Solar Energy Potential Estimation and its Utility for Irrigation Using Geo-Spatial Technology to Ensure Energy Security

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ABSTRACT

World development is highly dependent on sustainable utilization of energy resources. Conventional energy generation through fossil fuels is no longer a viable solution to meet ever growing demand. Renewable energy is the key to solve the problems of energy sector due to its potential. In present study, energy demand of the farmers for irrigation purpose is identified through participatory approaches and the data pertaining to existing supply of electricity is obtained from governmental agencies. Solar insolation varies over space depending on the topographic conditions and atmospheric conditions and also based on the day and season of the year. Using the in-situ solar irradiance data, elevation data and land use data, the solar energy potential is estimated for the district of Namakkal, Tamilnadu using geo-spatial technology. The annual average solar potential of the study area is found to be 5.2 kWh/sq.m/day. The study also estimated the cost incurred by an individual in installing 5kW systems and the time period of return on investment. It is found that the study area has enormous potential to tap solar energy and can solve the power crisis in irrigation sector.

***Keywords**: Renewable Energy, Solar Potential, Energy Security, Geo-spatial technology*

INTRODUCTION

Electrical utilities of many Indian states are facing acute power shortage and the demand is expected to be growing rapidly in the foreseeable future. India is experiencing negative balance since 1980's in terms of energy production and consumption. India consumes about 4% of worlds primary energy despite of 17% of world population located in India. India is mostly dependent on coal for energy generation[1]. About 52% of energy is generated through coal powered plants[2]. It is estimated that India has the potential to generate 35 MW per square kilometre using solar photovoltaic (PV) and solar thermal energy[3]. Keeping in view of the development and environmental concerns, India is the first country in the world to have established a dedicated ministry for renewable energy named Ministry of New and Renewable Energy (MNRE). Under the National Action Plan on Climate Change (NAPCC), Government of India (GOI) has launched Jawaharlal Nehru National Solar Mission (JNNSM) in the year 2010[4]. This project aims at making India a global leader in the field of solar energy, by targeting to achieve a capacity of 20,000 MW in grid power and 2000 MW of off-grid solar utility[4].

Renewable energy accounts for about 33% of total primary energy consumption in India. Indu R. Pillai and Rangan Banerjee[5] have reviewed the status and potential of different renewable energies and established a diffusion model to help set the energy targets. From this review it is estimated that solar energy has the potential to over achieve the targets. Studies suggested that by the year 2025, photo voltaic energy would be more economic than fossil fuel electricity[6]. Indian solar energy market has huge potential with nine solar cell manufacturers, about 22 Photo Voltaic module manufacturers and 50 PV system manufacturers[1,7].

Scientific and strategic planning is needed to harvest the solar energy so as to improve the efficiency of the system. Selecting suitable location for establishing solar panels and distributing the power from the generation station requires detailed spatial analysis. Incoming solar radiation (insolation) varies with sun-earth distance, elevation, aspect, topography, atmospheric conditions and also with time. In order to estimate the solar energy potential of an area, spatially continuous and reliable data on solar radiation is essential[8,9]. Remote Sensing and GIS has the potential for estimating the solar energy potential and sites suitable for harvesting solar power[10]. Geospatial technology serves as an important tool in building Decision Support System (DSS) in renewable energy sector. Many researchers have used GIS in selecting sites suitable for solar power harvesting, distribution and decentralized planning[11-15].

Energy security refers to affordable and uninterrupted availability of energy to meet the sudden changes in supply-demand in short-term and also timely investments on energy supply in line with economic developments and environmental needs in long-term[16-18]. Present study identifies the gap between the total demand and supply of electricity for irrigation purposes. In-situ data and remote sensing data is collected to calculate the solar potential and sites suitable to harvest solar energy. The study also accounts for the cost associated with adopting renewable energy options at farm level as an individual farmer or as a community. This comprehensive study empowers the policy makers and end-users in achieving energy security, food security and sustainable irrigation management.

STUDY AREA AND DATA DESCRIPTION

Namakkal District of Tamil Nadu, India is selected for the present study. Namakkal District is formed from Salem District in the year 1997. The Geographical area of the district is 3363.35 kms which lies between 11.00 and 11.360 North Latitude and 77.280 and 78.300 East Longitude[19]. Figure 1 shows the location map of the study area. The average rain fall in the Namakkal district is 776 mm.The average temperature during April and May is 36˚C and during January the temperature is around 25˚C.The Major Agricultural crops cultivated in the study area are Rice, millets, cereals, pulses, sugarcane, groundnut, gingely and cotton[20].

To estimate the solar resource potential, in-situ data of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI) data from February 2012 to January 2013 are collected from National Institute of Wind Energy (NIWE) for the stations namely Pondicherry, Erode, Trichy, Ramanathapuram, Vellore, Karaikudi and Kayathar. The data include meteorological data such Relative Humidity, Air temperature, Wind direction, Wind speed and Atmospheric pressure.

Direct Normal Irradiance (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky. It is measured using Pyreheliometer which are installed at the stations mentioned above. Diffuse Horizontal Irradiance (DHI) is the amount of radiation received per unit area by a surface (not subject to any shade or shadow) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere and comes equally from all directions, and is measured using Pyranometer. Global Horizontal Irradiance (GHI) is the total amount of shortwave radiation received from above by a surface horizontal to the ground. Global horizontal irradiation is the most important parameter for evaluation of solar energy potential of the study area. Global radiation is said to be the sum of direct and diffuse radiation and is calculated by the formula $GHI = DHI + DNI * \cos(Z)$, where 'Z' is the solar zenith angle.

To validate the reliability of the NIWE data, monthly average GHI data is obtained from National Renewable Energy Laboratory (NREL) for different stations such as Chennai. Coimbatore Cuddalore, Dindigul, Erode, Karaikudi, Karur, Krihnagiri, Namakkal, Nilgiris, Pondicherry, Salem, Sivaganga and Trichy for the year 2012.

The Shuttle Radar Topography Mission (SRTM) collected elevation data on a near-global scale to generate the most complete high- resolution digital topographic database of Earth. Gap-filled SRTM data for the study area is downloaded from Consultative Group on International Agricultural Research (CGIAR) website[21]. Land use map for the study area is obtained from Institute of Remote Sensing, Anna University, India as vector file to identify the suitable sites to install solar power systems.

The Agricultural load on electricity supplied to Namakkal district is required to identify the energy gap for irrigation purposes. This data is provided by Tamil Nadu Electricity Board (TNEB), Namakkal District. Agricultural load for the whole of Namakkal district provided by TNEB is 17.9088 million units per month[22]. Irrigation statistics like the area under irrigated crops and number of pumps used for irrigation are also collected from the governmental agencies[19].

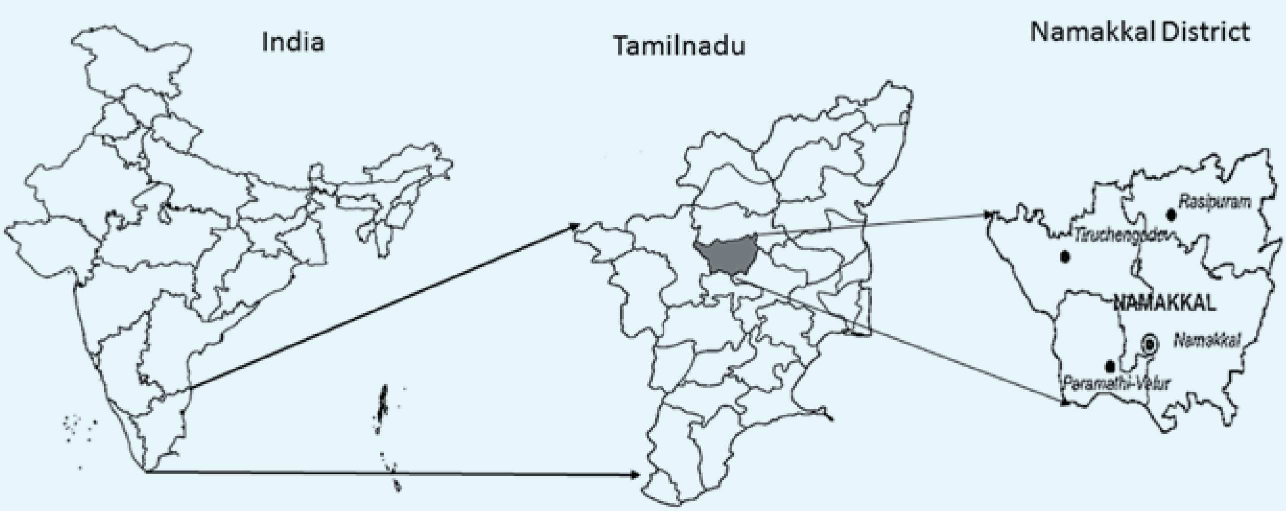

Fig. 1 : Location map of the study area

METHODOLOGY

In order to understand the practical difficulties experienced by the farmers of the intermittent power supply for the irrigation purpose, a field survey was conducted in the Pallipatti and Pudhupalayam villages of Namakkal District. On interaction with the farmers, the existing agricultural practices and the acute power shortage conditions were realized. Major crops cultivated in the study area are Sugarcane, Tapioca, Sorghum and Turmeric which require continuous supply of water during the growth period. The motors running for the irrigation purpose are mostly electricity driven. Since there is an acute power shortage, the farmers are unable to irrigate the crops efficiently, leading to frequent crop failures. To overcome this problem the farmers are in need for an alternative source of power supply for the irrigation purpose. The data on electricity supplying for the purpose of irrigating the crops for the study area for one month is obtained from TNEB, Namakkal District. The Total agricultural load for the whole of Namakkal district is 17.9088 million units per month. At present an average of four hours of power supply is available for irrigation.

Solar irradiation maps for Namakkal district, are generated by interpolating the Global Horizontal Irradiation point data for various places such as Chennai. Coimbatore Cuddalore, Dindigul, Erode, Karaikudi, Karur, Krishnagiri, Namakkal, Nilgiris, Pondicherry, Salem, Sivaganga and Trichy obtained from CWET and NREL by the method of Inverse Distance Weighted (IDW) in Arc GIS spatial analyst.

The Solar Radiation Analysis tools, in the ArcGIS Spatial Analyst extension, enable user to map and analyze the effects of the sun over a geographic area for specific time periods. It accounts for atmospheric effects, site latitude and elevation, steepness (Slope) and compass direction (Aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography. The resultant outputs can be easily integrated with other Geographic Information System (GIS) data and can help to model physical and biological processes as they are affected by the sun. Incoming solar radiation (insolation) originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is intercepted at the earth's surface as direct, diffuse, and reflected components.

Direct radiation is intercepted unimpeded, in a direct line from the sun. Diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. Reflected radiation is reflected from surface features. The most important data requirement is an accurate, georeferenced digital elevation model. Solar Analyst module may not determine the scene center latitude automatically when the dataset is opened. For this, the other required inputs are the Julian date and the local time of day of image acquisition. As a reminder, the Julian day of year is simply the sequential number from 1 to 365 (or 366 if a leap year). We can use the Julian Data Calendar, found in the CEO Tools folder on the workstation desktop, to calculate this. Local time of day is a function of latitude. The solar irradiation map giving the annual solar potential for the study area is generated.

For harnessing the solar energy for the purpose of irrigation, the site suitable for installing the solar panels has to be determined. The area solar irradiation map generated is overlaid with the land use map of the study area to find out the feasible site for harnessing the solar energy for irrigation purpose.

Major setback in adopting solar power system is the cost involved. The farmers will not opt the solar power system if it is out of their strength. Research is going on to harness the solar energy by low cost solar panels. Here the cost included in the installation of 5 kW system and Grid Parity is studied to understand the cost effectiveness. Figure 2 shows the flow chart of the steps and methods involved in present study.

RESULTS AND DISCUSSIONS

The monthly average GHI data for various stations are interpolated and the solar irradiation map for the study area is generated for all the twelve months. The solar irradiation

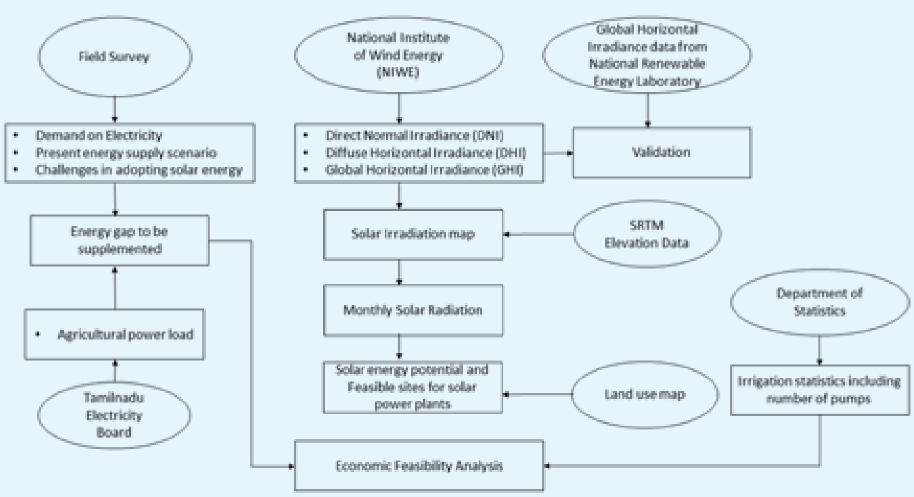

Fig. 2 : Methodology flow-chart

map generated will give the solar energy potential of the study area. It is inferred that the maximum solar energy potential of 6.4 kWh/sq.m/day is available in the month of March and the minimum solar potential of 4.2 kWh/sq.m/day during December. The annual average solar energy potential of the study area can be inferred from Figure 3. The Irradiance value or the amount of power that can be generated from solar energy in Namakkal District lies in the range of 5.12 to 5.20 kWh/sq.m/day.

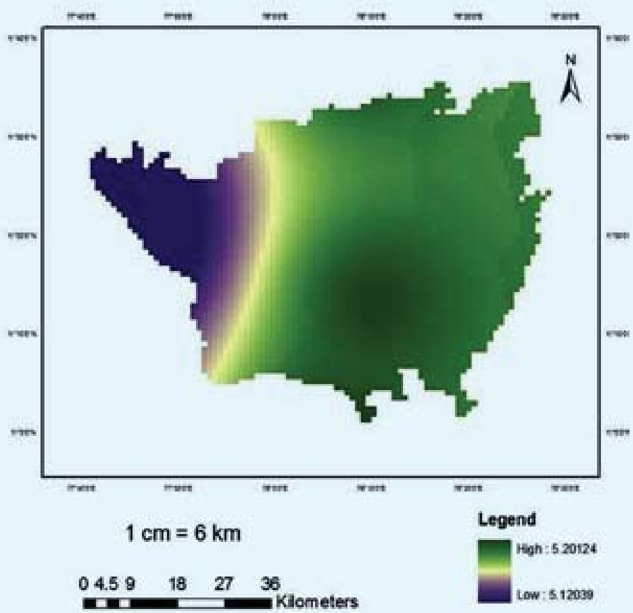

Fig. 3 : Annual average solar potential map

Land Use map acquired from Institute for Remote Sensing and the Area Solar Irradiation map from ArcGIS Solar Analyst module are overlaid to find the sites suitable for the installation of solar panels in the study area. Figure 4 shows is the overlaid map of Area solar irradiation map and the Land Use map of the study area.

Table 1 gives us a summary of areas of various land uses categories namely Agriculture lands, Built-up lands, Forest lands, Wastelands and Water bodies. Waste land are given high priority to establish community based solar power systems. Total area of wastelands in Namakkal district is 260606741.062 sq. meters.

Table 1 : Land Use statistics of Namakkal District

S.No	Land Use Class	Area (in square meters)
1	Agriculture	4981625187
2	Built-up	127701245.2
3	Forest	410161011.3
4	Wastelands	260606741.1
5	Waterbodies	187515052.7

Since wastelands are viable sites for the installation of community based solar grids, energy potential in waste lands is calculated based total area of wastelands and their maximum irradiance values. Irradiance value of waste lands is 5.19 kWh/m^2/day and the total area of waste lands is 260606741.062 square metres. Thus it is estimated that maximum potential of waste lands is 1352548.981 MW (product of total area and irradiance value).

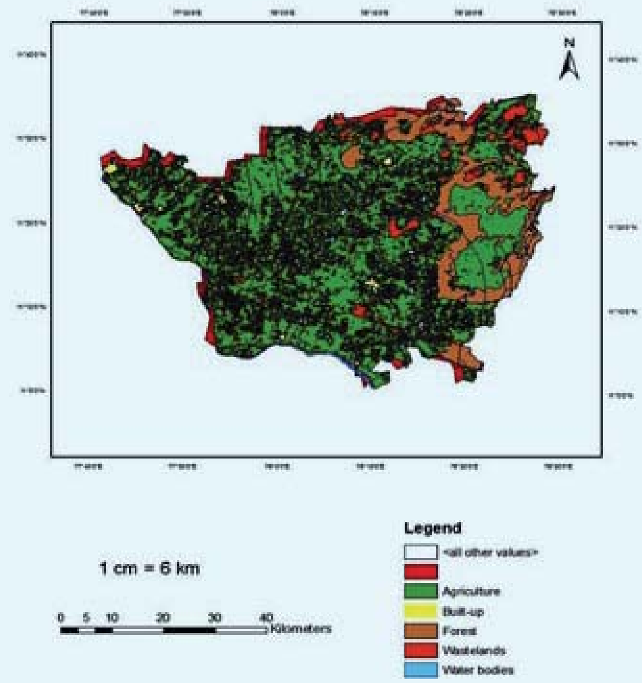

Fig. 4 : Land use map overlaid with solar irradiation map

From the field survey it is estimated that the average rating of irrigation pumps to be 5 horse power and a minimum of five hours of electricity is needed for the agricultural purposes. And each five horse power pump consumes 3.73 kWh energy if it is run for five hours. From the statistical records, it is estimated that the total number of electric pumps[22] used for irrigation is 77,729. If all of these pumps are run for three hours a day, will consume 8, 66,430 kWh energy and will consume 14, 44,050 kWh energy if operated for five hours a day. However, the existing power supply is just 5, 96,960 kWh per day which accounts for energy deficit of 2,69,4705 kWh if pumping is done for 3 hours and 8,47,090 kWh if pumping is done for 5 hours. This energy gap can be filled by resorting to solar energy as an alternate source of power since the maximum potential of wastelands itself is a huge 13, 52,548 MWh/day.

Though the solar energy is abundant in nature, the cost involved in harnessing the solar energy is quite expensive. Most of the farmers are small land holders and cannot afford for the costs incurred in establishing expensive solar power system. There is a desperate need for the reduction in cost for erecting the solar panels. The four important components in a solar power system are solar modules, battery, inverter, charge controller and other balance of system components. There are various types of solar panels, among them the important types of solar panels are Polycrystalline (or multi-crystalline) modules and Monocrystalline solar cells. A rough estimation of costs incurred in installing 5 kW system by an individual for the purpose of irrigation is presented here.

Size of each commercially available 250 W poly crystalline module is 1.6 m x 1 m, therefore the required space is approximately 32 sq.metres. And to establish 5 kW system, a total of twenty panels are required. Cost of each panel is about 17,500 and for twenty panels. The cost would be 3,50,000 Indian Rupees. Inverter, batteries and other equipment would cost about 1,00,000 Indian Rupees. Therefore the total cost incurred to install the 5 kW system with the installation cost is approximately Rs.4,50,000. If the system is operated for five hours a day, the output would be 25 kWh per day. Considering the efficiency of the panels and the energy losses, the output would be nearly 17.5 kWh per day. The Return on Investment would be approximately five years and the life expectancy of the system is nearly 25 years.

CONCLUSION

Solar radiation varies with time and space and geo-spatial technology offers optimal solution in identifying the resource potential and suitable sites through robust scientific analysis. The deficiency in power supply for irrigation can be solved by harnessing solar energy in individual agricultural farms or by means of centralized solar power generation and distribution as a community. As per the results of the survey conducted in the study area, we infer that farmers will come forward to invest in solar power generation if promoted as a community based initiative and the costs are borne by a number of farmers. Government is expected to continue providing subsidies and other incentives in adopting renewable energy options. Also, farmers expect the Government to extend its support to make solar power cheaper and easily available to all the citizens. It is also of prime importance to account for the costs involved and benefits in adopting newer technologies for sustainable growth of solar energy sector. It is recommended that the Government should strengthen its capacity building initiatives in renewable energy to reap maximum benefits, by involving all the citizens as an individual and also as a community. Fossils fuels are no longer viable for the world and for a greener and better future, investment in solar and other clean energy sectors is the best option in foreseeable future.

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