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Renewable sources of energy and mathematical modeling of solar insolation: a

review

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Introduction

In the past century, it has been seen that the consumption of non-renewable sources of energy has caused more environmental damage than any other human activity. Electricity generated from fossil fuels such as coal and crude oil has led to high concentrations of harmful gases in the atmosphere. This has in turn led to many problems being faced today such as ozone depletion and global warming. Vehicular pollution has also been a major problem. [1-2]

After the industrial revolution in the mid-eighteenth century and also due to uncontrolled increase in the population, human beings started to require more energy for consumption. Hence, non-renewable energy sources in the form of coal, oil, and wood began to deplete with time [3]. Since these resources are limited and also are a cause of environmental pollution, these energy sources need to be replaced by alternatives. [4].

Alternative sources of energy have become very important and relevant to today's world. These resources, such as the sun, wind, biomass, geothermal energy etc. can never be exhausted and are therefore called renewable. They cause fewer emissions and are available locally. Their use can reduce chemical, radioactive and thermal pollution to a large extent. They stand out as a viable source of clean and limitless energy. These are also known as non-conventional sources of energy.

Need of Renewable Energy Resources

The ecological footprint is a measurement that compares rates of human resource consumption and waste generation with the biosphere's rates of resource regeneration and waste assimilation, expressed in terms of the area necessary to maintain these flows [5]. Therefore, the world's consumption of renewable and non-renewable natural resources can be expressed by ecological footprint [6].

`` The world's human population has exceeded its ecological footprint by about 20 percent. In simple words it means that people are consuming Earth's Energy Sources resources faster than the Earth can replace them.

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ABSTRACT

Energy is the primary need of any society. It is consumed in transportation, in industries and for the heating, lighting and water-pumping etc. To fulfil its energy demand, our society is dependent on fossil fuels such as oil, coal and natural gas. But fossil fuels are conventional resources and are depleting fast. Therefore, it is necessary to find some alternatives sources, so as to fulfil the ever increasing demand for energy. This demand can be fulfilled by utilizing renewable energy sources. This paper studies various types of available non-conventional energy sources. It also includes a brief review of the work done by different researchers on mathematical modeling of solar irradiance.

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Some of the consequences of exceeding the ecological footprint such as depleted fisheries, diminished forest cover, scarcity of fresh water, and build-up of wastes etc. have already become evident.

The world demand for energy is expected to increase steadily until 2030 according to many scenarios. Global primary energy demand is projected to increase by 1.7% per year from 2000 to 2030, reaching an annual level of 15.3×10^9 tons of oil equivalent (toe) [7]. The projected growth is, nevertheless, slower than the growth over the past 30 years, which ran at 2.1% per year. The global oil demand is expected to increase by about 1.6% per year from 75×10^6 barrels per day to 120×10^6 barrels per day [4].

Since energy cannot be created or destroyed and with the expected population increase, it is anticipated that there will be energy crises in the future, which may lead to an energy dilemma due to the finite amount of readily available fossil fuels.

Deposited fossil fuels, in the form of coal, that are used through combustion are expected to last for approximately the next 300 years at the most, and from then onward human beings will be left with renewable energy resources only [4]. The renewable energies are expected to play an active role in the future energy share because they satisfy the following prerequisites:

 \checkmark They are environmentally clean, friendly, and do not produce greenhouse gases.

 \checkmark They have sufficient resources for larger scale utilization as the solar energy resource is almost evenly distributed all over the world with maximum possible generatable amounts increasing toward the equator.

Air pollution from combustion processes has caused serious damage and danger to forests, monuments, and human health in many countries, as has been documented by official studies and yearly statistics.

Table 1: Oil Consumptions by Different Countries in 2009

S. No.	Total Oil Consuming Countries in 2009				
	Top Oil Consuming Countries	Barrels per day (MBD)			
1	United States	20,698,000			
2	China	7,855,000			
3	Japan	5,041,000			
4	India	2,748,000			
5	Russia	2,699,000			
6	Germany	2,393,000			
7	South Korea	2,371,000			
8	Canada	2,303,000			
9	Brazil	2,192,000			
10	Saudi Arabia	2,154,000			
11	Mexico	2,024,000			
12	France	1,919,000			
13	Italy	1,745,000			
14	United Kingdom	1,696,000			
15	Iran	1,621,000			
16	Spain	1,615,000			
17	Indonesia	1,157,000			
18	Taiwan	1,123,000			
19	Netherlands	1,044,000			
20	Australia	935,000			

Source: Anne Maczulak [6]

 Table 2: Predicted Worldwide Energy Consumption in

 Different Countries

Predicted Worldwide Energy Consumption (Quadrillion BTU)							
Region	2010	2015	2020	2025	2030		
North America	131.4	139.9	148.4	157.0	166.2		
Asia	126.2	149.4	172.8	197.1	223.6		
Europe	84.4	87.2	88.7	91.3	94.5		
Central and south America	28.2	32.5	36.5	41.2	45.7		
Middle East	25.0	28.2	31.2	34.3	37.7		
Africa	17.7	20.5	22.3	24.3	26.8		
Total World	509.7	563.0	613.0	665.4	721.6		
Source: Timeforchange org Anne Maczulak (2009) [6]							

Therefore, it is necessary to use clean energy sources. The nature and pattern of agriculture, industry, and trade should not unduly impinge on ecological health and resilience otherwise; the very basis of economic growth will be shattered through environmental degradation, more so as a consequence of climate change [8].

The major areas of environmental problems that have been classified by

Dincer I. [9] are as follows:

✓ Major environmental accidents

- ✓ Water pollution
- ✓ Maritime pollution
- ✓ Land use and siting impact
- ✓ Radiation and radioactivity
- ✓ Solid waste disposal
- ✓ Hazardous air pollution
- ✓ Ambient air quality
- ✓ Acid rain
- ✓ Stratospheric ozone depletion
- ✓ Global climate change leading to greenhouse effect.

It has been recently realized that renewable energy sources and systems can have a beneficial impact on the following essential technical, environmental, and political issues of the world. These are:

✓ Since renewable energy resources are non- polluting, therefore by using them, major environmental problems such as acid rain, stratospheric ozone depletion, Greenhouse effect and smog can be dealt with without extra efforts.

 \checkmark Environmental degradation can be controlled to a great extent.

 \checkmark Rate of depletion of the world's non-renewable conventional sources such as coal, oil, and natural gas can be made slower.

 \checkmark Increasing demand of energy in the developing countries can be met without the fear of exhausting energy resources.

But the basic problems in using renewable energy on large scale are:

✓ Storage of solar and wind energy should be improved

 \checkmark The cost effectiveness of the renewable sources is one of the most important issues that must be tackled in a reduction direction. At present, large scale fossil energy production is cheaper than the available solar and wind alternatives [10].

However, renewable energy now, by and large, is becoming cost competitive with conventional forms of energy and are expected to reach to masses in the near future.

Various Renewable Energy Resources

To improve the economy and living conditions of the people of the society, sufficient energy at affordable prices is essential. We need energy for agriculture, industries and for electrification. With the limited availability, rising prices and exponentially increasing energy demand, one must think about the alternatives. Renewable energy sources can solve the problem. Renewable energy sources include: hydroelectricity, geothermal, solar photovoltaic, solar thermal, tide, wave, ocean, wind, solid biomass, biogas, liquid biomass and renewable municipal solid waste. [11]

Hydroelectricity:

Energy in water can be harnessed and used. Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy. Hydroelectricity refers to potential and kinetic energy of water converted into electricity in hydroelectric plants

Water flowing downstream is a powerful force. Water is a renewable resource, constantly recharged by the global cycle of evaporation and precipitation. The heat of the sun causes water in lakes and oceans to evaporate and form clouds. The water then falls back to Earth as rain or snow, and drains into rivers and streams that flow back to the ocean. Flowing water can be used to power water wheels that drive mechanical processes . The energy of flowing water can be used to generate electricity. **Geothermal Energy:**

Geothermal energy is from thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. 20% of Earth's geothermal energy originates from the original formation of the planet and the remaining 80% comes from radioactive decay of minerals [12].

It is actually the heat emitted from within the earth's crust, usually in the form of hot water or steam. It is used for electricity generation, heat production for sale to third parties or directly as heat in its primary form. From hot springs, geothermal energy has been used for bathing since Palaeolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation [13-15]

Solar energy:

Energy received from sun is referred to as solar energy. It can be exploited for electricity generation and hot water production. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy.

Active solar techniques are employed to convert solar energy into another more useful form of energy. This would normally be a conversion to heat or electrical energy. These include the use of photovoltaic panels and solar thermal collectors to harness the energy. Eg. Electricity generation by photovoltaic cells and seasonal heating of swimming pools [16] *Passive solar techniques* include orienting a building to the Sun, selecting materials with favourable thermal mass or light dispersing properties, and designing spaces that naturally circulate air [17]

Tide / wave / ocean:

Water covers almost two thirds of the earth, and thus, a large part of the sun's radiant energy that is not reflected back into space is absorbed by the water of the oceans. This absorbed energy warms the water, which, in turn, warms the air above and forms air currents caused by the differences in air temperature. These currents blow across the water, returning some energy to the water by generating wind waves, which travel across the oceans until they reach land where their remaining energy is expended on the shore. Mechanical energy derived from tidal movement, wave motion or ocean current and exploited for electricity generation is called tidal energy. Although not yet widely used, tidal power has potential for future electricity generation [18].

Wind Energy:

Wind energy is the kinetic energy of wind which can be exploited for electricity generation by wind turbines.[19] Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electrical power, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships.[20]

Biomass:

Biomass (plant material) is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, plants capture the sun's energy. When the plants are burnt, they release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, with only as much used as is grown, the battery will last indefinitely.[21]

In general there are two main approaches to using plants for energy production: growing plants specifically for energy use (known as first and third-generation biomass), and using the residues (known as second-generation biomass) from plants that are used for other things. The best approaches vary from region to region according to climate, soils and geography.[23]

Solid biomass covers organic, non-fossil material of biological origin which may be used as fuel for heat and electricity production. [23]

Liquid biomass includes bio-alcohols, such as bio-ethanol, and oils, such as bio-diesel, bio-fuels and bio-additives such as bio-gasoline bio-diesel and other liquid bio-fuels. Bio-diesel is made from vegetable oils, animal fats or recycled greases.

Bio-diesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from dieselpowered vehicles. Bio-diesel is produced from oils or fats and is the most common bio-fuel in Europe. Bio-fuels provided 2.7% of the world's transport fuel in 2010. [24] Gaseous bio-fuels include biogas, landfill gas and synthetic gas.

Gaseous bio-fuels include biogas, landfill gas and synthetic gas. Biogas is derived principally from the anaerobic fermentation of biomass and solid waste and is combusted to produce heat and/or power. [25]

Municipal waste - renewable:

Renewable municipal waste consists of the bio-degradable part of municipal waste products that are combusted directly to produce heat and/or electricity. It comprises waste produced by the residential, commercial and public services sectors that is collected by local authorities for disposal in a central location, including biodegradable hospital waste. [26]

Renewable energy can replace conventional fuels in four distinct areas: electricity generation, hot water/space heating, motor fuels, and rural (off-grid) energy services.

Power generation: Renewable energy provides 19% of electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas. For example, 14% in the U.S. state of Iowa, 40% in the northern German state of Schleswig-Holstein, and 20% in Denmark. Some countries get most of their power from renewables, including Iceland (100%), Norway (98%), Brazil (86%), Austria (62%), New Zealand (65%), and Sweden (54%). [22]

Heating: Solar hot water makes an important contribution to renewable heat in many countries, most notably in China, which now has 70% of the global total (180 GWth). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50–60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly. [22]

Transport fuels:

Renewable bio-fuels have contributed to a significant decline in oil consumption in the United States since 2006. The 93 billion litres of bio-fuels produced worldwide in 2009 displaced the equivalent of an estimated 68 billion litres of gasoline, equal to about 5% of world gasoline production. [24] In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power, requiring utilities to use more renewable energy (even if this increases the cost), and providing tax incentives to encourage the development and use of such technologies. There is substantial optimism that renewable energy investments will pay off economically in the long term [27].

Renewable energy has the potential to bring power to communities, not only in the literal sense, but by transforming their development prospects. There is tremendous latent demand for small scale, low cost, off-grid solutions to people's varying energy requirements. [28]

Mathematical modeling of Renewable Sources of Energy

French professor Augustine Mouchot predicted in 1873: "The time will arrive when the industry of Europe will cease to find those natural resources, so necessary for it. Petroleum springs and coal mines are not inexhaustible but are rapidly diminishing in many places. Will man, then, return to the power of water and wind? Or will he emigrate where the most powerful source of heat sends its rays to all? History will show what will come [29]."

By 1873, concerns of running out of coal prompted experiments with using solar energy [30]. Development of solar engines continued until the outbreak of World War I [31]. Though the importance of solar energy was recognized in a 1911 Scientific American article: "in the far distant future, natural fuels having been exhausted [solar power] will remain as the only means of existence of the human race [32]."

In the 1970s environmentalists promoted the development of alternative energy both as a replacement for the eventual depletion of oil, as well as for an escape from dependence on oil, and the first wind turbines appeared. Solar had always been used for heating and cooling, but solar panels were too costly to build solar farms until 1980 [33].

By 2008 renewable energy had ceased being an alternative, and more capacity of renewable energy was added than other sources in both the United States and in Europe [34].

Modeling Solar Radiation

In September 1911 Frank Shuman [35], an American entrepreneur, wrote in Scientific American: "The future development of solar power has no limit. Where great natural water powers exist, sun power cannot compete; but sun-power generators will, in the near future, displace all other forms of mechanical power over at least 10 per cent of the earth's land surface; and in the far distant future, natural fuels having been exhausted it will remain as the only means of existence of the human race."

The idea of using the power of the sun for heating and lighting was intuitive. Passive solar energy has been used as a form of light and heat since early mankind. In the 5th century B.C., the ancient Greeks designed their homes to capture the sun's heat during winter. Later, the Romans improved on solar architecture by covering south-facing windows with clear materials such as mica or glass, preventing the escape of solar heat captured during the day.

Historical evidence suggests that all the way back to the 7th century B.C., humans figured out how to make fires by concentrating the sunlight with magnifying glass. In the 1767, the Swiss scientists Horace de Saussure [36] invented first solar oven as an insulated rectangular box with a glass cover. It became the prototype for solar collectors used to heat water.

With an increasing number of solar energy applications the need for solar radiation data becomes more and more important. The kind of data required depends on application and user. For efficient conversion and utilisation of this resource an accurate detailed long-term knowledge of the available global solar radiation is of prime importance. Fluctuations of solar radiation are known to have a significant influence on electric power generation by solar energy systems. To ensure an efficient use of the solar resource this behaviour has to be considered in operating strategies for the systems.

The amount of solar energy that reaches the earth in one hour is sufficient to supply the world's energy needs for one year. [37] Harvesting this energy efficiently is a huge challenge. Ground based pyranometers [38] are capable of measuring solar radiation at specific networks but not at large spatial resolutions. In most countries, including India, number of the observing stations is inadequate. Therefore it is essential that some reliable mathematical models be developed to estimate the solar radiation for places where measurements are not carried out and for places where measurement records are not available.

Solar radiations modeling can be grouped as statistical modeling and physical modeling. [39], Statistical models are considered simpler as they do not require precise information on the composition of the atmosphere.

Many authors have suggested empirical formulas to employ these parameters to estimate the solar radiation.

The first attempt to analyse the hourly global solar radiation (GSR) data was made by Whiller [40] who presented curves, based on measured total (direct plus sky) solar radiation data for several stations viz. Durban (latitude $29^{\circ}30^{\circ}$), Cape Town (latitude $33^{\circ}54^{\circ}$), Pretoria (latitude $25^{\circ}45^{\circ}$), and Windhoek (latitude $23^{\circ}34^{\circ}$) in the Union of South Africa, which enable the hourly distribution of total solar radiation on a horizontal surface to be determined for any locality, and any time of year on a

long-term basis. Hottel and Whiller [41], used data of widely separated locations to obtain the curves of hourly to daily radiation ratio against the sunset hour angle.

Seyed Fazel Ziaei Asl *et. al.* [42] developed a model to forecast the daily GSR for Dezful city in Iran (32° 16' N, 48° 25' E) according to measured values of daily mean air temperature, relative humidity, sunshine hours, evaporation, wind speed, and soil temperature between 2002 and 2006., using Multi-layer perceptron (MLP) neural networks. The measured data between 2002 and 2005 were used to train the neural networks while the data for 214 days from 2006 were used as testing data.

K. K. Gopinathan and Alfonso Soler [43] studied several years of measured data on global and diffuse radiation and sunshine duration for 40 widely spread locations in the latitude range 36° S to 60° N and used them to develop and test models for estimating monthly-mean, daily, diffuse radiation on horizontal surfaces. Applicability of the clearness-index (K) and sunshine fraction (S/S_0) models for diffuse estimation and the effect of combining several variables into a single multi-linear equation are tested. Among clearness-index and sunshine-fraction models, S/So models are found to have better accuracy if correlations are developed for wide latitude ranges. equation the following An of form $H_d/H = 0.87813 - 0.33280K - 0.53039S/S_0$ is recommended for estimating monthly-mean, daily, diffuse radiation for any location in the world in the latitude range 36° S to 60° N

F. M. Ragab & A. K. Som [44] used the data of the direct, diffuse and global radiations in Bahrain as measured by Eppley pyranometers and compared these values with predicted data of the same fluxes obtained using three different models namely Hottel [45], Liu, B. Y. & Jordan, R. C. [46] and A1-Sadah, F. H., Ragab, F. M. & Arshad, M. K [47].

Collares-Pereira and Rabl [48] developed an analytical expression for hourly to daily global radiation ratio in terms of the sunset hour angle. The hourly correlation between daily diffuse transmission coefficient and daily clearness index obtained by Orgill and Hollands [49], Bruno [50], and Bugler [51]can be used to estimate the ratio of hourly diffuse to hourly global radiation.

Liu and Jordan [46] determined the hourly distribution of diffuse radiation from daily radiation, whereas Gopinathan [52] obtained the same from sunshine duration. No general formula is available yet for prediction of the solar radiation reaching the Earth's surface over a given period of time at any location [53]

Time series statistical models have been used to study the stationary and sequential characteristics of hourly series of global irradiation. This methodology has been used in the study of daily and hourly series of global irradiation by Brinkworth, [54]; Bendt *et al.*, [55]; Boch *et al.* [56], Aguiar *et al.*, [57]; Guinea *et al* [58];Palomo [59]; Aguiar and Collares - Pereira,[60].

G. V. Parishwad *et. al.* [61] developed a procedure has been for the estimation of direct, diffuse and global hourly solar radiation on a horizontal surface for any location in India.

O. P. Singh *et. al.* [62] evaluated the hourly global radiation for the plane areas of Uttar Pradesh using regression constants based on the model proposed by Al-Sadah *et al.* Comparison between estimated and measured values showed that the constants derived for Lucknow (latitude 26.75"N, longitude 80"E) provide good estimates of the hourly global radiation except for the sunrise and sunset hours.

LL. Mora-Lo Pez and M. Sidrach-De-Cardona Proposed [63] methodology to generate hourly series of global irradiation.

The only input parameter which is required is the monthly mean value of daily global irradiation, which is available for most locations.

Lumb [64] and Brinsfield *et al* [65], considered the possibility of correlating solar radiation with reported cloud cover. Kasten and Czeplak [66] have furthered that work. The most comprehensive investigation in this respect was undertaken by Haurwitz [67-68] who performed a comprehensive research by analysing 11 years of hourly data from Blue Hill, Massachusetts.

The Angstrom [69] correlation has served as a basic approach to estimate global radiation long time. Prescott [70] has put the correlation in a convenient form as $H/H_0 = a + b n/N$.

Many authors viz. Fritz and MacDonald [71]; Black *et al.* [72]; Medugu D. W. and Yakubu D. [73]; Mateer, [74]; İnci Türk Toğrul [75], Stanhill, [76]; Chia, [77]; Samuel [78], etc. established the values of *a* and *b* for different sites.

Griffin Salima and Geoffrey M. S. Chavula [79] discussed a procedure that was adopted for the development of a linear regression model for estimating solar radiation in Malawi. By making use of sunshine-hours data recorded at six selected meteorological stations in the country, namely: Salima, Makoka, Karonga, Bolero, Chileka and Mzimba over the period 1991-1995, a set of Angstrom constants were obtained and averaged in order to develop the linear regression model. This model has potential for generating ground observation data of solar radiation at any given location in the country using sunshine hours as the only required input. Averaged results for linear regression models for the six selected stations were used in developing the linear regression model for estimating solar radiation in Malawi: $H/H_0 = 0.29 + 0.38 n/N$

Attempts have been made to develop a model that can consider the physical processes but still maintain the simplicity of the Angstrom model. Researcher like Iqbal [80], Gopinathan [81], Yeboah-Amankwah and Agyeman [82], Ninomiya [83], Sahin and Sen [84], Leckner, [85]; Bird, [86] Worked in this direction.

Several empirical models have been used to calculate solar radiation, utilizing available meteorological, geographical and climatological parameters such as sunshine hours by Kadir Bakirci, [87]; Koussa *et al.*, [88]; Bulut and Buyukalaca, [89]; Akinoglu and Ecevit, [90] air temperature by Fletcher [91], and latitude by Raja [92], precipitation by Rietveld [93], relative humidity by Alnaser, [94] and Trabea & Shaltout, [95]; and cloudiness by Kumar and Umanand, [96]. The most commonly used parameter for estimating global solar radiation is sunshine duration.

Yang K. *et. al.* [97] developed a hybrid model to estimate global radiation *H*. Unlike Angstrom correlation $H/H_0 = a + b n/N$, this model suggested that $\frac{H}{H_0} = \left(a + b \frac{n}{N}\right) H_b + \left(c + d \frac{n}{N}\right) H_d$. H_b and H_d are effective beam

radiation and effective diffuse radiation, which imply latitude, elevation and seasonal effect on radiation. H_b and H_d are calculated by an arithmetic model derived from spectral model. The hybrid model was designed for estimating monthly mean daily global radiation with hourly-recorded bright sunshine time, and its applicability was verified at observatories in Japan.

A. Zeroual, M. Ankrim, And A. J. Wilkinson [98] developed a diffuse global correlation using data available in Marrakesh for diffuse component calculation purposes and

carried out a statistical comparison of three specific models for estimating daily global radiation on tilted surfaces and to recommend the most accurate for the Marrakesh (Morocco) location.

A theoretical model was described by Douglas V. Hoyt [99] that is designed to give the total global insolation falling on the earth's surface and the transmission of the atmosphere, He compared it to a model by Braslau and Dave [100] and found to agree to within a few percent in all cases.

Solar radiation is very important for crops as it is the source of energy for photosynthesis. The importance of solar radiation on coconut was recently highlighted by several authors like Foale [101], Panabokke [102], Peiris, *et. al*, [103]. To estimate solar radiation at the Coconut Research Institute, Lunuwila (7° 20' N; 71° 5 3'; 30.5 m) an alternative model was developed from measured sunshine hours data only by T S G Peiris and R O Thattil [104]. The model had good fit ($R^2 = 0.90$, P < 0.001) and was found to have agreement with the estimates obtained from the Angstrom model. The alternative model is more flexible and useful in estimating crop evapo-transpiration, and for cropweather modeling.

Based on modified Angstrom model M. Muzathik [105] recommended a new linear model $H/H_o = 0.2207 + 0.5249 (n/N)$ to estimate monthly average daily global solar radiation for Terengganu state areas and in elsewhere with similar climatic conditions areas where the radiation data is missing or unavailable.

G. V. Parishwad *et. al.* [106] divided India into four regions of rainfall, namely, region of heavy, medium, low and very low rainfall. Using ASHRAE [107] equations with the modified constants, monthly-mean-hourly solar radiation values are estimated for ten cities from different regions of India.

Iranna Korachagaon and V.N. Bapat [108] presented a study to estimate the monthly average global solar radiation (GSR) at various locations for India, by the generalized Iranna-Bapat's model [109]. This model uses the most commonly measurable meteorological parameters such as ambient temperature, humidity, wind-speed, moisture for a given location. A total of 57 locations spread across India are used to validate this model. The computed values from Iranna-Bapat's model are compared with the measured values. Iranna-Bapat's model demonstrated acceptable results, and statistically displayed lower $RMSE \ll 10\%$ for many locations.

F.J. Batlles *et. al.* [110] in their work analyzed the results provided by different models in the estimation of hourly direct irradiance values. They selected several models proposed by Orgill and Hollands [47], Erbs *et al.* [111], Reindl *et al.* [112], Skarveit and Olseth [113], Maxwell [114], and Louche *et al* [115]. These values were registered in six Spanish locations with different climatic conditions.

L Hontoria *et. al.* [116] presented a new neural network approach for the generation of synthetic hourly irradiation series, a relevant problem in the photo-voltaic field.

A two-dimensional (2-D) representation model of the hourly solar radiation data is proposed by Fatih O. Hocaoglu *et. al.* [117] The model provides a unique and compact visualization of the data for inspection, and enables accurate forecasting using image processing methods.

N.Z. Al-Rawahi, Y.H. Zurigat and N.A. Al-Azri [118] In this work, they modelled hourly terrestrial radiation: direct beam, diffuse and global solar radiation and calculated them based on daily measured data for a horizontal surface. In addition, the same parameters were modelled for inclined

surfaces. Most of the parameters modelled in this work represent a part of the input data required by building thermal simulation and solar energy systems software. Important trends of the solar radiation on tilted surfaces as a function of time and direction were presented and discussed.

Shafiqur Rehman [119] utilized monthly mean daily values of global solar-radiation and sunshine duration at 41 locations in Saudi Arabia and developed an empirical correlation for the estimation of global solar radiation at locations where it is not measured. He also presented the comparison between the present correlation and other models developed under different geographical and varied meteorological conditions.

Viorel Badescu [120] tested seven existing relationships between monthly mean clearness index and the number of bright sunshine hours under the climate and latitude of Romania and derived New (best-fit) correlations.

A comparison between some regressions correlations for predicting the global solar radiation received on a horizontal plane has been made by Kacem Gairaa and Yahia Bakelli [121]. Seven models for estimating the global solar radiation from sunshine duration and two meteorological parameters (air temperature and relative humidity) are presented. The root mean square error (RMSE), mean bias error (MBE), correlation coefficient (CC), and percentage error (e) have been also computed to test the accuracy of the proposed models. Comparisons between the measured and the calculated values have been made. The results obtained show that the linear and quadratic models are the most suitable for estimating the global solar radiation from sunshine duration, and for the models based on meteorological parameters, Abdalla and Ojosu's models give the best performance with a CC of 0.898 and 0.892, respectively.

Amauri P. Oliveira *et. al.* [122] carried out measurements of global and diffuse solar-radiation, at the Earth's surface. Data ranging from May 1994 to June 1999 in Sao Paulo City, Brazil, were used to develop correlation models to estimate hourly, daily and monthly values of diffuse solar-radiation on horizontal surfaces. The polynomials derived by linear regression fitting were able to model satisfactorily the daily and monthly values of diffuse radiation. The comparison with models derived for other places demonstrates some differences related mainly to altitude effects.

S. Safi [123] analysed two procedures for modeling daily global solar radiation. The prediction results showed that the sequences of values generated have the same statistical characteristics as those of sequences observed. The comparison between the two methods used indicates that the developed model based on the "lost solar component" is better than the model obtained using the conventional procedure based on the clearness index.

A. Y. Habbane, J. C. McVeigh [124] described how one particular formula, the Barbaro *et al.* [125] model, has been modified to determine solar irradiance from sunshine hours for a number of stations located in hot dry arid climates.

Wong L.T., Chow W.K. [126] reviewed solar radiation models for predicting the average daily and hourly global radiation, beam radiation and diffuse radiation. They considered seven models using the Angstrom–Prescott equation to predict the average daily global radiation with hours of sunshine and predicted the average daily global radiation for Hong Kong

 $(22.3^{\circ}N \text{ latitude}, 114.3^{\circ}E \text{ longitudes})$ Comparisons among model predictions with measured data were made.

R. C. Srivastava, and Harsha Pandey [127] estimated Angstrom–Prescott model parameters for seven different sites in

India. By averaging out these parameters, a Angstrom–Prescott correlation given by $H/H_0 = 0.1382 + 0.5564 n/N$ is developed for India, which is found to be a good fit. Also, a new parabolic correlation has been developed so that coefficient of Angstrom-Prescott models can be estimated by $a = -17.222(n/N)^2 + 27.18(n/N) - 10.533$,

 $b = 18.676(n/N)^2 - 29.395(n/N) + 12.098$ even if only sunshine hour data is available.

Thus many attempts have been made by various researchers to measure solar radiation mathematically. Since solar energy has the potential to generate virtually unlimited, essentially clean, carbon-free electricity. Also it holds great promise, as large part of the earth is receiving plenty of sunshine. For example India gets sunshine for – four to six hours a day for over 300 days a year, therefore, the countries like India should look to the sun to reap the benefits of its energy. Shuba V. Raghavan *et. al.* [128].

Conclusion

Renewable energy is the future of our society. With the increasing urbanization and industrial development, demand for energy is increasing at an exponential rate, while the conventional non-renewable energy sources such as petroleum, coal, and natural gas are dwindling rapidly. In the coming years, a country which will be able to conserve its non-renewable energy sources will definitely rule the world. Therefore, in the game of power it has become very important to set new policies towards the energy sources. Mathematical modeling can help in taking such decisions.

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