Energy Transaction from Sun to Earth – The Abundance Underutilized

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Abstract

All living things thrive only on energy. The Sun, which is a ball of hydrogen and helium gases, radiates energy to the earth. The Sun by itself is not a place to live, but it enables living on earth. It provides the required warmth, weather, energy, climate for a pleasant living. Organisms such as plants, which are the basis of many food chains, use energy from the Sun for photosynthesis. Undisputedly, the Sun is responsible for almost all the energy needs of the earth, either directly or indirectly. The electrical energy sources like Hydro power, Fossil Fuel, Wind, Bio-mass etc. rely indirectly on the Sun. A brief discussion on the Sun, followed by numerical calculations to arrive at the quantum of energy received by the earth from the Sun in the current energy scenario, is presented. A detailed analysis on the distribution of this energy across various phenomena on the earth, the geographical & seasonal aspects associated with it, which is referred to as the Solar Energy Budget is also discussed in this paper.

Keywords: The Sun, Fusion, Solar energy, Atmosphere, Earth, Solar Energy Transaction, Solar Energy Budget, Renewable energy.

1.Introduction

Renewable and Clean energy sources are the only solution to offset the effects of climatic disturbances like global warming, CO_2 emission etc. Though indispensable in the near future, the use of Fossil fuels and Oil is on the reduction mode and the renewable energy production is being scaled up. The share of renewable energy sources in the total energy production in India is the second highest, with a share of 17.51 % [2].

Among the renewable sources, the share of Solar power is 65 %, leading the way forward. The capacity of solar power is increased more than eight times in India, in the last four years, from 2,630 MW to 22,000 MW [3].

In order to fully appreciate the performance and efficiency of the solar energy, it is imperative to quantify the amount of energy received from the Sun. Comparison of the energy from the Sun with the energy needs of the humankind, emphasizes the scope for the high potential in the solar power sector[1].

The Sun is a dwarf star, at the heart of the solar system, bubbling with energy due to thermonuclear fusion. Without the Sun's heat and intensive energy, life on earth would be un-imaginable [4].

The use of solar energy by the humankind is not a recent one. Concentrating the Sun's heat was done for lighting fire, way back in 7^{th} Century BC [5],[10]. If the geographical location of the country is ideal, it has a tremendous potential for generating Solar power. Suitable climatic conditions of a country also facilitate more power production with increased efficiency and reduced production cost. The energy generated will be able to cater a substantial portion of the total need [6, 8].

The direct conversion of sunlight into electrical energy is possible using smaller photovoltaic (PV) solar cells [7], Higher cost of Installation, in case of renewable energy sources is the main challenge. With the advent of new technological developments, the installation cost may be brought down, making solar energy more practicable [9]. A theoretical feasibility of 90 % penetration of renewable power sources in the final energy mix is expected by the year 2051. To achieve this level of deployment of renewable energy in India, many interventions are necessary to remove several barriers [11].

2. The Evolution of the Sun

According to NASA, about 4.5 billion years ago, Solar nebula, which is a huge rotating cloud of gases and dust, collapsed due to the overwhelming gravity and created our Solar system. About 99.8 % of that mass was pulled towards the centre, to form the Sun.

The Sun is a yellow dwarf star, containing mainly hydrogen and helium. By mass, it has 70.6 % hydrogen and 27.4 % helium. The cause of energy in the Sun is the Thermonuclear Fusion, which is a process, sustained by the extremely high temperature and pressure at the core of the Sun. Thermonuclear fusion causes the hydrogen atoms to disintegrate and their nuclei are separated. Four such nuclei, fuse together to form one helium atom. But the mass of one such helium atom is much less than that of the four constituent hydrogen nuclei. The matter disappeared during the fusion process is emitted into the space as the radiant solar energy. This is the energy we get in the form of light and heat, which sustains all the life on the earth.

2.1 Structure of the Sun

Gravitational attraction is the cause that holds the enormous mass of the Sun together, resulting in extremely high pressure and temperature at its core. The six regions of the Sun are (i) the core (ii) the radiative zone (iii) the convective zone in the interior (iv) the visible surface (Photosphere) (v) the chromosphere (vi) the outermost region (the corona).

The temperature at the core is 15 million degree Celsius. It takes about 170,000 years for the solar energy to reach the top of the convective zone through the radiative region. In that process the temperature becomes 2 million Celsius. Further moving upwards, on the visible surface of the Sun the temperature is about 5500 degree Celsius. That is pretty much cooler than the blazing core, yet it is hot enough to not only melt the carbon (diamonds, graphite) but also to boil it. In about eight minutes time, the radiation from the surface of the Sun reaches the earth, as sun light.

3. The Energy from the Sun

Quantification of the energy from the Sun is vital, though it is in larger scale. This is very much necessary, in order to appreciate the capacity of the solar energy. Energy in terms of Joules is considered. Comparison of the energy requirement of the mankind with the energy showered by the Sun will be made. This information will put a lot of things in perspective.

The composite image in Fig. 1 is the global view of earth at night, compiled from over 400 satellites images, by NASA.

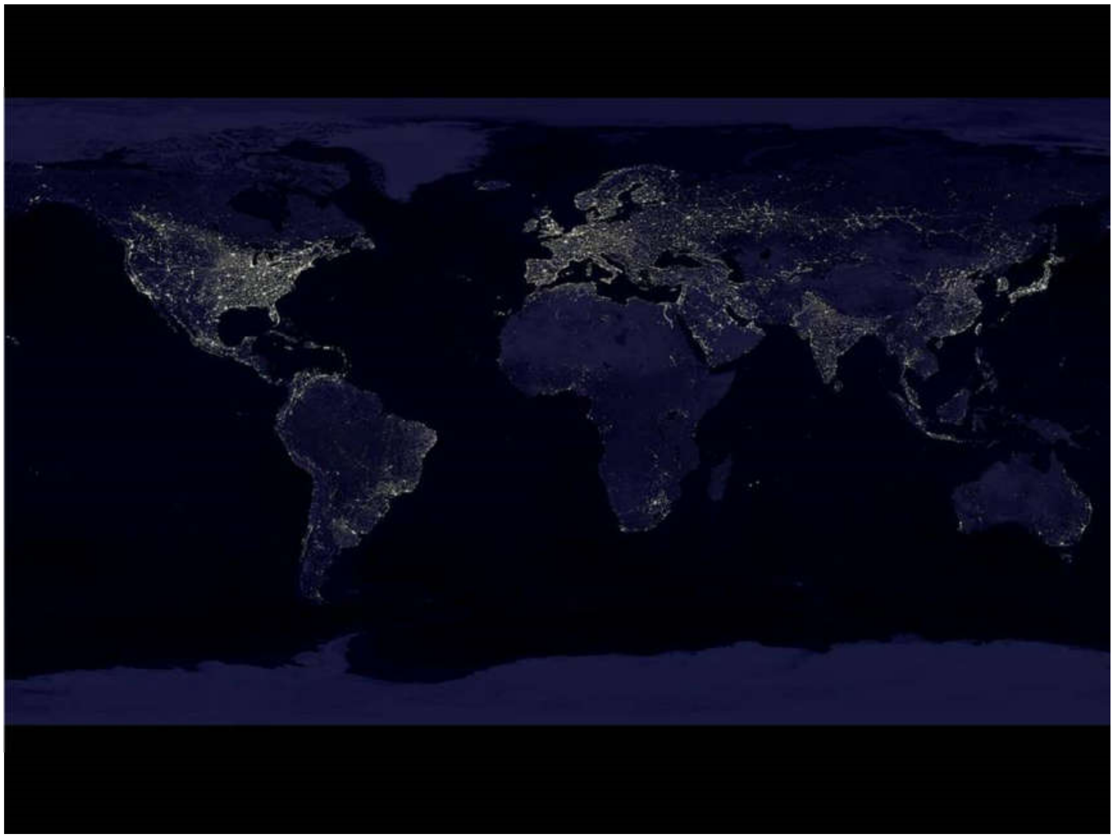

Fig 1. Composite satellite image of the earth at night

The image and the pattern of lighting gives a broader picture on the composition of energy usage by various countries based on their status like developed, developing and underdeveloped. At any point of time the energy demand is always rising due to the contributing factors like the population growth, industrial activity, lifestyle change etc. But the technological developments occur simultaneously, which contributes to accomplish, most of the needs with less energy. These are the competing factors, which determine the change in energy demand over a period of time.

The overall energy need of the world is calculated as 500×10^{18} Joules or 500 Exa Joules. That is a pretty much larger scale. With this as the starting point, the energy from the Sun will be calculated and compared, to get an idea of the abundant power that is showered on the earth by the Sun, but not yet fully harnessed by the humankind.

3.1 The Power of the Sun

The surface of the Sun is at a temperature of 5500 degree Celsius. The Sun at the centre of the solar system is analogous to the situation, where an electric lamp which gives out power, in terms of electrical watts, is placed at the centre of a room. With that perception, considering the Sun as a lamp which is lighting the entire Solar system, it is found that the Sun gives out 384×10^{24} watts. i.e. 384 Yotta watts.

Surface of the Sun ~ 5500 ° C
Core of the Sun ~ several million ° C

Power from the Sun is 384 Yotta Watts

$= 384 \times 10^{24}$ W

$= 3.84 \times 10^{26}$ W

3.2 The Geometry of the Sun-Earth orbit

The Sun has a radius of 700,000 Km. Earth is going around the sun, in the orbit that is roughly around 149 Million Km in radius. Though the orbit is not a perfect circle, it is assumed as a circular orbit. The radius of the earth is 6371 Km.

From the above parameters, it is observed that radius of the Sun is roughly 100 times that of the earth. And, the radius of the earth's orbit is 200 times the radius of the Sun. Fig. 2 shows the Sun- Earth orbit (not to scale).

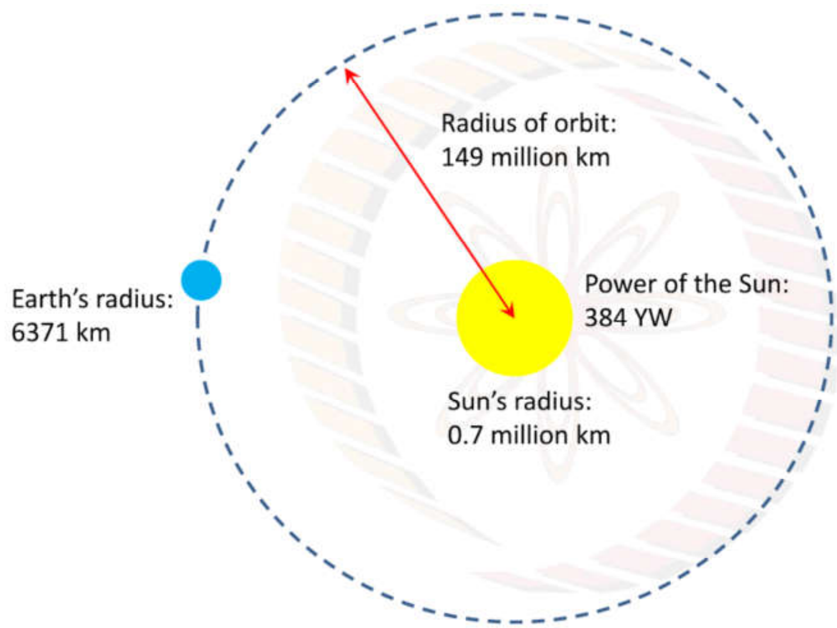

Fig 2. Sun- Earth orbit

The Sun is spherical in dimension and radiates power in all the directions, across the entire orbital sphere. Out of all the energy released from the Sun per second, only that part of energy falling on the earth's location at that moment, will be the energy received.

Electrical power in watts is equivalent to joules per second. So, 384 Yotta joules per second is coming out of the Sun and radiate out in all the directions uniformly. Of that energy, earth is able to receive only a small fraction, that falls on it.

The intensity i.e. power per unit area has to be found for the entire earth's orbit and then from that how much power is received by the earth's surface can be calculated.

3.3 Intensity of Sun's radiation at the Earth's Orbit:

Earth's orbit , which is a sphere of radius, 1.49×10^{11} m, whose area is used in the formula below.

$$= \frac{3.84 \times 10^{26}}{4 \times 3.14 \times (1.49 \times 10^{11})^2}$$

$$= 1377\ W/m^2$$

This is the intensity that is spread out in all the directions. It is necessary to find out the cross sectional area of the earth, on which a fraction of this emitted energy, is falling.

Area of the earth's disc is circular and is given by $A = \pi r^2$.

$$= 3.14\ \times (6.371 \times 10^6)^2$$

$$= 1.27 \times 10^{14} m^2$$

This is the area on earth, that can receive $1377\ W/m^2$ of intensity.

3.4 The Power received by the Earth

So, the power in watts, that is received from the Sun, by the earth

$$= 1.27 \times 10^{14} \times 1377$$

$$= 1.755 \times 10^{17} \text{ W or J/s}$$

Thus, in one second, the energy received on the surface of the earth is 1.755×10^{17} J.

So, in one year, the quantity of the energy received can be derived as shown.

$$= 1.755 \times 10^{17} \times 60 \times 60 \times 24 \times 365$$

$$= 5.5 \times 10^{24} \text{ J}$$

= 5.5 Million Exa Joules per year

The energy requirement for the entire world, for the entire year is estimated as 500 Exa Joules.

The energy received from the Sun in a year is 5.5 Million Exa Joules.

It will be interesting to calculate the time taken by the Sun, to deliver this annual energy requirement of the Humankind. It can be obtained by dividing

$$\frac{500}{5.5 \times 10^6} = 9 \times 10^{-5}\ years$$

It equals to 0.79 hours. Considering only 70 % of energy is received on the earth's surface, during this time (since 30% of incident energy gets reflected back and wasted), it is

0.79/0.70 ~ 1 hour.

So, the World's energy requirement for a year is delivered by the Sun, in just One Hour.

4. The Solar Energy Budget

The power received from the Sun, by the earth was calculated as 1.755×10^{17} W (or) J/sec. This is equivalent to 175×10^{15} W (or) 175 Peta Watts. This is the power that arrives at the outer reaches of our atmosphere. The detailed study and analysis on this energy at the earth and its atmosphere, how it gets distributed, and the associated phenomena, constitute the Solar Energy Budget. It is significant to note that the intensity of solar radiation, the geographical location and the time of the day are the key factors in this energy distribution.

The earth has five layers in its atmosphere. The troposphere, which is the lowest section (within the 0 to 12 Km range) possess 80 % of the mass of the earth's atmosphere. The energy from the surface of the Sun has to pass through these layers and then only, after a definite period of time (8 minutes), the feeling of heat occur on the surface of our skin. Fig. 3 shows the distribution of the 175 PW arriving at the earth's atmosphere.

On top of the atmosphere, 6 % gets reflected. Another 16 % gets absorbed by the atmosphere in the air molecules and fine dust particles in it. Only 78 % of energy remain at this stage. Out of this, a significant quantity 20 % gets reflected back by the clouds. This reflection is necessary to maintain earth's temperature. When travelling above the clouds, an overwhelming amount of blinding/glaring light can be observed, which is due to this reflection. Similarly in the snowy regions also people suffer with snow blindness because of the same phenomena. Though inconvenient, it helps to control and maintain the temperature on the earth.

Next, another 3 % gets absorbed in the clouds. Further 4 % reflected by the surface of the earth. And this leaves a quantity of 51 % of 175 PW. So far, the reflected quantity is 30 % and the absorbed quantity is 19 % (remain in the atmosphere, alive and active). Leaving the reflected quantity of 30 % away, we have 70 % (i.e.) Balance 51 % added to the absorbed quantity of 19 %, which is to be accounted for.

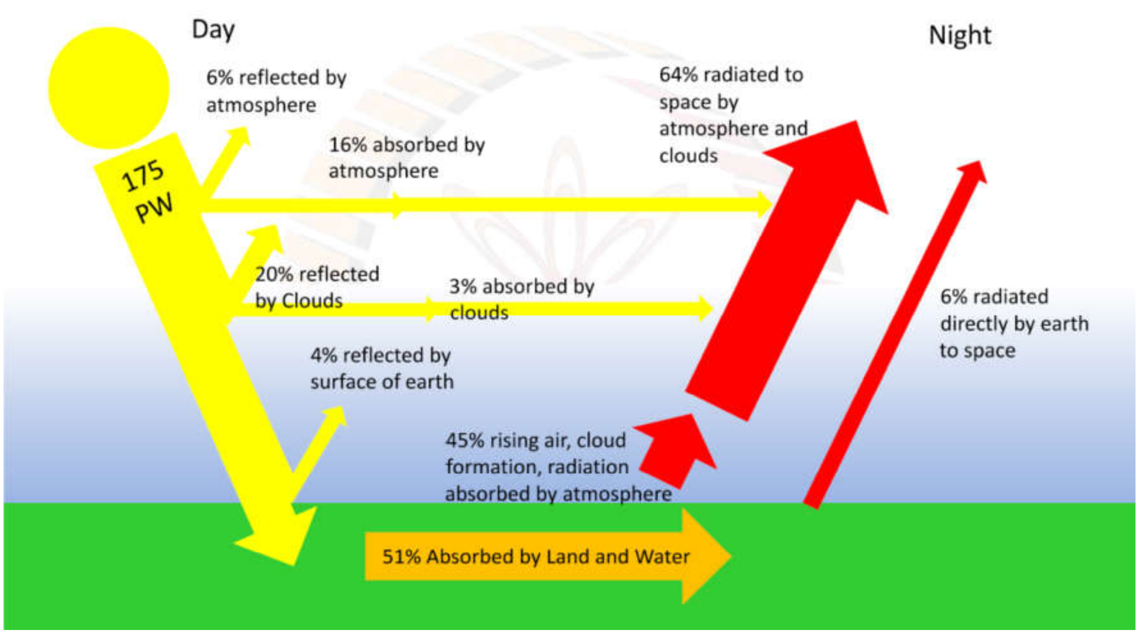

Fig 3. Distribution of Solar energy in the earth's atmosphere

Next, from the 51 % that arrived on the earth's surface, a large fraction 45 % is used for heating up the land and sea. In turn, layers of air above them, gets heated up. Convection takes place and the hot air moves up and cold air comes down. This is fundamental to our weather phenomena. The second important process is cloud formation. The latent heat needed to evaporate water to form clouds, is from this share. Third factor is the radiation from the heated land and water in to the atmosphere.

Now the 45 % of energy added with the 19 % of the already absorbed quantity (in cloud[3 %] and in atmosphere [16 %]) makes up 64 %.

Balance 6 % of the 51 %, is directly radiated to the space from the earth, without any absorption by the atmosphere.

So, 64 % and 6 % , makes up a total of 70 %, to balance the Solar Energy Budget.

It must be noted that the radiation towards the earth happen during day time, when the space and atmosphere are hot. The reverse happens in the night when earth is hotter than the space and atmosphere, resulting in radiation from the earth into the space akin to the black body radiation principle.

5. Future of the Solar Energy

With abundant energy from the Sun, it is necessary to explore the avenues for garnering the solar energy to the maximum possible extent. Moreover, it is clean and renewable and must replace the conventional sources/modes of power generation.

Harnessing solar energy can be broadly divided into two categories. One is Solar Photovoltaic that converts illumination from the Sun into electricity based on photovoltaic effects. The other is Solar Thermal which uses solar radiant heat into generating electricity.

USA, Germany, Japan, Spain, Italy and China are the countries which lead the world in Solar PV arena in terms of Installed Capacity and Manufacture of PV modules and systems.

The majority of Crystalline(c-Si) solar cells have a commercial efficiency in the range of 13 - 16 % with a life time of 25 years. The target set for the efficiency is 23 % by the year 2020. The commercial thin film(TF) module has much lower efficiency in the range of 6 – 12 %, with a set target of 15 % by 2020. Many other photovoltaic technologies are under research viz. Concentrating PV, Organic PV, advanced thin film and novel concepts and materials of Nano scale.

Under Solar Thermal, it is found that 30 % of the industrial processes need heat in the range of 250 °C or below. Solar air heaters and solar water heaters can be employed to meet the needs up to 80 °C. Beyond that Solar thermal concentrators can be employed. For thermal applications, that require heat up to 700 °C can be equipped with Solar concentrators.

The R & D should focus on reducing the initial cost of the solar power installation and arrive at a cost-effective energy storage methodologies, in order to adopt solar power on a larger scale.

6. Conclusion

The abundance with which the Sun showers energy on the earth, is so overwhelming and understood from the fact that the world's current energy requirement for one full year is supplied by the Sun, in a single hour. The sunlight is critical for human sustenance. The livelihood of all the living organisms depend on Sun's energy. It is for the humankind to find more efficient, economical and practicable ways to harness and store the Solar energy. Sun's energy is delivered free of cost, at every door step, clean and renewable. It is sad to recall that for every penny spent on the fossil fuel and oil, two pounds are needed to invest towards environmental protection, considering the rate at which the carbonisation and global warming occur. Research should focus on the better, bulk energy storage technologies. National Policies should emphasise more on the use of solar and other renewable energy, by subsidising this sector. More International policies should be in place, to promote the research on implementing optimum utilisation of solar energy in a convenient and cost-effective way.

References

[1] Dr. Prathap Haridoss, Department of Metallurgical and Materials Engineering, Indian Institute of Technology,Madras, NPTEL Online Course on Non-conventional Energy Resources.

[2] www.cea.nic.in

[3] www.mnre.gov.in

[4] www.nasa.gov

[5] Lorand Szabo (2017) The History of Using Solar Energy, The 7th International Conference on Modern Power Systems (MPS 2017)

[6] Bharat Raj Singh, Onkar Singh, Future Scope of Solar Energy in India, Research Gate Publication 308302825

[7] Mohd Rizwan Sirajuddin Shaikh, Santosh B Waghmare, Suvarna Shankar Labade, Pooja Vittal Fuke, Anil Tekale, A Review Paper on Electricity Generation from Solar Energy, International Journal for Research in Applied Science & Engineering Technology, vol. 5 Issue IX, Sep 2017

[8] Harendra Kumar Yadav, Vijay Kumar and Vinay Kumar Yadav, Potential of Solar Energy in India: A Review, International Advanced Research Journal in Science, Engineering and Technology, Vol 2, Special Issue 1, May 2015

[9] Arun Kumar Singh Tomar, K K Gautam, Renewable Energy in India: Current Status and Future Prospects, International Journal of Engineering Science Invention, Vol 7, Issue 6, Ver III, June 2018

[10] The History of Solar, Energy Efficiency and Renewable Energy, US Department of Energy

[11] The Energy Report – India, 100 % Renewable Energy by 2050, WWF – India and The Energy and Resources Institute.