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# Development of Rasterized Mapusing PVGIS for Assessment of Solar PV Energy Potentialof Odisha

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**Abstract**-Solar energy is a potential resource among the various renewable energy options which is clean, inexhaustible and eco-friendly. The development of usage and installation of PV system needs a relevant solar policy making planthrough proper assessment of solar PV Energy potential.The study uses theestimate of the photovoltaic potential of an area under considerationusing the PVGIS online software.The study divides the total geographic area of into a grid of 'mxn', each square having its particular coordinate approximately at the midpoint of the location. The PVGIS evaluated the value of incident solar radiation and generated PV energy at each central coordinate.The evaluation of energy potential for four cases (based on mounting and tracking)uses two important parameters: total incident Global radiation for a year and total annual PV Energy production. A methodology is presented to plot the rasterized maps of the solar energy potential.The paper further discusses a case study of Odisha to show the usefulness of the proposed methodology todevelop a district wise strategy for promoting the installation of grid-connected PV system.

**Keywords**: PVGIS; PV potential; Estimation, Rasterized Maps, Odisha

**Nomenclature**

| Variables | Parameters and values | Unit |
|---|---|---|
| $P_K$ | Peak installed power of the module | kW |
| A | Area of the surface of the module | $m^2$ |
| $eff_{nom}$ | Nominal efficiency | % |
| eff | Actual efficiency | % |
| $eff_{rel}$ | Relative efficiency | % |
| $T_m$ | Temperature of the module | $^0C$ |
| $T_{amb}$ | Ambient Temperature | $^0C$ |
| P | Actual power of the module | kWh |
| G | Global irradiance | $kWh/m^2$ |
| $K_T$ | Temperature coefficient of the module | °C/ $(W/m^2)$ |

## 1. Introduction

The energy potential of solar energy is enormous compared to other renewable sources. In the recent years,theinvestmentinsolar photovoltaic or PV systems becameprofitable, regarding both the environment and the economy. The usage and growth of grid-connected PV systems are increasing rapidly throughout the world. By October 2013, the capacity of the total worldwide solar PV installation reached to 135 GW, showing an increase of 112 GW in previous four years [1].India, due to geo-locational advantage, has vast potential for solar energy generation. Most parts of Indiareceive about 7000 $MJ/m^2$ of global solar radiant energy in a year. The Installed capacity of grid-connected renewable energy in India stands at 36,470.64 MW as of June 2015; out of which solar power has a share of 4,060.65 MW [2].About 58% of the total land area receives annual average global insolation abovefive$kWh/m^2$/day [3]. Total theoretical solar PV potential of India is over five trillion MWh annually [4]. The Government of India announced the Jawaharlal

Nehru National Solar Mission (JNNSM) in 2010 to promote ecologically sustainable growth while addressing energy security challenges of India. One of the many objectives of JNNSMis to increase the installed solarPV generation capacity to 100 GW by the end of 2022 [5].

Odisha, a state in India, located South of the Tropic of Cancerthatis richin Energy resources.Economic growth of Odisha depends upon the utility of energy resources, majorly arising from coal and hydroelectric power which contributes 74.7% and 24% of the total electricity production [6]. The comparison between annual generation and anannualdemand of electrical poweris shown in Figure1 [7]. As per the trend line the demand for electricity is increasing rapidly; however,the production is stagnantover last decade.Considering coal to be nonrenewable and limit for the establishment of dams for hydroelectric power, Odisha cannot opt these two types further for power-generation. Renewables sources, such as Solar, Wind, and Biomass, are suitable options for bridging the gap. Considering geo-location of Odisha, solar PVis a viable alternative among all renewables. Odisha, with around 300 clear sunny days each year, receives a daily average solar radiation of 5.5 kWh/m$^2$. According to the solar policy of Odisha 2013, its gross renewable energy potential stands at 53,820 MW. The possible potential for power generation in the Solar PV is 8000 MW [8]. The first solar powerplant (REHPL Balangir Solar Power Project) of Odisha commissioned in 2011 under the JNNSM situated at Balangir [9]. The list of already commissioned Solar Power plants in Odisha as shown in

Table1.

Planning power-generation using PV system requires supporting data such as solar irradiation, temperature, geography and the climate at the installation site. The economic viability of the solar PV systems in the energy market depends on the system installation cost, availability of the land, public awareness, and government policies. Different Software or hardware setups are used to estimate PV production capability of a system in any particular region. A typical hardware setup to determine the Solar PV production in a given area contains essential components like data acquisition system, solar PV modules ( i.e., crystalline silicon, polycrystalline silicon), and sensors ( pyranometers, thermometers, and anemometer). A study shows the evaluation of PV potential in Gobi desert of Mongolia from actual data measured over a period by using a data acquisition system with c-Si and p-Si module [10].

**Table**1. Commissioned Solar PV Power Plants of Odisha in MW scale

| Name | Location | Capacity | Technology | Commissioned |
|---|---|---|---|---|
| ACME Odisha Solar Power Pvt. Ltd. | Balangir | 25 MW | Crystalline Silicon | 2015 |
| Aftaab Solar Pvt. Ltd. | Balangir | 5 MW | Thin film | 2012 |
| Alex Green Energy Pvt. Ltd. | Balangir | 5 MW | Thin film | 2013 |
| Raajratna Energy Holdings Pvt. Ltd. | Balangir | 1 MW | Thin film | 2011 |
| Molisati Vinimay Pvt. Ltd. | Deogarh | 1 MW | Crystalline Silicon | 2011 |
| MGM Minerals Ltd. | Khordha | 1 MW | Crystalline Silicon | 2011 |
| Pantime Finance Company Pvt. Ltd. | Nayagarh | 1 MW | Crystalline Silicon | 2012 |
| S N Mohanty(Tata BP Solar) | cuttack | 1 MW | Crystalline Silicon | 2011 |
| Jai Iron Steel | Sambalpur | 1 MW | Crystalline Silicon | 2012 |
| Abacus Holdings Pvt. Ltd. | Subarnapur | 1 MW | Thin film | 2012 |
| Shri Mahavir Ferro Alloys Pvt. Ltd. | Sundargarh | 1 MW | Crystalline Silicon | 2012 |

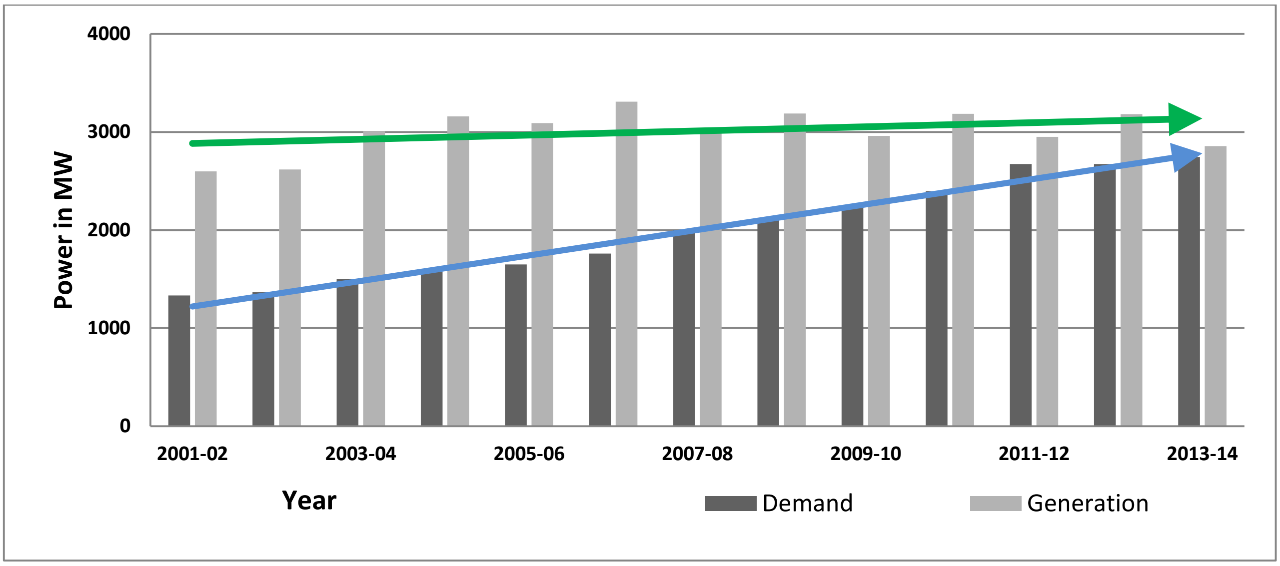


**Figure**1. Annual demand and Generation of power in Odisha**[7]**

Howard O. Njoku[11]determined the PV electric production of Nigeria by using databases with data of monthly mean daily insolation incident on horizontal surfaces obtained from the online open-access NASA Surface meteorology and Solar Energy.The study shows that all locations in the country are capable of annually generating the PV production above 1,000 kWh/kWp.A case study carried out by Brito, M.C. et al. [12],describes the assessment of the solar insolation and PV potential of Lisbon suburb, using LiDAR data and the ArcGIS extension using Solar Analyst tool. The estimation indicates the total PV potential of the 538 identified buildings to be around 11.5 GWh/year for an installed capacity of 7 MW.Solar based Software like TRANSYS, PVsyst, GRASS-GIS and PVwatts are used to measure the production of electricity from PV systems in various locations throughout the world [13; 14; 15].The (Photovoltaic Geographical Information System) PVGIS is also another solar-based online tool that evaluates the potential of PV production throughout the world [16; 17; 18]. A study presents a method to predict PV production in Concentrating Photovoltaic installations by using Global Horizontal Irradiation and the PVGIS database [19]. Another methodology uses the '*r.sun solar radiation model*' (provides the radiation data) and PVGIS estimation utility to estimate the PV potential [20; 21]. The PVGIS is also used to compare output performance of fixed, one axis, and two-axis tracking PV system [22; 23].

The objective of the paper is to provide an alternate method to estimate and analyze the solar PV Energy potential in different parts of Odishabased on the radiation, temperature, and other geographical data. All the required parameters are estimated for four different kinds of PV system with different orientation and tracking option installed. Based on estimation, a methodology is proposed to develop rasterized plots to study the feasibility of a region for PV power production.The paper further discusses the usefulness of the proposed methodology to develop a strategy for promoting the installation of grid-connected PV system.

## 2. Geography of Odisha

Odisha is one of the twenty-nine states of India with a vast amount of natural resources.The stateslike West Bengal, Bihar, Andhra Pradesh, Madhya Pradesh, and ocean like the Bay of Bengal surrounds the land of Odisha. Thelocation of Odisha is in between 17.49N latitude to 22.34N latitude and 81.27E longitude to 87.29E longitude. The region spreads over an area of 155 707km$^2$, 800 km from north to south and 500 km from east to west.The state consists of 30 districts, 58 sub-divisions, 314 blocks and 103 urban local bodies with a total population of around 42 Milion [24; 25]. Therasterized maps provided in Figure 3, Figure 4, andFigure 6uses *GoogleMy Map* [26], an online mapping tool.The map displays the division of the total geographical area of Odisha into 1195 square blocks. Solar-GIS website is the source for the block-wise geographical and meteorological data[27]. The Methodology sectionprovides the details about the method used for the division of area and plotting of maps.

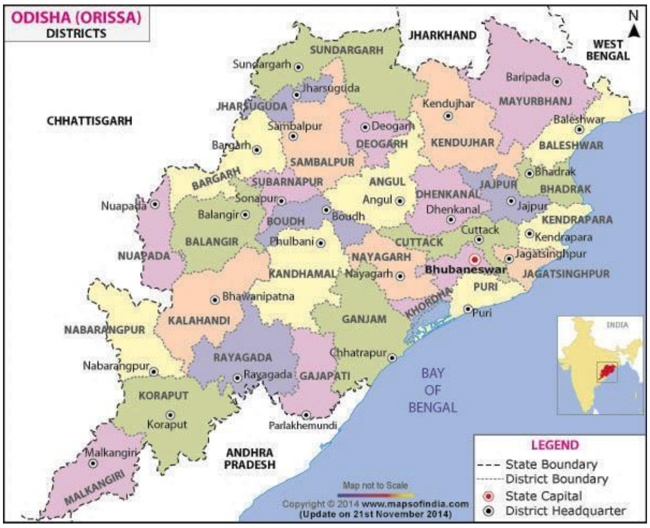


**Figure 2.** Political map of Odisha showing 30 districts **[28]**

The state of Odisha situated on the eastern coast of the Indian peninsula is quite rich in natural resources. Odisha is one of the richest biodiversity regions in Southeast Asia.

The statecontainsharboring dry and moist deciduous forests as well as mangroves with several rare and endangered floral and faunal species.Figure 3 shows the distribution of wetland, forest, and land cover throughout the Odisha.The state consists of four Physiographic Zones namely Coastal Plains, Central Table Land, Northern Plateau and the Eastern Ghats.Three major rivers that are Mahanadi, Brahmani, and Baitaranireside in the state. Odisha is home to the Hirakud Dam, one of the longest dams in the world. The mountain ranges cover about three-fourth of the entire regionof the state. Odisha also has plateaus and rolling uplands, which have the lower elevation than the plateaus [24; 25].Figure 4 shows the plotted elevation map of Odisha.

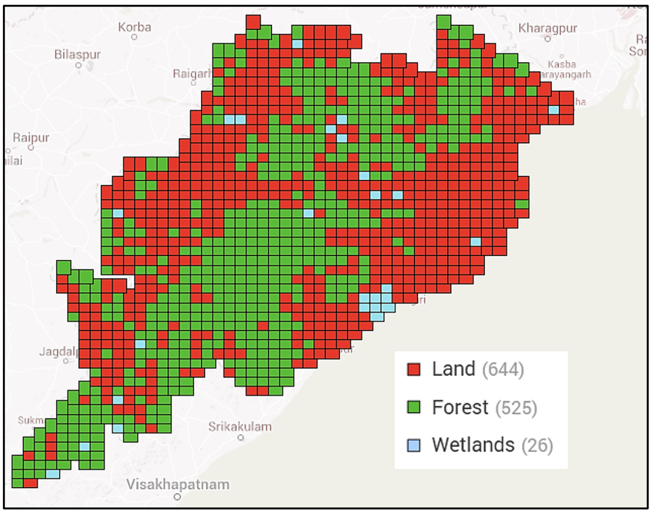


**Figure 3.** Distribution of Wetland, Forest, and Land cover of Odisha

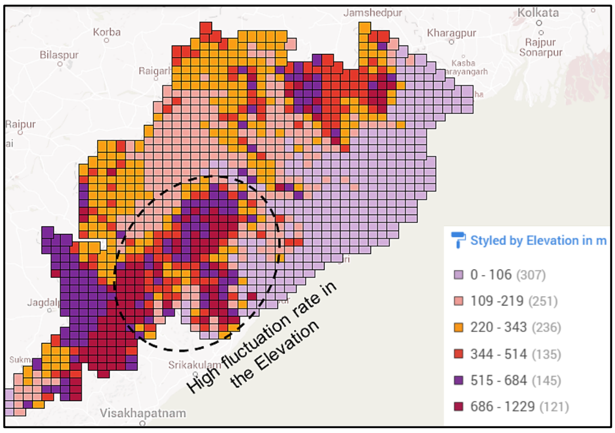


**Figure 4.** Elevation map of Odisha plotted by using data from Solar-GIS

## 2.1. *Forest Resources*

The recorded forest land of Odisha is about 58 136 km$^2$ that is 37.34% of the geographical area of the state. From the total forest area, 45.29% is reserved, 26.7% is protected, and 28.01% is un-classed. There are two kinds of the forest we can see in the state. In the northeast region of Odisha, the forest is classified as the tropical-moist-deciduous type. In the southwest region of Odisha, the forest is classified as the tropical-dry-deciduous type. The State forest consists of 7,060 km$^2$ of ‘Very Dense Forests’ (VDF) with crown density above 70 %, 21,366 km$^2$ ‘Moderately Dense Forests’ (MDF) with crown density ranging from 40-70 % and 20,477 km$^2$ of ‘Open Forests’ (OF) with crown density ranging from 10% to 40%. Tree cover outside of forests (TOF), assessed separately, is 4,301 km$^2$. Figure5 shows the distribution of these forest covers with respect to the total geographical land of Odisha. The actual forest cover is highest in Kandhamal(71.19%) followed by Malkangiri(57.95%), Gajapati(57.09%), Deogarh(53.07%) and Nayagarh(53.50%). The coastal districts such as Balasore, Bhadrak, Jagatsinghpur, Jajpur, Kendrapara and Puri have less than 10 % of total forest areas [29].

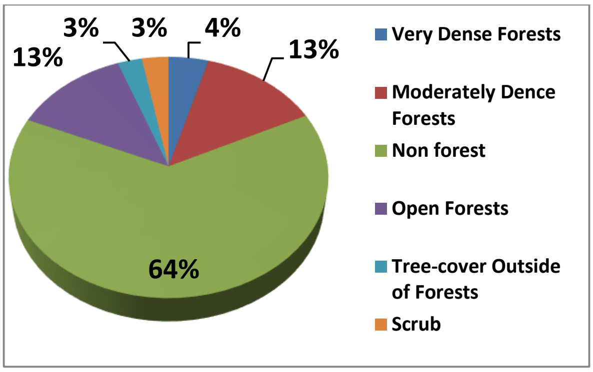


**Figure**5. Distributions of forest cover in Odisha

## 2.2. *Surface water resources*

The land of Odisha depends largely upon monsoon for its water resources. The state contains anextensivenetwork of rivers and streams. Almost all the Rivers are interstate Rivers. Major basins like Mahanadi, Brahmani, and Subarnarekha originate in other states but a significant portion of their catchments lie in Odisha, and they drain out to the Bay of Bengal. Similarly, there are other basins like Indravati, Vansadhara, Nagabali and Kolab, which originate in Odisha but then meet their major parent basins in other states or drain out in other states. Most of the catchments of Budhabalanga and Baitarani basin lay in Odisha [30; 25].

The total area of wetlands in the state is 3478.7825 km$^2$. From the overall distribution of wetlands of each district, it is observed that Puri district has the highest area of wetland, i.e. 1175.2375 square kilometers, which is 34 % of total wetlands of the state. Chilika is the largest brackish water lagoon resides at Puri, Ganjam, and Khordha district. According to the amount of rainfall, the area of Chilika varies between 906 to 1165 Km$^2$ [31].

## 2.3. *Climate Details*

Tropical monsoon weather represents the climate of Odisha. Searing hot summers with considerably strong monsoon downpours and cold and pleasant winters mark the climate of Odisha. There are mainly three kinds of weathers felt in Odisha that are summer, monsoon, and winter. Rainfall is the primary source of water in Odisha that varies from 1200 mm to 1700 mm across the state. The average rainfall in Odisha is measured around 1482 mm [31]. Odisha receives about 78% of rainfall during the months of June and September [25]. The maximum temperature ranges between 35-40℃ and minimum temperature are between 12-14℃ [32]. The annual average air temperature data retrieved from Solar-GIS is plotted on the map of Odisha in Figure 6 [27].

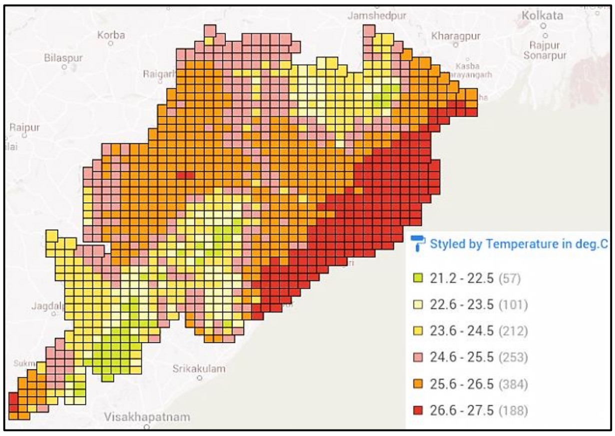


**Figure 6.** Average annual air temperature map of Odisha Plotted by using data from Solar-GIS

## 3. Estimation of PV potential with PVGIS Estimation tool

PVGIS is a popular and free-to-use GIS-based online calculator implemented by Joint Research Centre from European Commission. PVGIS is portable and can be used even on a smartphone, hence no need for installation. Due to all these reasons, anyone with minimal basic knowledge can use the software to analyze the PV potential of any region, country, or state that covers the PVGIS database range. Web-basedPVGIS takes data on solar radiation to make estimates of the performance of PV systems and to do the other calculations possible [23].

The software uses an extensive database provided by Climate-SAF (CM-SAF). CM-SAF is the Satellite Application Facility on Climate Monitoring that uses data, based on calculations from satellite images [16]. The database represents twelve years data of global radiation, measured using meteorological geostationary satellites and ground stations [33]. Before September 2014, the PVGIS database included only the European and African regions and after September, it is expanded to cover all the Asian countries [34]. There are two parts of PVGIS one is for estimation of Europe and another is for evaluation of Africa and Asia. The Google map is clearly visible on the left side of the PVGIS page. Above the map, there are three input boxes. As is seen from Figure 7, Use either top box (search box) or two bottom input boxes to provide information regarding the coordinate (latitude and longitude) details of the location [34]. PVGIS provides four kinds of calculation tools [34] which are PV Estimation tool, Monthly Radiation tool, Daily Radiation tool, and Stand Alone PV tool.

PV estimation tool calculates six output parameters depending upon the coordinate location and type of PV system selected: average daily, monthly, and total annual electricity production and average daily, monthly and total annual sum of global irradiation per square meter.Other input parameters required to set before running calculator arePV technology, Installed peak PV power, estimated system losses, mounting option, and tracking option.

### 3.1. *Input parameters for PVGIS*

The input parameters for the PV system are the technology of solar panel used, installed peak power, mounting option and system losses. The options available under ‘PV technology’ are crystalline silicon cells, thin film modules made from CIGS, thin film modules made from CdTe, and other modules. The performance of the PV module varieswith respect to the technology selected. The dependence on temperature and solar irradiance changes as per the used technology. The “other module” option provides a fixed loss of 8% due to the temperature in the region [35].

Installed peak PV power is the nominal installed power of the PV module, power the PV module can produce under STC (Standard Test Condition). As per the datasheet of the module, with 1000W/m$^2$ solar irradiance, 25℃ module temperature, 1.5 air mass, one m$^2$ surface area, and 100% efficiency, the module produce a constant output power of 1KW [35]. The efficiency under STC can vary with respect to the technology used. In such cases, the module surface area can be changed to adjust the 1KW output. The peak installed power is given by

$$P_K = A \times eff_{nom} \tag{1}$$

Significant losses in the system occur due to cables and inverters. Depending upon location under study, the presence of dirt and snow on module adds to the losses. Although the default value given is 14%, theuser is free to provide the suitable value [35]. With mounting position option, the user can set the orientation of the fixed module as per need.

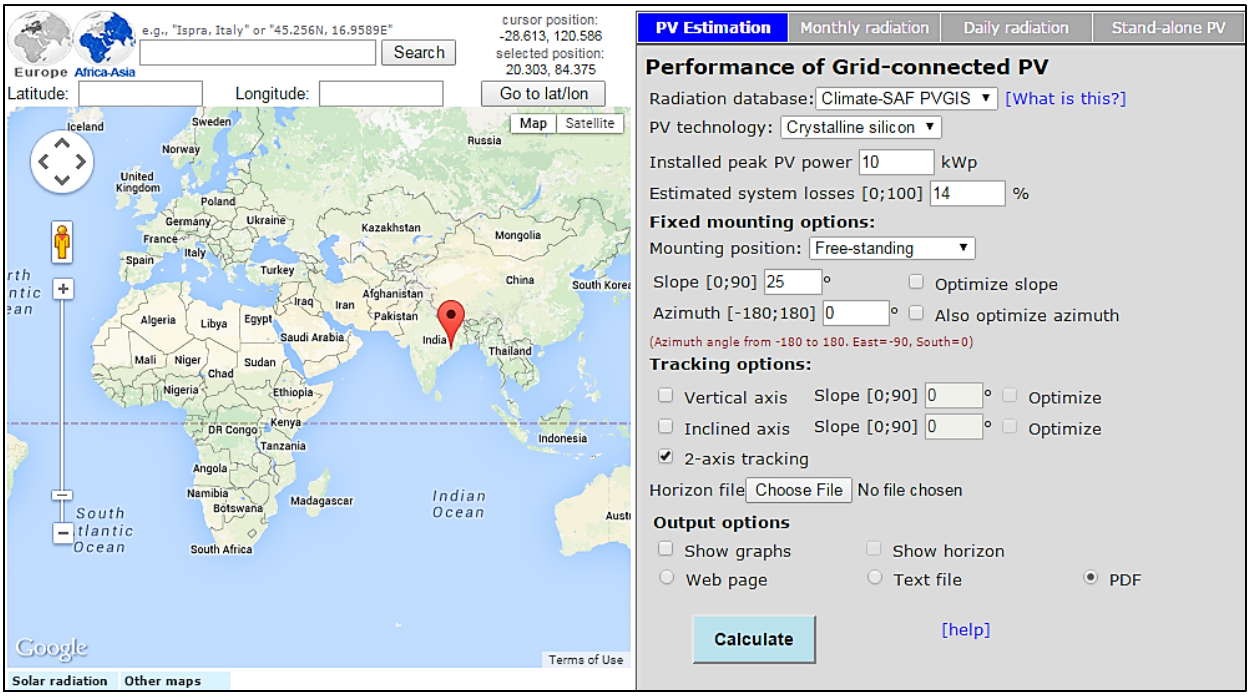


**Figure 7.** PVGIS interface**[35]**

There are two mounting options available with PVGIS: 1. Freestanding- the air flows freely behind the module, 2: Building Integrated - the restriction of air flow behind the module. The user can also set inclination angle with respect to the horizontal plane (in the range of $0^0$ to $90^0$), or can select optimal slope option to insert the optimal value as input. The user can input the azimuth angle of the module depending on the direction the module is facing which may fall in the range is from $180^0$ to $-180^0$. The direction of the south is $0^0$;East is -$90^0$; and the west is $90^0$ [34].

The user can choose from three different tracking options that allow the PV module to follow the movement of the sun [35]. In vertical axis tracking, the modules are mounted on a vertical rotating axis, at an angle. In inclined axis tracking, the modules are mounted on an axis that forms an angle with the ground and points in the north-south direction. The plane of the modules is assumed to be parallel to the axis of rotation. In two-axis tracking, the modules are mounted on a tracking system to ease the movement in the east-west direction with an optional tilt angle with respect to ground. The study considers four cases, tabulated in Table 2 to be implemented considering the orientation and mounting option of the PV system to estimate PV Energy potential of Odisha.

**Table 2.** Implementation of four cases according to the mounting position of PV module

| **Case no.** | **Mounting position** | **Tracking option** |
|---|---|---|
| I | Freestanding | Terrestrial, No tracking, 25° inclination facing south |
| II | Freestanding | Terrestrial, Two-axis tracking |
| III | Building-Integrated | No tracking, 25° inclination facing south |
| IV | Roof-top | Two-axis tracking |

### *3.2. The PVGIS energy rating method*

The PVGIS energy rating method defines the formulation of theactual power output of the PV estimation tool. The real power output of the PVGIS depends on the solar irradiance, temperature, and actual efficiency of the module.

$$P = G' \times A \times eff(G, T_m) \quad \text{or} \quad G' \times A \times eff_{nom} \times eff_{rel}(G, T_m) \qquad (2)$$

Where; $G' = G/1000$ and$T'_m = T_m - 25$

$$T_m = T_{amb} + K_T G \qquad (3)$$

$K_T$ is the temperature coefficient that depends on the mounting structure of the PV module.Based on measurements done at laboratory for freestanding mounting the value of the coefficient is 0.035 $^0$C/ (W/m$^2$) and based on values referred from literature [35]for the building-integrated system it is 0.05 $^0$C/ (W/m$^2$).Equating eq. (1) and (2)

$$P = G' \times P_K \times eff_{rel}(G', T'_m) \qquad (4)$$

The formula for estimating the relative efficiency(refer equation-5) provided by the PVGIS considers three major effects in the PV system: The temperature effect, low radiation effect, and the reflectance of the radiation from the surface of the module.

$$eff_{rel}(G', T'_m) = 1 + k_1 \ln(G') + k_2 ln(G')^2 + k_3 T'_m + k_4 T'_m \ln(G') + k_5 T'_m ln(G')^2 + k_6 T'^2_m \quad (5)$$

Where $k_1$ to $k_6$ are the coefficients that can be found out by comparing the measured value of different PV technologies used [35].

### 3.3. *Uncertainties in Data and Calculations*

Uncertaintiesin Data and Calculationsprovided PVGIS;affect all the measurements and calculations done inthe PVGIS to estimate the energy production. There are four kinds of uncertainties that majorlyinfluence the accuracy of the software: uncertainties due to Ground station measurements, Interpolation, diffuse radiation data, and long term average data.

During ground station measurements, most of the measurements are made with the pyranometer [33] where the source of error is the instrument itself. Taking proper care of instrument during measurements, reduces the effect of uncertainties. Some the uncertainties are random in nature e.g. Amount of the dust in the atmosphere due to local climatic condition and change in the elevation of the region. PVGIS database uses spatial interpolation technique between ground stations to get radiation data for the unknown region. The uncertainties due to spatial interpolation depend upon the number of ground stations in an area. The uncertainties in the measurement decrease as the number of stations present in a given region increase. The changes in the measurement increase as the distance between the station increases.

The uncertainties are higher in measuring diffused irradiation as compared to the direct. The diffuse radiation data can be found out from other metrological parameters producing uncertainty of 2% in the result.PVGIS uses long-term average data during calculation; however, it provides results of instantaneous in nature. The averaged value creates an uncertainty of 1 % in the result. Interdependency of the parameters, e.g. $T_m$ and $G$, provide additional uncertainties [35].

## 4. Methodology for plotting the rasterized maps

Themethodof plotting maps divides the total area of Odisha into 1195 Square regions, defined by midpoint coordinate; the Area of individual is approximately 130 Km$^2$. The procedure to plot the various maps is as follows;

1. *Defining the area under study:* To set the area under study four coordinate positions (latitudes and longitudes) are selected such a way that the rectangular box created by joining the positions should contain the defined region. In Figure 8 X1 and X2 define the minimum and maximum latitude position and Y1 and Y2 defines the minimum and maximum longitude location respectively. For Odisha, therangeis selected from 17.811N to 22.568N in latitude and 81.431E to 87.495E in longitude.


Figure 8 indicating the coordinates that define the total area of Odisha

2. *Dividing the area under study:*Figure 9divides the defined area into m×n equal and square grids. The division of grid depends upon the proportion ratio of the difference in the latitude and longitude. To do so, first the difference between ranges is calculated (For Odisha the division is 50×50 and the difference in the latitude and longitude is4.757N and 6.064E respectively). The difference in the latitude and longitude is divided by m and n respectively to get the distance between each coordinate that is the increment or decrement between each coordinate. These values are found to be 0.09514N and 0.12128E for Odisha.

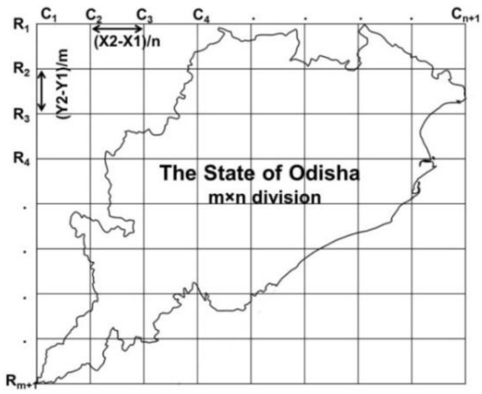


Figure 9 Division of Odisha into m×n squarish grids

3. *Defining the center point of corner grid area:* Step 3defines the new value forlongitude and latitude. Placing each coordinate at the midpoint of each grid is necessary. In Figure 10 the previous value of latitudes and longitudes (X1,X2,Y1, and Y2) are changed to new values (X1',X2',Y1', and Y2'). The following formula define the above purpose;

$$(New\ latitude)_{max} = (latitude)_{max} - (increment\ in\ latitude \div 2) \quad (6)$$

$$(New\ latitude)_{min} = (latitude)_{min} + (increment\ in\ latitude \div 2) \quad (7)$$

$$(New\ longitude)_{max} = (longitude)_{max} - (increment\ in\ longitude \div 2) \quad (8)$$

$$(New\ longitude)_{min} = (longitude)_{min} + (increment\ in\ longitude \div 2) \quad (9)$$

The new starting and ending ranges of Odisha are 17.8586N to 22.5204N in latitude and 81.4916E to 87.4343E in longitude.

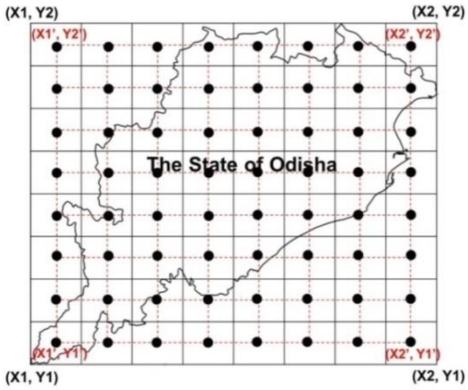


Figure 10defining the center points of corner grid area

4. *Removing unwanted region:* Step 4 removesall the squares that fall outside the region of Odisha. All the grids falling within the area of Odisha are selected in the form of rows and columns ($R_m$, $C_n$) as shown inFigure 11.

With the row and column data, all the required coordinates can be found by using the equation 10 and 11. The unwanted coordinates are removed from the analysis shown inFigure 12 . All the formulated coordinates are saved in the Excel format for further processing.

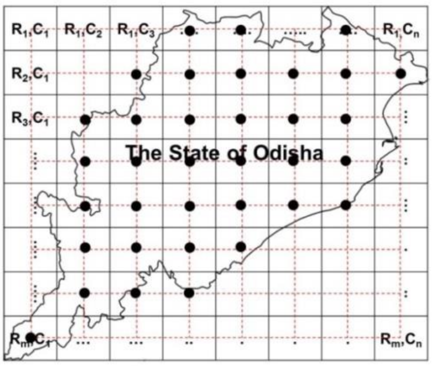


Figure 11 defining each grid into rows and columns

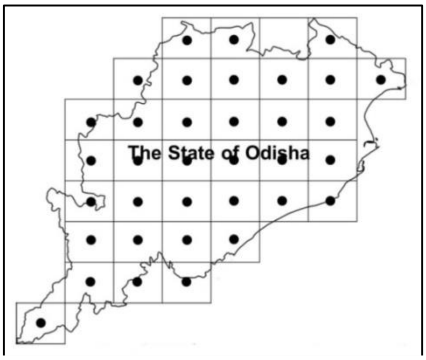


Figure 12 Removal of unwanted regions of Odisha

$$longitude = (New\ longitude)_{min} + [(column\ no. - 1) \times increment\ in\ longitude] \quad (10)$$

$$latitude = (New\ latitude)_{max} - [(row\ no. - 1) \times increment\ in\ latitude] \quad (11)$$

Some error in estimation may arise due to the squares lying on the boundary of the state. The error can be minimized by decreasing the area of the grid under consideration i.e. increasing the density of grid or by increasing the resolution.

5. *Creation of database with the potential estimation parameters:* By using the all the coordinates saved in the Excel file the potential estimation parameters like total electricity production for the year and total global radiation received for the year are estimated using PVGIS. The user can get coordinate-wise temperature, elevation, and land cover data from the SolarGIS [27]. The newly acquired parameters with respect to coordinates are updated in the Excel file before plotting the map.

6. *Preparing the final rasterizedmap:* Google-My Maps [26] is an online map-plotting tool that uses data imported from Excel files to generate the icons at the selected coordinates. The database created in the previous step can be imported into the mapping tool to plot the final rasterized map. The toolcreatessymbols and colors, eight in the current case, depending on the range of the data.

## 5. Results and Discussion

The procedure described in theearlier section is used to produce the various maps of theoutput parameters for all four cases that define the potential of PV production using the PVGIS PV estimation tool.The proposed methodology can be applied to any region, small or large to plot the rasterized maps. The PVGIS and SolarGISgive information in anumerical format for only one place at a time; however, the methodology gives the representation of the estimated data for a region under study to understand the scenario better as a whole. For example, the temperature map provided in Figure

6 denotes more fluctuation in average air temperature data in the southwest region compared to the restof Odisha.The cause of the variation in temperature is attributed to the presence majority of forest-land and change in elevation due to thepresence of hillyregion. Forest-land should be ignored from the potential region for plant establishment for important reasons such as cause fordeforestation, animbalance in theecosystem, and impact on ecology.Rest of the section puts forward the analysis of the PV potential maps for the state of Odisha and shows the usefulness of the maps to suggest the strategy for installing freestanding PV system throughout the state.

Figure 13displays the estimation of total yearly incident Global radiation on the map of Odisha for case-I and case-III. The Optimal inclination angle for the PV panel in Odisha varies in between $22^0$ to $27^0$ [34]. Aninclination of $25^0$ is provided to the system because the angle is approximately the mean within the range of optimal PV panel angle for Odisha.Theazimuth angle of $0^0$is provided as aninput parameter so that the system would face the direction of south. The incident radiation range is from 1820 kWh/m$^2$ to 2180 kWh/m$^2$.Figure 14 shows the estimation of total yearly incident Global radiation on the map of Odisha for case-II and case-IV. The calculation assumes that the modules do not concentrate only on the light directly from the sun but can utilize all the light falling both directly from the sun and the rest of the sky. Comparison of Figure 13and Figure 14 indicates the improvement of estimated radiationvalues (1820-2180 kWh/m$^2$ to 2140-2850 kWh/m$^2$) due to the addition of two-axis tracking system.

Figure 15 shows the estimation of total annual PV energy production for the case-I, fixed system with $25^0$ inclination facing the direction of South. The northwest side of Odisha has more potential for PV Energy production. The southwest side shows less potential for PV Energy Production and the variation in potential is quite high.Change in elevation in the region due to thepresence of mountains primarily affects the PV energy output(Figure 4). The range of PV production is in between 1300 kWh/kW$_p$ to 1550 kWh/kW$_p$.Similarly,Figure 16 shows the estimation of the total annual PV energy production for case-II, a system with two-axis tracking. The range production of PV energy showsimprovement(1510 kWh/kW$_p$ to 2030 kWh/kW$_p$) compared to the case-I due to theinvolvement of tracking system. The estimations around coastlines are quite uniform and fall within the mid-range. Due to the high value of average temperature in the coastline area, which also happened to be flat, the estimates for energy potential shows uniformity.

Case-III uses Building integrated type of mounting position in the PV modulethat causes the temperature of the module rises faster and more in comparison to previous cases (case-I and case-II). The structure implements additional losses in the PV energy production of the PV module. Figure 17 shows the total annual PV energy production for a fixed $25^0$ inclined module, facing the south direction. The range of estimated value of PV production decreases from 1300-1550 kWh/kW$_p$ to 1220-1460 kWh/kW$_p$substantially because of the building integrated mounting.Case-IV provides PV energy production estimate for the PV module with two-axis tracking with the building-integratedtype mounting position (referFigure 18). For the building-integrated structure, having highertemperature coefficient ($K_T$), the total production range decreases to 1400-1880 kWh/kW$_p$. With two-axis tracking the produced output value depends more on the effect of global radiation, so the distribution of color ranges in map plotted in Figure 14 is almost similar to the map in Figure 18.

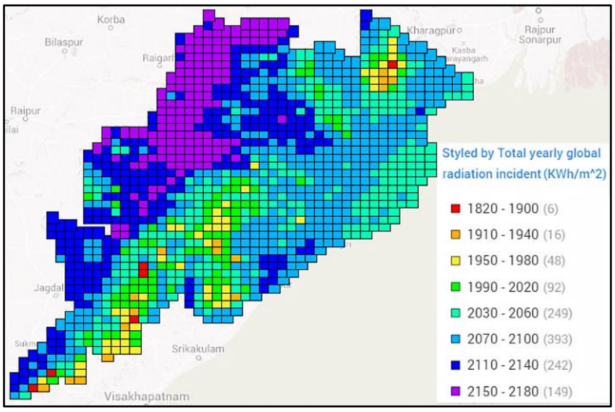


**Figure 13.** Total Yearly Global Radiation map of Odisha plotted for case-I and case-III

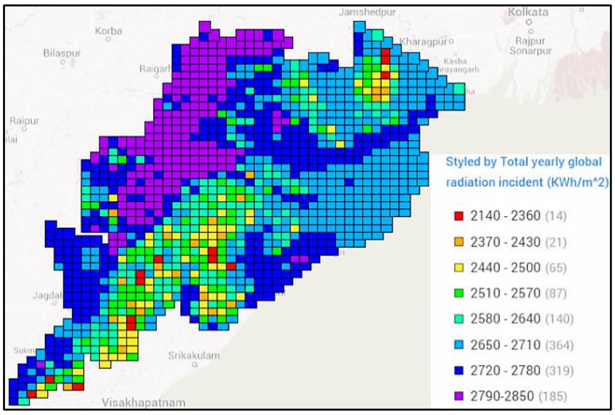


**Figure 14.** Total Yearly Global Radiation map of Odisha plotted for case-II and case-IV

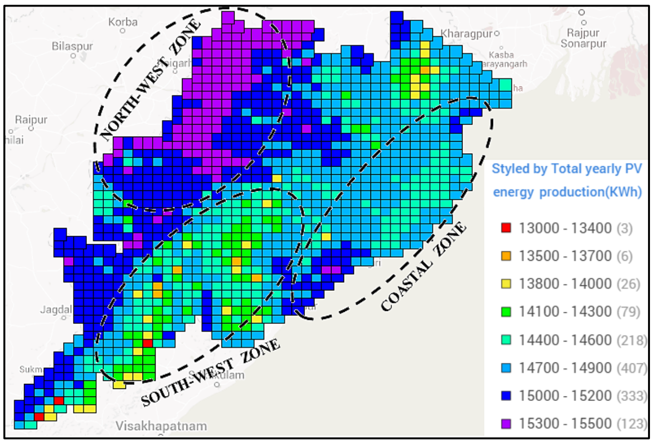


**Figure 15.** Total Yearly PV Energy Production map of Odisha plotted for case-I

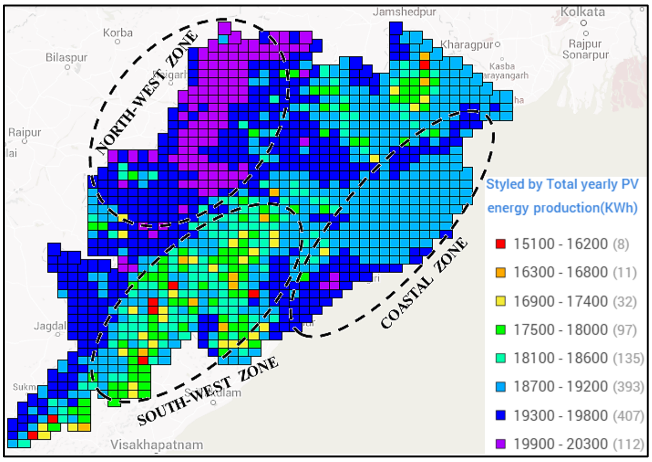


**Figure 16.** Total Yearly PV Energy Production map of Odisha plotted for case-II

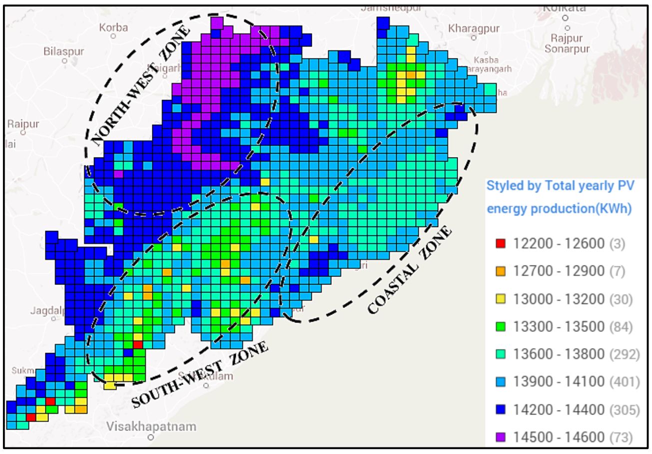


**Figure 17.** Total Yearly PV Energy Production map of Odisha plotted for case-III

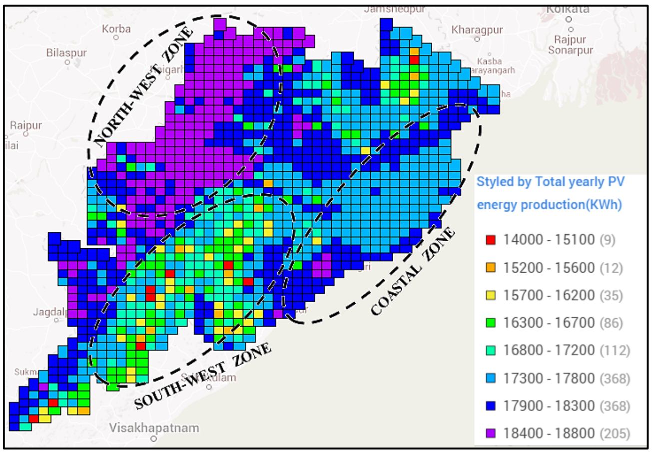


**Figure 18.** Total Yearly PV Energy Production map of Odisha plotted for case-IV

**Table 3.** Strategy for installing freestanding grid connected PV system based on developed rasterized maps for the state of Odisha

| | | Non-Tracking PV system | | | Two-axis Tracking PV System | | | Forest and Wetland Zone | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | Low Potential Zone | Medium Potential Zone | High Potential Zone | Low Potential Zone | Medium Potential Zone | High Potential Zone | | |
| Production Ranges (kWh) | | *13000-14000* | *14100 - 14900* | *15000 - 15500* | *15100 -17400* | *17500 - 19200* | *19300 -20300* | | |
| Area in $Km^2$ | Actual value | 438 | 48945 | 44708 | 292 | 38572 | 55227 | 61616 | **155707** |
| | Estimated value | 390 | 43550 | 39780 | 260 | 34320 | 49140 | 71630 | **155350** |
| | % of error | 10.96 | 11.02 | 11.02 | 10.96 | 11.02 | 11.02 | 13.98 | **0.23** |
| No.of Blocks | | 3 | 335 | 306 | 2 | 264 | 378 | 551 | **1195** |
| Percentage of area (%) | | 0.25 | 28.03 | 25.61 | 0.16 | 22.1 | 31.63 | 46.11 | **100** |
| Major Districts falling within the zone | | Kalahandi, Koraput | Angul, Cuttack, Baleswar, Dhenkanal, Kendujhar,Bhadrak, Ganjam, Jagatsinghpur, Mayurbhanj, Kendrapara, Nayagarh, Jajpur, Koraput, Khordha, Puri, | Boudh, Balangir, Deogarh, Bargarh, Ganjam, Jharsuguda, Kalahandi, Nabarangpur, Sambalpur, Subarnapur, Nuapada, Sundargarh | Kalahandi, Koraput | Cuttack, Baleswar, Dhenkanal, Bhadrak, Jagatsinghpur, Kendrapara, Jajpur, Kendujhar, Khordha, Koraput, Puri, Mayurbhanj, Nayagarh | Angul, Balangir, Baleswar, Deogarh, Bargarh, Dhenkanal, Ganjam, Jharsuguda, Khordha, Kalahandi, Puri, Nabarangpur, Sambalpur, Subarnapur, Nuapada, Sundargarh | Kandhamal, Angul, Boudh, Deogarh, Gajapati, Ganjam, Kendujhar, Kalahandi, Koraput, Malkangiri, Puri, Mayurbhanj, Rayagada, Nayagarh, Sambalpur, Nuapada, Sundargarh | – |
| Populated cities | | – | Berhampur, Cuttack, Bhubaneswar, Balasore, Baripada, Bhadrak, Puri | Berhampur, Sambalpur, Rourkela | – | Cuttack, Bhubaneswar, Balasore, Baripada, Bhadrak, Puri | Berhampur, Balasore, Puri Bhubaneswar, Sambalpur, Rourkela | – | – |
| Major Industrial Zone | | – | Talcher, Choudwar, Balasore, Chandikhol, Duburi, Paradeep, Khurda, Joda | Jharsuguda, Rourkela, Hirakud | – | Choudwar, Balasore, Chandikhol, Duburi, Paradeep, Khurda, Joda | Jharsuguda, Talcher, Rourkela, Hirakud, Balasore, Khordha | – | – |
| Urban Zone | | – | Cuttack, Bhubaneswar, Balasore, Baripada, Bhadrak | Sambalpur, Rourkela | – | Cuttack, Bhubaneswar, Balasore, Baripada, Bhadrak | Balasore, Bhubaneswar, Sambalpur, Rourkela | – | – |
| Commissioned Solar power Plants | | – | Khordha, Cuttack, Nayagarh | Balangir, Deogarh, Sambalpur, Subarnapur, Sundargarh | – | Khordha, Cuttack, Nayagarh | Balangir, Deogarh, Sambalpur, Subarnapur, Sundargarh | – | – |

The total region of PV production is divided into four zones: i.e. Forest and wetland zone, Low potential zone(three color ranges from the top of legend), Medium potential zone( three color ranges in the middle of the legend), and High potential zone (two color ranges at the end of the legend).Table 3represents the overall analysis of the plotted PV production in Odisha. The estimationof the freestanding PV system alone is considered in the analysis as its production ability is much better as compared to building-integrated PV system. The estimated area provided inTable 3is the product of the number of square blocks in theestimated zone with the area of each square (130km$^2$).The comparison of theactual area of the defined zones with the estimated one establishes an average error of 11.4%. The percentage of the area of thelow potentialzone is very less (0.16% and 0.25%) compared to other zonesthat show the higher production capability of PV Energy in Odisha. The distribution of area for themedium potentialzone(28.03 %) is largest for non-tracking PV system; however, with two-axis tracking PV system the high potential zone (31.63 %) covers more portion of the land.

The medium potentialzone falls within and around the coastal region of Odisha. The elevation and temperature in the above region are uniform keeping the PV production uniform. The zoneconsists of mostlythe urbanregion of Odisha with high the population density. There are some major industries located in the medium potential zone e.g. Ferro Alloys, Thermal Power, Pulp and Paper, Coke Oven, Iron, Mineral Processing, and Rubber Industries. The urbanization and the coastal placement of the region make the price of the land extremely high which createsa significant disadvantage while planning theinstallation of big solar power plants in $MW_p$ range. Proper policy making plan and supportive approach of the Government could only make the installation of solar PV plant possible in the region. In the southwest region, mostly categorized as the forest zone of Odisha, all the low potential zone falls making it unsuitable for installation of new power plants.The observed variation in production is a result of thehigher rate of variation in the elevation compared to other zones.The northwest side of Odisha falls into the category of the high potential zone. All the major industries fall within the medium potentialzone e.g. Rourkela steel plant, Hirakud Dam, Thermal Power Plant, Sponge Iron, Aluminum and Coal Washeries and so on. The potential of the northwest side to install a new solar power plant is highin the production of PV energy is high, and the population density is less compared to other non-forest areas in Odisha. The good availability and low price of the land makenorthwest region perfect for establishing new and large PV plants.

The plotted rasterized maps were useful for analysis, decision making for individual or PV projects, and policy making for a state. The mapping method can be extended to the analysis of battery integrated PV systems. The Mapping method can also be extended to other similar studies for a state like thepotential of wind energy, production of power from algae,etc. However, there are certain limitations of the methodology especially when using tools from different platforms. The database required for mapping need to be collected from some software like PVGIS or SolarGIS manually and coordinate-wise. The collection of data is time-consuming when aiming for maps of higher resolutions and challenging for month-wise estimation. Google-My Maps has a limitation of plotting maps with only 2000 data points or less simultaneously. The user can use QGIS Software to plot for ahigher number of data points at a time. Software (online or offline) can be developed which can calculate the energy yield on inputting the necessary parameters and implements the methodology to plot the rasterized maps directly and without any limitations.

## 6. Conclusions

In the study, a new method of using PVGIS to estimate the PV energy production potential is shown for the region of Odisha. With the implementation of the methodology, the estimated results are plotted in the formof rasterized maps. All the software and tools used in the method are readily available online and are free to use. The methodology applies to any state, country, and region that covers the database of PVGIS or any related software. The usefulness of the rasterized maps plotted using proposed method comprehends analysis of the land, decision making for individual or PV projects, and policy making for the state. A case study of 1195 locations in Odisha is taken to verify the application of the methodology. The PV Energy potential with freestanding system throughout the area of Odisha falls within a range from 1300 kWh/kWp to 1550 kWh/kWp for a fixed PV system and from 1510 kWh/kWp to 2030 kWh/kWp for a PV system with two-axis tracking. The percentage of the areaof high potential zone increases when equipped with the two-axis tracking PV system. Considering estimated PV potential, availability of land, presence of industrial area, and population density, northwest region of Odisha is qualified to construct new PV power plants.

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