Solar Potential Estimation of Solar Resource Using Remote Sensing and GIS Technology

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Abstract: *To meet the ever increasing electricity demand in the urban area, roof-top solar PV offers a feasible and alternative solution along with conventional power supply from the electricity grid. Geographic Information Systems can be used as a significantly useful tool for potential rooftop distribution mapping. This paper aims to map potential roof-top area available in PEC University of Technology Chandigarh and evaluating the possible electricity supply from such installations. In this work, ArcGIS software has been used to compile and analyze the geographic data for potential bright roof-top area. This type of study will encourage the entrepreneurship in the field of rooftop solar home system in the urban areas of a country.*

Keywords: *Geographic Information System (GIS), GPS Device, PV cell, Remote sensing, Solar potential estimation*

1. Introduction

Solar radiation is a key factor determining electricity produced by photovoltaic (PV) systems. Electricity is one of the mostly used forms of energy which is consumed in various residential as well as in industrial applications. Fossil fuels have the major share in providing the large amount of electricity demand which requires burning of a huge quantity of fossil fuels across the globe. This fossil fuel usage is also one of the main reasons for the greenhouse gas emission resulting global warming. Renewable energy resources provide an alternative solution by replacing hydrocarbon based fossil fuels [1]**.** These resources are also often termed as green energy since these don't cause greenhouse gas emission. Among renewable energy resources, solar photovoltaic energy conversion is the most promising one to meet the energy demand. Solar photovoltaic modules can be integrated on the roof-top of buildings in urban areas to harvest energy efficiently. The Indian Government has launched the Jawaharlal Nehru National Solar Mission, which aims to achieve a total installed capacity of 20 GW for grid-connected solar power by 2022[2]. However, given the fact that India has an estimated 78.87 million urban households and 167.83 million rural households (according to 2011 census), roof-top photovoltaic systems hold a great promise. Thus there is a need to explore and demonstrate the potential of rooftop photovoltaic systems, at least in some major cities in India with good solar irradiance like Jaipur, Jodhpur, Mumbai, Ahmadabad, Nagpur etc.

The focus is mainly on large centralized solar power stations. A roof-top solar photovoltaic system consists of one or more solar panels, installed on rooftops of residential, commercial or Institutional buildings, thus enabling direct conversion of solar energy to electricity. This system can either be grid-connected or stand-alone. The installation of PV systems in connection with buildings has important benefits. No additional area is needed because the solar generator can be mounted in or on existing parts of a building such as a roof or facade. The flat roofs are especially suitable for the installation of solar generators. With landscape scales, topography is a key factor that determines the spatial variability of radiation. Variation in orientation (slope and aspect), elevation, and shadows cast by topographic features all affect the solar radiation's amount received at different locations. This spatial variability also changes with time, day and year. Therefore, Geographical Information System (GIS) tools are required and essential for such analyses. The solar radiation analysis tools, in the ESRI ArcGIS Spatial Analyst extension enables to map and analyze the effects of the sun over a geographic area for specific time periods[3].

2. Constraints Affecting Solar PV Potential

For the implementation of PV plant depends on three main factors: Technical, Economical and Environmental. These factors depend on the geographical location, biophysical attributes and socio-economic infrastructure of the region under study. Fig. 1 shows the classification of the factors and constraints affecting the land suitability for PV plant in PEC University of Technology Chandigarh. The solar radiation is considered the fundamental and decisive factor in this land suitability analysis; the higher Solar radiation the more suitable is the land.

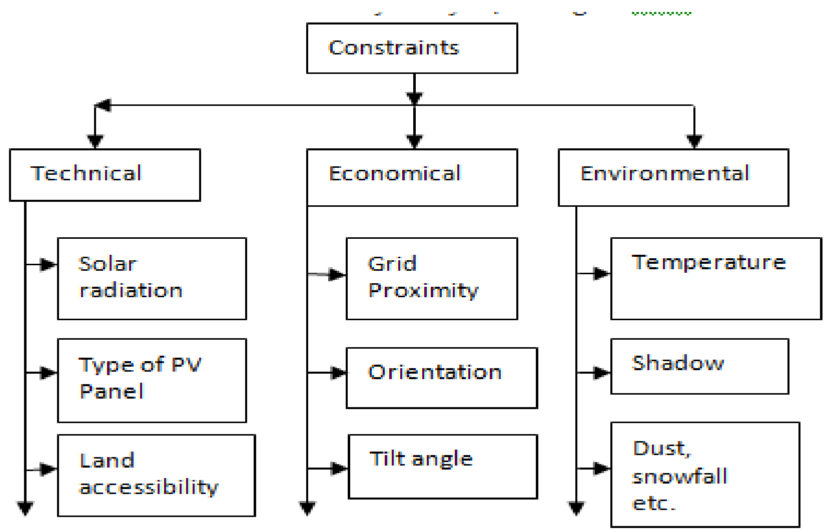

Fig. 1 Constraints affecting land suitability PV farms

Land use is also considered as an important factor because it is not possible to construct large PV plant on populated, reserved and sensitive areas. Due to fluctuations in environmental conditions, temperature change and hence irradiance level changes and is measured in watt per meter square.

Temperatures play another major factor in determining the solar cell efficiency. The cell voltage reduces by 2.2 milli volt per degree rise of temperature. This result is experimentally proved. Here the temperature acts as negative factor affecting solar PV performance [4]. The performance of photovoltaic (PV) modules and systems is affected by the orientation and tilt angle. As these parameters determine the amount of solar radiation received by the surface of a PV module in a particular region. Normally the region that lies in the northern hemisphere the panel installed on these building should be facing south or facing the equator and for southern hemisphere facing the north tilt from horizontal at an angle approximately equal to the site latitude[5], so that maximum irradiance is captured. Sometimes there is a thick layer of dust accumulated on the surface of PV panels. It significantly affects the performance of PV module. When selecting the roof area for the photovoltaic array, efforts should always be made to avoid shading or areas known for accumulation of substances that will result in cell shading. Shading is another very important factor that drastically affects the performance of PV module [6].

3. Geographic Information Systems(GIS) For Mapping

This paper uses the ArcGIS for determination of the tremendous potential of renewable energy systems, extensive research is being carried out by researchers from different disciplines. Use of Geographic Information System (GIS) offers advantage in planning for performing efficient operation and control of the system of any place. It is a computer-based tool for mapping and analysing phenomena existing and happening on earth surface. In short, GIS can be defined as a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information.GIS store and process data in two different formats, vector and raster [10,11]. In vector format, the view is presented as a mosaic of interconnected lines and points those can represent any position and boundaries of locations. In vector data models, the data are represented by lines (arcs), polygon, points and intersection points. The raster format has appeared by aerial and satellite image technology, where geographical objects are represented as grid-cell structures, known as pixels.

The GIS process is shown below it relates the real world with the computer based programme and helps in decision making.

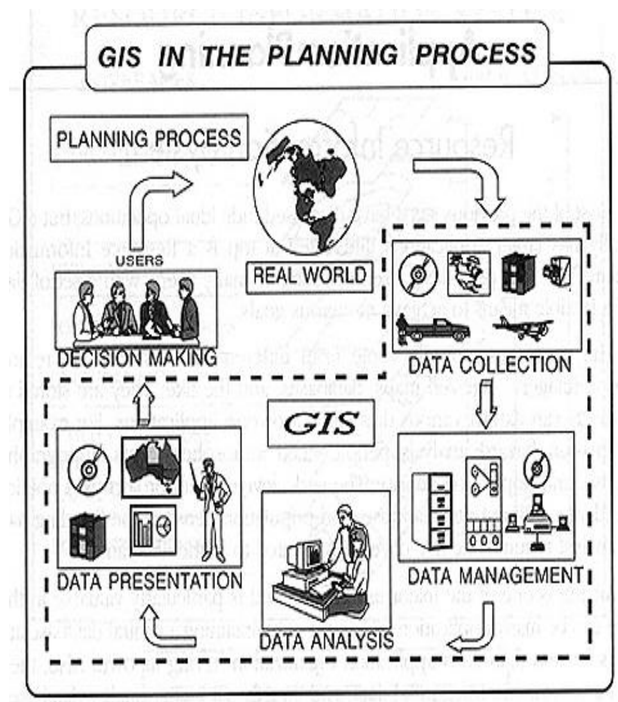

FIG. 2 GIS Process

4. Methodology

4.1 Study area

The selected region is PEC Chandigarh situated in the north of India and is one of the most suitable city for solar potential extraction. Chandigarh is the planned city of India which is mostly urbanized. The rooftop of the buildings is better from the point of view of solar PV utilization. The rooftop are evenly distributed and flat**.**

The campus of PEC Chandigarh is spread over 166.4 acre. The college campus extends over an area of 146 acres of the land situated close to the beautiful Shivalik hills. The campus is divided into various functional zones like hostels, Main College Building, Administration Block, Residential Complex for staff and faculty and a shopping centre.

Working with ArcGIS the most pre-requisite is to take the toposheet of the study area using satellite images here image is taken by Google earth along with this the co-ordinate points are also taken for georeferencing the image with the base map. Digitization is the another important element of ArcGIS to be consider with this tool the desired area is digitized and the basic properties and attributes are joined and geocoding is done and the analysis report is obtained.

The renewable energy potentials are mainly calculated from renewable energy resource maps, available meteorological data and other geographic information including land cover, land use and topographical maps.

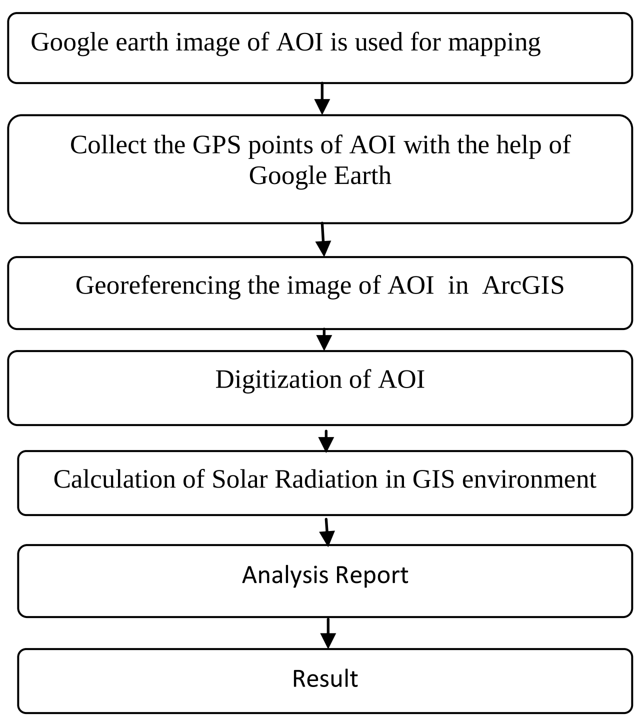

Fig.3 Flowchart of methodology adopted

4.2. Google earth imagery

Satellite imagery for this analysis is obtained from Google Earth. Google Earth uses two satellites for providing the

Satellite imagery, IKONOS and GE-1. The imagery for PEC Chandigarh is shown below which is provided by Google earth. Fig.1 is a sample image which shows a part of the PEC Chandigarh campus with the roofs demarcated. It is located in north part of India

Fig.4 Sample Satellite Image for rooftop PV Potential estimation

4.3 Georeferencing

Georeferencing is a process of associating a raster image of a map with spatial locations. Fig 4 satellite image is georeferenced with the map of Chandigarh city. For this purpose the co-ordinates are taken from Google earth using GPS. The ArcGIS 10.1 is the basic tool (software) which is used for the storing, analyzing, processing and displaying geographically referenced information. The Coordinate system specifies the geographical location of an area in terms of longitude and latitude. The coordinate system used here is projected coordinate system. Geographic locations are mostly represented using a coordinate reference system, which in turn can be related to geodetic reference system such as WGS 84.

4.4 Digitization

Digitizing in GIS is the process of converting geographic data either from a hardcopy or a scanned image into digital format by tracing the features. During the digitization process ,features from the traced map or image are captured as coordinates in either point, line or polygon format.

Features on a paper map are traced with a mouse cursor and the x,y coordinates of these features are automatically recorded and stored as spatial data.

The Google Earth imagery is processed in ArcGIS and raster image is digitizing in the form of polygon. These polygon shows the rooftop of the interested area where one wants to install the solar PV panel. This paper considers the ten rooftop for analysis purpose. For one of ten rooftops solar potential is calculated.

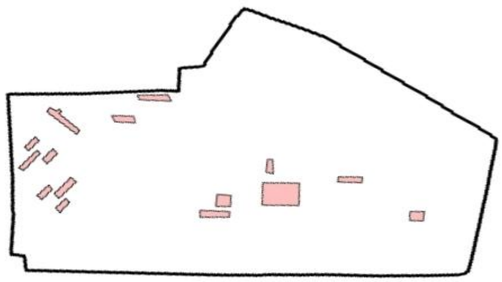

Fig .5 Digitized map of study area in ArcGIS

4.5 Solar radiation map

The spatial analyst tool of ArcGIS is used to generate the solar radiation map of the study area; this tool can work only with the georeferenced image, which shows the area that is more suitable for the solar PV installation.

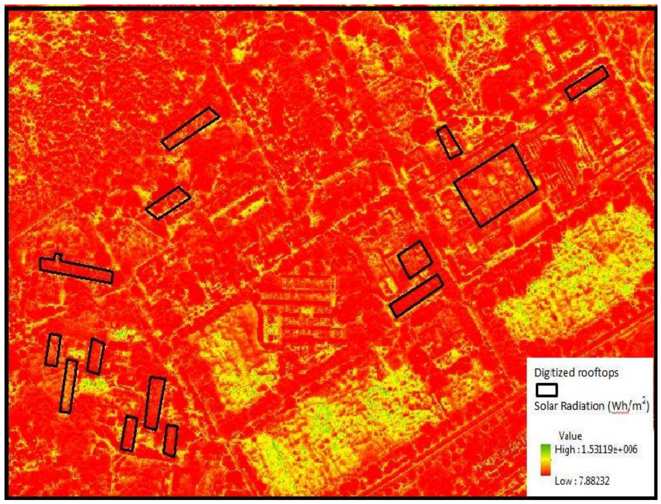

Fig .6 solar radiation map of study area

In the above solar map the area which is shown by light green color has maximum radiation level and is more suitable for installation of PV module and orange color show the minimum radiation and least suitable for installation.GIS technology offers to calculate the solar potential by calculating the solar radiation level. For this solar radiation in Kwh/m^2, efficiency of solar panel, performance factor and available area are used which gives solar potential in GWh/year.

5. Results

5.1 Calculating PV Potential on Building Rooftops:

Many web-based GIS solar tools use simplified formulas to assess PV potential. Súri et al. (2005) suggest Equation for estimating PV potential which was chosen for this evaluation as it incorporates both the peak power rating for the panel type and a system performance ratio [13].

The average and total PV output potential for the sample set rooftops were calculated by applying the average incoming solar radiation determined by the Area Solar Radiation tool to the Súri formula:

$$E=365\ P_k\ r_p H_{h,i}$$

Where E(kWh) is yearly potential electricity generation , P_k (kW) is the peak power installed, rp is the system performance ratio (typical value for roof mounted system with modules from mono- or polycrystalline silicon is 0.75) and $H_{h,I}$ is the monthly average or yearly average value of daily global irradiation on the horizontal or inclined surface [13].

Table 1 PV potential calculated data for rooftop layer attribute table

Column	Unit	Description
Average Incoming Solar Radiation kWh	kWh /(m^2/yr)	1kWh=1,000 watts ,kWh is the standard unit of energy , calculated by dividing Area Solar Radiation tool results by 1,000
Total Incoming Solar Radiation on Rooftop	kWh/yr	Average incoming solar radiation multiplied by rooftop area
Average PV Potential per square meter	kWh/(m^2/yr)	Calculated using the chosen equation
Total Rooftop PV Potential	kWh/yr	Average PV multiplied by rooftop Area

Table 1 explains the PV potential calculated data for rooftop layer. Column gives the items to be calculated for analysis purpose . with the application of ArcGIS first two elements were known and suri's formula average and total rooftops pv potential was calculated.

Table 2 calculated PV potential of each rooftop

Rooftops	Peakpower installed	Avg Incoming Solar Radiation(kWh m^2/yr)	Rooftop area (m^2)	Average PV Potential(kWh m^2/yr	Total potential(kWh /yr)
0	90	594.63	1373	77.47	106366
1	70	531.67	1954	66.59	130116
2	60	492.25	835	61.65	51477
3	80	324.06	2102	40.58	85299
4	80	576.71	2018	72.23	145760

5	80	979.19	1058	122.64	129756
6	150	931.57	5397	166.67	899517
7	60	768.57	794	96.26	76430
8	30	320.19	1173	40.10	47037
9	30	925.60	565	115.93	65500

with the help of ArcMap solar radiation on each rooftops is calculated with tool in the sequence Spatial Analyst Tool Extraction-> Extract-> Value to Point. This tool gave the radiation value at each point that was extracted from raster solar radiation map. The average of incoming solar radiation was taken as shown in Table 2 . Suri's formula is applied for each rooftop and average PV potential was calculated. For the calculation of total PV potential average PV potential was multiplied with rooftops area.

Table 3 No. of panel theoretically estimated and existing

Rooftops	Rooftop area(m^2)	Size of each panel(m^2)	No of panel(theoretical estimate)	No of panel(existing)
0	1373	1.5	915	360
1	1954	1.5	1300	280
2	835	1.5	556	240
3	2102	1.5	1400	320
4	2018	1.5	1345	320
5	1058	1.5	7.5	320
6	5397	1.5	3500	600
7	794	1.5	529	240
8	1173	1.5	782	120
9	565	1.5	376	120

Table 3 explains the theoretically estimated number of PV panel and existing panel. Theoretical Rooftops area was calculated in ArcMap by digitizing the rooftops. The size of existing panel was 1.5m^2 with this number of theoretical panel was estimated for each rooftop. But existing panel were less in no. than theoretical it was due to many factors(solar irradiance ,temperature orientation and tilt angle, shading, dust). If those factors were overcame maximum possible potential might be received hence for the ideal modeling of PV panel installation on the rooftops it is desired to install the module over the complete roof area. If this was done then no of panel on each rooftops will increase and hence output power will also increases.

6. Conclusion

This study sought out to answer the question: What is the PV potential for residential rooftops in PEC University of Technology Chandigarh? This work provides a high level overview of photovoltaic energy potential in the study area and proposes a method to model two pieces of information that were unavailable at the time the study was implemented. These include high-resolution incoming solar radiation data and total rooftop area. While it is not possible to calculate exact installed capacity for the proposed energy generation, we can make an estimate based on calculated rooftop area. The ArcGIS enables to calculate these parameter, digitization of rooftops calculate rooftop area and solar analyst tool generates a solar radiation map that represent minimum and maximum radiation on the rooftops. Based on the total study area regression analysis findings presented in this document (Table 2) which show the total PV potential in KWh/year. When reporting these PV potential and rooftop area estimates, it is essential to discuss the uncertainty inherent in these findings. For this study it was assumed that the entire rooftop can be used for PV generation.

For this study 10 rooftops of campus were taken into consideration with total rooftops area of 17269m^2 calculated theoretically in ArcMap with this much area no of panel installed on 10 rooftops should be near about 11408 but practically existing were 2920 and very less as compared to the theoretically estimated. In the similar way total incoming radiation was 1737263 KWh/year but existing panel were utilizing only 380103.6 KWh/year. Thus if the rooftops of an area are flat and evenly distributed it become very easy to harness the solar energy otherwise a major portion of incoming solar radiations is wasted.

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