ESTIMATION OF ROOFTOP SOLAR POWER POTENTIAL USING GIS

Student (M.Sc. Geoinformatics), The Energy and Resources Institute (TERI)

10, Vasant Kunj, Institutional Area, New Delhi, DL 110070

Abstract

In the present study, a methodology for estimation of rooftop solar power potential is presented using GIS (Geographic Information System) approach. Monthly solar energy on individual building is calculated. The methodology is implemented on 1688 buildings in 1× 1 sq. km of Vikaspuri area. The source of building data is Google Earth (GE) imagery, SPOT 2.5m spatial resolution. The most important input parameters considered for the methodology are DEM with spatial reference, the latitude of the scene centre along with input point feature class which specifies the location to analyze solar radiation. Point solar radiation tool of ArcGIS v10 is used to calculate the global solar radiation, direct radiation, diffuse radiation in Watt-Hours/sq. meter and direct-duration in hours at the surface at the local scale. Results are validated with solar GHI (Global Horizontal Irradiance) data developed by U.S. NREL in cooperation with India's Ministry of New and Renewable Energy (MNRE).The results show that the amount of solar insolation on a building of individual month can be calculated and then accordingly size of solar photovoltaic system that a person needs to be installed on his roof can be estimated. This methodology could help for those regions interested in identifying buildings with high solar power potential so that photovoltaic systems can be mounted on roof which converts solar radiation into direct current electricity which is cost effective to a common man and the most important it is one of the ways for reduction of carbon footprint.

Keywords: GIS, DEM, point solar radiation tool, solar power potential, solar GHI data, and Photovoltaic system.

About the Author

Ms. Swati Goyal

I am a student pursuing M.Sc. Geoinformatics (IIIrd semester) from TERI university, New Delhi. I have attended a national symposium on space technology for Food and Environmental security organized by ISRS, ISG, ISAP, IARI, and ICAR. I have done my minor project on 'Estimation of rooftop solar power potential using GIS' in India Habitat Centre (IHC), Lodhi road under the guidance of Dr. P.K. Joshi and Er. Alekhya Datta.

E mail ID: swatty.19@gmail.com

Contact No: +91 – 9811516392

Introduction

Energy is one of the vital factors to sustain a modern economy and society. India faces threatening challenges to meet its energy needs and in providing adequate energy in various forms in a sustainable manner. As electricity demand escalated, with supply depending largely on fossil fuels plus some hydro power and then nuclear energy, concerns arose about carbon dioxide emissions contributing to possible global warming. Wind, wave, solar and other renewable power sources should be use to check for the global warming. According to report compiled by ICLEI south Asia, May 2007, in most parts of India, there are about 300 clear sunny days in a year. This is equal to over 5,000 trillion KWh/year, which is far more than the total energy consumption of the country in a year potential.

In order to meet the energy demand, solar energy should be harnessed which can be done by using solar photovoltaic systems.

Solar Photovoltaic systems have found applications in households, agriculture, defence and many others. In last two decades, the cost of photovoltaic systems has gone down significantly, increasing affordability for dispersed rural applications. One of the advantage of Solar photovoltaic is that sunlight is free and most important reduces carbon footprint. Infact, over 30 tonnes of CO_2 could be saved over the system's lifetime thereby a bit work can be done for the environment (Ice energy, [2]).

One of the most important advantages of photovoltaic systems that solar energy peak power generation usually coincides with peak energy demand e.g. in hot summer days.

All these advantages have motivated to install solar photovoltaic systems on roofs of the buildings whether it is a house building or industrial building. And for installation purposes, solar power potential needs to be known which can be calculated by the methodology that will be dealt in further section.

Literature review

1) Switch to Solar power in Delhi makes sense

According to the report written by BRIDGE TO INDIA [GREENPEACE India, June 2013] Delhi can be 2 GW solar city by 2020 on which they arrived by combining three perspectives :

a) Availability of roof top space to reach a geographic potential,
b) Economic viability of solar for different tariff groups and system sizes'
c) Assess that how much grid connected power could be handled by grid.

On the rooftops of Delhi built up area around 2.6 GW of solar photovoltaic can be installed. Total area of Delhi (only the NCT) is 1,483 Km^2 so if it is exclusively available for solar installations, 123 GW of installed capacity which would be more than Delhi's expected peak power demand of 6 GW for 2013. The rooftops of buildings would be ideal for the installation of solar PV in Delhi because of the high cost of land in the city. Also, "Delhi receives higher irradiation in relation to many other cities of the world that make a dedicated effort to go solar" [Greenpeace India, June 2013]

Electricity crisis, increase in demand of power day by day and often claiming Delhi to be the world's greenest capital has motivated to select one of the areas from Delhi for this study.

2) Review about solar irradiation estimation using GIS tool

ArcGIS is a platform for designing and managing solutions through the application of geographic knowledge. It has a spatial analyst tool which has further solar radiation tool which has three types of tools:

a) **Area solar radiation**: derives incoming solar radiation from raster surface.
b) **Point solar radiation**: derives incoming solar radiation for specific locations in a point feature class.

c) **Solar radiation graphics**: Outputs from the Solar Radiation Graphics tool are raster representations and are not maps that correspond to the outputs from the area or point solar radiation analysis.

Some of the parameters need to be considered while dealing with point solar radiation tool specifically sky size/resolution for the viewshed, sunmap and skymap concept behind them need to be known.

Hemispherical viewshed algorithm : [J.B. Kodysh et al., 2013] The radiation intercepted by earth gets modified by the topography and other features of surface and characteristic of individual building like size of the roof, slope and orientation which usually impacts the final solar radiation striking the surface. Radiation intercepted as direct, diffuse and reflected.

So these factors are taken into account and GIS based upward looking hemispherical viewshed algorithm is presented for estimating solar radiation potential [Fu and Rich, 2000].

Viewshed calculation: It determines for a particular location on a DEM which part of the sky is obstructed.

Sunmap calculation : Since the position of the sun varies through time for the same location which is calculated on the basis of latitude, day of year, and time of the day using standard astronomical formulae. Zenith and azimuth angles are projected into two-dimensional grids with the same resolution used for viewsheds. These sunmaps are used in the final solar radiation calculation to estimate the amount of direct solar radiation received by a given location.

Skymap calculation: The entire sky is divided into series of sky sectors defined by zenith and azimuth division. To estimate the amount of a diffuse solar radiation receives on a particular location on a DEM, it is used.

Global solar radiation (GR): It is the sum of direct and diffuse radiation for all the sectors.

$$GR=DR+FR$$

Where, DR is direct solar radiation for all sunmap sectors and FR is diffuse solar radiation for all skymap sectors.

3) ASTER GDEM:

[Aster GDEM wiki]ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) is a Japanese sensor which is one of five remote sensory devices on board the Terra satellite.

The global digital elevation of the model is the most complete mapping of the earth ever made covering 99% of the surface, a joint operation between NASA and Japan's METI.

Region of study:

The study area is of 1×1 sq. km of Vikaspuri (Geographic extent: 28.641369°N, 77.079918°E), Delhi.

It is an upper middle class residential colony in Delhi, India. It comes under the Patel Nagar subzone of west Delhi.
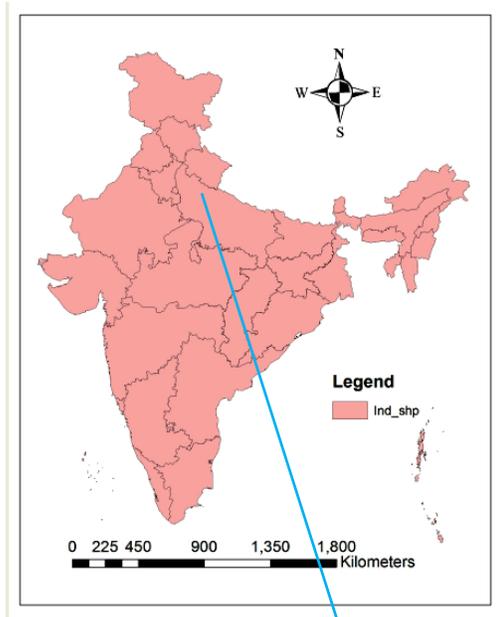
Coordinate System: WGS 1984 UTM Zone 43N
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Northing: 0.0000
Central Meridian: 75.0000
Scale Factor: 0.9996
Latitude Of Origin: 0.0000
Units: Meter
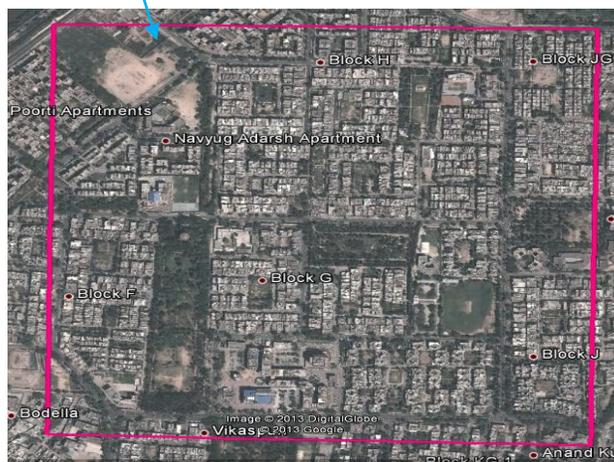
Figure 1: Showing study area, Vikaspuri, Delhi.

Methodology:

The study area is of Vikaspuri, 1×1 Km^2. The source of building data is Digital Globe Google earth imagery, SPOT 2.5m spatial resolution.
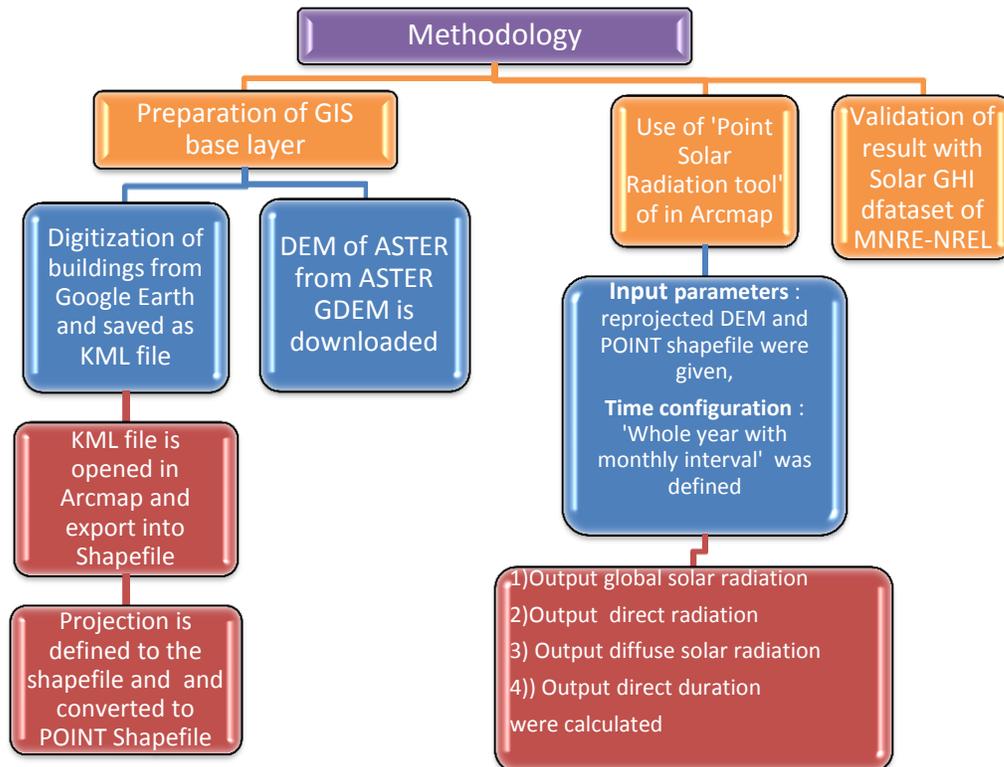
Figure2: Flowchart showing methodology

1) Preparation of GIS base layer:

1.1Digitization of buildings on Google Earth and creation of Shapefile in Arc map:

- The rooftop of each building of specified area is digitized by "Add polygon" option on Google earth itself so that the boundary is created of each rooftop of a building and then it is saved as a file in KML (Key Mark up Language) format. The file is opened in **Arcmap** of **ArcGIS v10** by using **'conversion tool' (in Arc tool box)** having 'KML to Layer' as a further tool and later the output that we get from it, is converted to Shapefile. Then the projection 'WGS_1984_UTM_Zone_43N' is defined to the Shapefile by using 'project' tool in arc toolbox.

  This projected Shapefile containing all the polygon shaped buildings is converted to point Shapefile by using 'Feature to point' tool which creates a feature class containing points generated from the representative locations of input features (polygon). This tool basically calculates the centroid of the polygon.

Figure 3: Digitized buildings of study area

Figure 4 : Building shapefile of study area

1.2 Downloading of ASTER DEM

The DEM (Digital Elevation Model) is downloaded from ASTER GDEM. The resolution of ASTER DEM is 30m*.*
The DEM is opened in the Arcmap and the similar projection or spatial reference is provided as of the buildings Shapefile i.*e.* *WGS_1984_UTM_Zone_43N.*

2) Use of Point solar radiation tool of ArcGIS v10
- After getting required DEM of the study area and Point Shapefile of the buildings, these are used as an input parameters in 'Point solar radiation tool' in Arc toolbox.
  In **Arcmap** there is a **'spatial analyst tool'** which further have solar radiation tool which further contains three types of solar radiation tool in which point solar radiation solved the purpose as it derives incoming solar radiation on specific locations in a point feature class.
  The required input parameters in point solar radiation tools are:

  a) **Input Raster**: DEM is given as an input since it contains the spatial reference; the mean latitude is automatically calculated by the tool.
  b) **Input point Feature class**: It specifies the locations to analyze the solar radiation so point Shapefile solves this purpose and hence given as the input.
  c) **Latitude**: Latitude from the DEM is automatically calculated since input raster contains the spatial reference. Because the solar analysis is designed for landscape scales and local scales, it is acceptable to use one latitude value for the whole DEM [ArcGIS Desktop help v10].
  d) **Sky size**: [ArcGIS help v10] Sky size is the resolution of the viewshed, sky map, and sun map rasters which are used in the radiation calculations (units: cells per side). These are upward-looking, hemispherical raster representations of the sky and do not have a geographic coordinate system. These grids are square (equal number of rows and columns).
  The resolution of the viewshed grid is taken in such a way so that it adequately represents all sky directions but should be small enough for rapid calculation, hence, default value 200 is chosen.

➢ **Hemispherical viewshed algorithm:** Factors like shading from adjacent feature, seasonal variation, building characteristic like roof size, slope, and orientation needs to be taken into account as it usually impacts the final amount of solar radiation received by the particular location on a DEM so viewshed calculation is performed.

For given location on a DEM, the viewshed algorithm calculates the sky obstruction and incoming solar radiation.

Cells in the DEM having higher elevation to another will 'shade' the cells which are lower in position to them so this shading analysis has been done using viewshed calculation.

➢ **Sunmap calculation**: Estimation of amount of direct solar radiation is done. Latitude, day of year and time of day using standard astronomical formulae are the input parameters.

➢ **Skymap calculation**: Estimation of amount of diffuse solar radiation is done. Zenith and azimuth divisions as input parameters are needed to be defined.

All these three calculations are taken care by tool itself after defining respective parameters needed for their calculation.

e) **Time configuration** : For the purpose of this study, 'whole year with monthly year interval' is selected in which year 2012 is specified and check the box 'create outputs for each interval' so that solar potential of individual building of each month could be calculated in attribute table.

f) **Zenith division and azimuth divisions**: Number of divisions used to create sky sectors in the skymap which are taken as 8 by default.

g) **Number of calculation directions**: The number of calculation directions needed is related to the resolution of the input DEM. Natural terrain at 30m resolution is usually quite smooth so fewer directions are sufficient for most situations, value given to it is 32.

h) **Transmittivity**: The fraction of radiation that passes through the atmosphere (averaged over all wavelengths). Value given is 0.5 which is a default value use generally for clearer sky.

i) **Diffusion proportion parameter**: It has an inverse relation with transmittivity. Default value taken is 0.3.

j) **Hour interval**: Time interval through the day (units: hours) used for calculation of sky sectors for sun maps. The default value is 0.5.

- After deciding the values of all input parameters, four output parameters were calculated :
  ➢ Output global radiation features : unit is Wh/m^2
  ➢ Output direct radiation features : unit is Wh/m^2
  ➢ Output diffuse radiation features : unit is Wh/m^2
  ➢ Output direct-duration features: unit is hours.
- The values of each of the output feature could be seen in attribute table.

Main focus is on output Global radiation which is calculated in Wh/m^2 but in attribute table they are recalculated in KWh/m^2 by using 'Field calculator'.

3) Calculation of monthly average value

The monthly average value of each month and every building is calculated in KWh/m^2 using 'Field calculator'. This is the required output.

4) Calculation of AREA of each building
Area of each and every building is calculated using 'calculate geometry' in attribute table.

5) Validation of Result with solar GHI datasets of MNRE-NREL

First ten buildings were selected, their Latitude and Longitude were noted down and then the corresponding latitude and longitude were searched in the dataset of solar GHI (Global Horizontal Irradiance), and then the values of solar potential of each and every month corresponding to that latitude and longitude were matched with the results we get.

- An algorithm is used to validate the data as follows:

$$\text{Mean Percentage error, MPE} = [\ \sum\{(H_{do} - H_{dc}/\ H_{do}) \times 100\}]\ /\ n$$

Where, H_{do} is the ground measured and H_{dc} is the satellite measured value and 'n' is the number of days/observation

- According to the MNRE- NREL solar GHI data(which is ground validated), the average solar radiation in June is 6.3 KWh/sq m while based on our method it is 5.9 KWh/sq m, so validation has been done by calculating the mean percentage error as follows :

$$\text{Mean percentage error} = [(6.3\text{-}5.9)/5.9] \times 100$$
$$= 6.7\ \%$$

Since the data of MNRE-NREL used is the average of solar potential from 2002 to 2008 and year selected for this study is 2012 so difference in result might be due to the change in climate condition or seasonal variation from 2008 to 2012.

Results

The monthly average solar radiation intensity on individual building is calculated.

solarad_monthly

FID	Shape	Jan(KWh/sq m)	Mar(KWh/sq m)	Apr(KWh/sq m)	May(KWh/sq m)	Jun(KWh/sq m)	Jul(KWh/sq m)	Aug(KWh/sq m)	Sep(KWh/sq	Oct(KWh/sq m)	Nov(KWh/sq m)	Dec(KWh/sq m)	JanGL
0	Point	2.255241	4.177634	5.193874	5.839201	6.067243	5.952951	5.494883	4.718624	3.322393	2.417741	2.01671	69.912
1	Point	2.415599	4.378093	5.315293	5.878895	6.064457	5.96954	5.594429	4.900724	3.528214	2.590189	2.1614	74.883
2	Point	2.351518	4.315682	5.277241	5.866113	6.077342	5.971807	5.561418	4.842598	3.464379	2.521362	2.099126	72.897
3	Point	2.187186	4.157896	5.164216	5.812139	6.035236	5.920471	5.45146	4.68031	3.297236	2.357993	1.94392	67.802
4	Point	2.236813	4.165632	5.15349	5.768471	5.97447	5.869673	5.42674	4.667695	3.308189	2.403309	1.991736	69.341
5	Point	2.236813	4.165632	5.15349	5.768471	5.97447	5.869673	5.42674	4.667695	3.308189	2.403309	1.991736	69.341
6	Point	2.236813	4.165632	5.15349	5.768471	5.97447	5.869673	5.42674	4.667695	3.308189	2.403309	1.991736	69.341
7	Point	2.236813	4.165632	5.15349	5.768471	5.97447	5.869673	5.42674	4.667695	3.308189	2.403309	1.991736	69.341
8	Point	2.276734	4.216886	5.211219	5.881256	6.109865	5.997924	5.531953	4.756412	3.389986	2.44375	2.047881	70.57
9	Point	2.203809	4.146379	5.145385	5.774228	5.999498	5.882868	5.428569	4.66095	3.279596	2.369124	1.947106	68.318
10	Point	2.043303	3.996798	5.055846	5.74378	6.001136	5.869111	5.363039	4.523805	3.115577	2.206402	1.795481	63.342
11	Point	2.071065	4.036725	5.09155	5.771656	6.03087	5.894523	5.402805	4.572412	3.1722	2.244742	1.818903	64.203

Figure 5: Attribute table showing monthly average solar radiation intensity (KWh/m^2) of each FID (building) month wise

Conclusion

Highest solar insolation is in month of June in which energy demand is at its peak which coincides with peak power generation by solar energy using solar photovoltaic systems.

By estimating solar power potential on rooftops, one can estimate Photovoltaic system's size that needs to be installed according to the area of the building, the yielding capacity of a PV system, amount of energy that is getting saved, how much it is cost effective and the money an individual is saving by using PV system and the most important aspect, reduction in carbon emission can be calculated.

It is a long term reliable power source; diesel generator dependency can be overcome. Moreover, city like Delhi has a very less space on ground so the idea of mounting it on the rooftops means it is reducing the requirement of land at national level.

References

1. Terra India, Kavitha Rao, 2013. Delhi created its own energy crisis. Available at <www.theguardian.com/environment/terra-india/2013/jun/07/delhi-created-own-energy-crisis>
2. Ice Energy. Advantages of solar photovoltaic (solar PV). Available at <http://www.iceenergy.co.uk/Renewable-Energy/Solar-PV/Advantages-of-Solar-Photovoltaic-%28Solar-PV%29>
3. NDTV. Demand for power in Delhi touches all-time high. Press release, 06 June 2013.
4. ICLEI South Asia, May 2007. Renewable Energy and Energy Efficiency Status in India. Available at <http://local-renewables.iclei.org/fileadmin/template/projects/localrenewables/files/Local_Renewables/publications/RE_EE_report_India_final_sm.pdf>
5. Fu, P., & Rich, P . M. (2000). The solar analyst 1.0 user manual. Helios Environmental modelling Institute, LLC. Accessed on 14th July,2013 from: <http://www.fs.fed.us/informs/solaranalyst/solar_analyst_users_guide.pdf>
6. J.B. Kodysh,O.A. Omitaomu, B.L. Bhaduri, B.S. Neish (2013). Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems.
7. ArcGIS 10 Help Library. Point solar radiation(spatial analyst).
8. ASTER GDEM. <gdem.ersdac.jspacesystems.or.jp>
9. ASTER GDEM wiki. <en.wikipedia.org/wiki/Advanced_Spaceborne_Thermal_Emission_and_Reflection_Radiometer>
10. GREENPEACE India,2013. Rooftop Revolution: Unleashing Delhi's Solar Potential. Written by 'BRIDGE TO INDIA'.
11. http://www.geospatialworld.net/Paper/Application/ArticleView.aspx?aid=30355