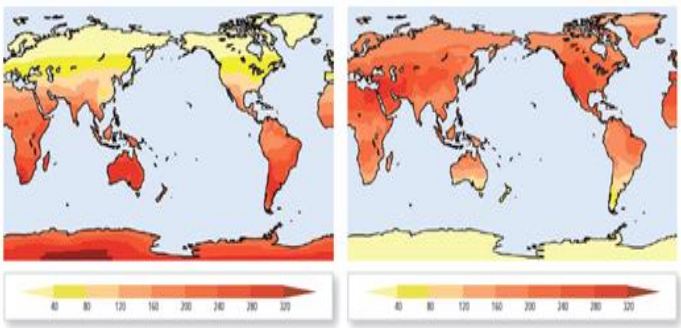

Figure 1. The global irradiance (W/m^3) at the earth's surface from satellite imaging radiometers and averaged over the period 1983 to 2006. Left panel; December, January, February, Right panel; June, July, August (ISCCP Data Products, 2006)

There are several ways to assess the global resource potential of solar energy. The *theoretical* potential, which indicates the amount of irradiance at the Earth's surface (land and ocean) that is theoretically available for energy purposes, has been estimated at $3.9*10^6$ EJ/yr (Rogner *et al.*, 2000). This could be achieved using Hargreaves equation (1.2).

Review of the relevant literature

Solar energy is one of the most abundant sources of clean and free global energy. Although in the developed parts of the world especially Europe and American continents a number of extended studies have been carried out to device most suitable methods of harnessing the solar energy, but very little or insufficient details are available in the developing world especially the African continent. Therefore a review of the available and relevant literature would be very important in laying the foundation on what could be done scientifically in the later part of the world.

Cases of application of solar radiation were viewed by some other researchers in this field. Such a case is the work performed by Motamedi and his co- workers (Motamedi *et. al.*, 2011) titled; Heating Usages of Solar Energy in A Combined Cycle for Residential Buildings of Khouzestan Province, it stated that the amount of annual solar energy radiation in Khouzestan province has rendered it a favorable condition to use solar energy in this region. The purpose of this project is to study the heating usage of buildings in a combined cycle. To this end, the researchers designed a model (*Dimention: 1m* x 1*m* x 0.7*m)*. Eight rows of copper pipes with 1 .375 *inch* diameter were installed on the roof of model. By using a Motor, Oil circulates inside of these pipes and after the passing through the pies, it will turn into the same cycle. The oil is heated by solar radiation and in its return path; heating is carried to interior air of the model by using a small radiator, which is installed in the main box. In order to reach maximum power and considering Green House Effect, the pipes are placed in glass boxes. Moreover, to increase its efficiency; cooper pipes were coated with black color. In the best condition and during about 20 days of data collection, $18^{o}C$ of temperature difference has been recorded between indoor and outdoor spaces; and went on to calculate η=12.3 % which is the efficiency of oil cycle.

The focus of Fadare *et al.* (2010) was on the feasibility of an artificial neural network (ANN) based model for the prediction of solar energy potential in Africa. Standard multilayered, feed-forward, back propagation neural networks with different architecture were designed using Neuro Solutions. Geographical and meteorological data of 172 locations in Africa for the period of 22 years (1983- 2005) were obtained from NASA geo-satellite database. The input data (geographical and meteorological parameters) to the network includes: latitude, longitude, altitude, month, mean sunshine duration, mean temperature, and relative humidity while the solar radiation intensity was used as the output of the network. The results showed that after sufficient training sessions, the predicted and the actual values of solar energy potential had Mean Square Errors (MSE) that ranged between 0.002 - 0.004, thus suggesting a high reliability of the model for evaluation of solar radiation in locations where solar radiation data are not available in Africa. The predicted and actual values of solar energy potential were given in form of monthly maps. The solar radiation potential (actual and ANN predicted) in northern Africa (region above the equator) and the southern Africa (region below the equator) for the period of April – September ranged respectively from 5.0 - 7.5 and 3.5 - 5.5 kW h/m^2/day while for the period of October – March ranged respectively from 2.5 – 5.5 and 5.5 - 7.5 kW h/m^2/day. This study has shown that ANN based model can accurately predict solar radiation potential in Africa.

While areas of applications of the solar radiation have been focused by notable set of researchers in this field, the concentration of various other teams are on the barriers to attainment of full utilization. One of this groups presented paper on Scaling up Renewable Energy in Africa 12th Ordinary Session of Heads of State and Governments of the African Union a program under the sponsorship of United Nations Industrial Development Organization (UNIDO). The paper in one of its subsections; Barriers to renewable energy development in Africa, discussed "the extent to which renewable energy can contribute to efforts to address the energy challenges facing Africa". In general, the role of renewable energy in meeting Africa's energy demand has been undermined by bad experiences, misinformation, technology push, and consequent negative perceptions. The balance between energy services for meaningful economic growth, on the one hand, and general welfare gains, on the other, continues to be a source of unnecessary conflict among stakeholders, as both are essential and complementary (UNIDO, 2009). It claimed that so far, certain technologies have been disseminated in circumstances that compromise their further adoption, as beneficiaries have been dissatisfied. The mismatch between energy service provision and income generation to meet the cost of services has been particularly disadvantageous for the promotion of renewable energy. In the paper the key barriers were categorized as being policy, regulation and institutional; information and technical capacity; and financial factors (UNIDO, 2009).

In a related study by John-Felix K. Akinbami (2001) on renewable energy sources, with a specific focus on solar irradiation and constraints, he observed that Nigeria is endowed with abundant energy resources, both conventional and renewable, which provide her with immense capacity to develop an effective national energy plan. In his paper titled renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework, he stated that introduction of renewable energy resources into the nation's energy mix have implications on its energy budget (Akinbami, 2001). The national energy supply system has been projected into the future using MARKAL, a large scale linear optimization model. However, this model may not be absolutely representative of the highly non-linear future of renewable energy. Results of the model reveal that under only a least cost constraint, only large hydro power technology is the prominent commercial renewable energy technology in the electricity supply mix of the country. Despite the immense solar energy potentials available, solar electricity generation is attractive only under severe CO_2 emissions mitigation of the nation's energy supply system. Similarly, the penetration of small-scale hydro power technology in the electricity supply mix is favoured only under CO_2 emissions constraints. Due to economy of scale, large hydro power technology takes the lion share of the entire commercial renewable energy resources share for electricity generation under any CO_2 emissions constraint. These analyses reveal that some barriers exist to the development and penetration of renewable energy resources for electricity production in Nigeria's energy supply system. Barriers and possible strategies to overcome them are discussed. Intensive efforts and realistic approach towards energy supply system in the country will have to be adopted in order to adequately exploit renewable energy resources and technologies for economic growth and development.

Ojosu (1997) had analyzed the daily solar radiation measurement at Ikeja (Lagos) for solar system design .The study aimed at clarifying the site potentiality of Ikeja (Lagos) for solar energy system design. The data used were the global solar radiation data for Ikeja meteorological station, Lagos for 5years from 1986 to 1990 measured by the Nigerian meteorological office, Oshodi. The results showed that, the chances of encountering a period of low radiation long enough to be serious concern in the use of solar energy systems for practical applications are small. However, the rainy season of June, July, August and September, and also the Hamattan period of December and January which may produce low radiation periods of up to 12 days below the mean global solar radiation need to be re- examined for design purposes.

Melodi and Famakin carried out research on Solar Energy Potential for Domestic Electricity Generation in Akure, Nigeria. The consistence and adequacy of solar radiation for electricity generation in Akure, applicable for the region, was investigated. Data of daily sunshine hours and the daily readings of a Gunn Bellani radiometer for the period 2001-2007 were analyzed using numerical statistical and graphing technique. Electricity equivalents (kWh: per annum; per month; per day; per capita) of Solar radiation were estimated using developed mathematical formulas. Residential load was estimated by load survey of typical residences and direct calculation methods. Power density equivalent and electricity equivalent per capita per day were estimated at 1000.7 W/m^2 and 104.43kWh/capita/day respectively, at 17% conversion efficiency of PV equipment and daily sunshine of about 5.21hours. Required surface area to harvest sufficient solar energy for daily house needs is 33.8m^2. It was concluded that daily solar energy reaching the location per capita can be converted to electricity that is about 4 times the per capita need per day – 29.4 kWh/capita/day.

Akachukwu (2011) carried out research on prediction of optimum angle of inclination for flat plate solar collector in Zaria, Nigeria. He fabricated a flat plate surface solar collector of dimension 0.5 m^2, hinged on a horizontal support for quick adjustment of inclination from 0 to 900, marked out at 1^o intervals on a telescopic leg graduated in degrees. Measurement of the solar radiation, varying degrees of inclination were taken between 12:00 noon and 2:30 pm for 4 days at clear sky hours, within the week of nth day of the year. The measurements were made for each month of the year in Zaria, Kaduna State, Nigeria. At each degree of inclination, the solar radiation intensity was replicated three times and the average value was taken. The flat plate was set truly facing south with an engineering prismatic compass. The result showed that the optimum angle of inclination of a flat plate for maximum collection of solar radiation intensities are 26.5, 24.5, 10.0, 19.5, 26.0, 30.0, 24.0, 21.0, 11.5, 19.5, 27.0 and 30.0, in the months of January to December, respectively. This work also revealed that the average angle of inclination at which a flat surface solar collector could be mounted at fixed position in Zaria is 22.50. The analysis indicated that when a flat surface was located at the predicted optimum angle of inclination for each month of the year, an average annual increment of 4.23 % solar radiation intensity was achieved, when compared with the yearly average solar radiation intensity harnessed by the same flat plate collector on horizontal position, and under the same condition. This percentage increase amounted to annual average solar energy gain of 370,670 MJ/m^2, at no extra-cost, other than positioning the solar collector at the identified optimum angle of inclination. Comparison of the measured and calculated optimum values of angle of inclination of a flat plate surface for trapping maximum solar radiation intensity for each month of the year indicated a high correlation with R^2 of 0.97.

Evaluation of the global solar energy potential at Chandrapur, India, latitude 20.06 N and longitude 70.3 E was carried out by Kondawar and his supervisor (Kondawar, 2012). The amount of incident solar radiation significantly determines the electricity produced by Photovoltaic (PV) system. The paper reports a novel method suitable to measure the potential of solar electricity generation in Chandrapur on the basis of solar radiation data obtained for one year. Further, possible plant capacity is estimated for an arbitrary chosen area. A developed PV model with assumed efficiency of 7% was employed for the study. However it was observed that, the month of March and April which offers the highest solar radiation, the result would have been far more accurate and yielded higher capacity plant. For future studies, designing, cost analysis efficiency calculations of this solar photovoltaic power plant now need to be done once the capacity is estimated, which can be carried out in future publications. Environmental impact of this photovoltaic plant can be taken up as one of the important issue in the near future.

Chiemeka and Chineke (2009) went on related work on evaluation of the global solar energy potential at Uturu, Nigeria, latitude 0.5.33°N and 06.03°N. According to them, the temperature data were obtained from 1st - 30th November, 2007 using the maximum and minimum thermometers placed in a Stevenson screen at 1.5 m above the ground level. The Hargreaves equation (1.2) was used to evaluate the solar energy potential at Uturu. The mean solar power potential obtained for the period over Uturu was 2.45 ± 0.29 KWh m^{-2} per day. A comparison of the mean global solar potential obtained at Uturu and that reported by Offiong (2003) showed that the insulation potential obtained at Uturu was 44.1% less. This difference may be attributed to the hilly nature of Uturu, coupled with the fact that the climate at Uturu varies significantly with the seasons of the year (Chiemeka 2009).

The Way Forward

The various literatures reported in this paper have indicated that, despite the very great simplification, Hargreaves model and its derivatives appeared to be well suited for the estimation of daily global solar radiation records. The principal advantages of the model in respect to other estimation methods are that it uses only maximum and minimum temperature records, requires no special calibration parameters while weather station parameters are directly derived from the latitude. In addition to the stated advantages, the model provides a simple and low cost system for estimating solar radiation. It does not require information from neighboring stations for special interpolation and it does not require expensive hardware for data processing. The model appears to be suited for most agro-meteorological and simulation studies requiring solar radiation data and it can extend the effectiveness of these applications to areas where radiation is not or is only rarely measured by meteorological networks.

Solar energy offers considerable advantages over the conventional energy systems by nullifying flaws in those systems long considered to be unchangeable. Solar power for home energy production has its flaws, too, which are outlined in another article, but they are dwarfed by some of the advantages as .Solar energy raw materials are renewable and unlimited .The amount of available solar energy is staggering roughly 10,000 times that currently required by humans and its constantly replaced. A mere 0.02% of incoming sunlight, if captured correctly, would be sufficient to replace every other fuel source currently used. Solar power is low - emission, solar panels produce no pollution, although they impose environmental costs through manufacture and construction. These environmental tolls are negligible, however, when compared with the damage inflicted by conventional energy sources: the burning of fossil fuels releases roughly 21.3 billion metric tons of carbon dioxide in to the atmosphere annually.

Mean while Solar power is suitable for remote areas that are not connected to energy grids. solar power provides green jobs. Production of solar panels for domestic use is becoming a growing source of employment in research, manufacture, sales and installation. Solar panels contain no moving parts and thus produce no noise. Wind turbines, by contrast, require gearboxes and blades. In the long run, solar power is economical, solar panels and installation involve high initial expenses, but this cost is soon offset by savings on energy bills. Eventually, they may even produce a profit on their use. Solar power conserves foreign energy expenditures. In many countries, a large percentage of earning is used to pay for imported oil for power generation. The United States alone spends $13 million per hour on oil, much of which comes from Persian Gulf nations. As oil supplies dwindle and prices rise in this politically unstable region, these problems continue to catalyze the expansion of solar power and other alternative energy systems. In summary, solar energy offers advantages to conventional fossil fuels and other renewable energy systems.

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