Evaluation and Analysis of the Photovoltaic Potential for Odisha

Rakesh Kumar Tarai

Department of Electrical Engineering
National Institute Of Technology Rourkela

Evaluation and Analysis of the Photovoltaic Potential for Odisha

A Thesis submitted to the

National Institute of Technology Rourkela

in partial fulfillment of the requirements

of the degree of

Master of Technology

in

Electrical Engineering (Industrial Electronics)

by

Rakesh Kumar Tarai

Roll No. 214EE5495

Under the Supervision of

Prof. Paresh Govind Kale

May 2016

Department of Electrical Engineering

National Institute Of Technology Rourkela

Department of Electrical Engineering
National Institute Of Technology Rourkela

May 19, 2016

Certificate of Examination

Roll Number: 214EE5495

Name: Rakesh Kumar Tarai

Title of Thesis: Evaluation and Analysis of the Photovoltaic Potential for Odisha

We the below signed, after checking the thesis mentioned above and the official record book of the student, hereby state our approval of the dissertation submitted in partial fulfillment of the requirements for the degree of Master of Technology in Electrical Engineering at National Institute of Technology Rourkela. We are satisfied with the volume, quality, correctness, and originality of the work.

Examiner

Paresh Govind Kale

Supervisor

Jitendriya Kumar Satpathy

Head of the Department

Department of Electrical Engineering
National Institute Of Technology Rourkela

Prof. Paresh Govind Kale

Assistant Professor

May 19, 2016

Supervisor's Certificate

This is to certify that the thesis entitled, **"Evaluation and Analysis of the Photovoltaic Potential for Odisha"** submitted by **Rakesh Kumar Tarai** in partial fulfilment of the requirements for the award of Master of Technology degree in **Electrical Engineering** with specialization in **Industrial Electronics** during 2014-2016 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. Neither this thesis nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Paresh G. Kale

Dedicated to my family and friends

Declaration of Originality

I, Rakesh Kumar Tarai, Roll Number 214EE5495 hereby declare that this thesis entitled "*Evaluation and Analysis of the Photovoltaic Potential for Odisha*" represents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, it comprises no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the section "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in the case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present thesis.

November 12, 2015 Rakesh Kumar Tarai

NIT Rourkela

Acknowledgement

There are many people who associate in the project directly or indirectly, whose support, and timely suggestions are highly substantial for completion of this project.

First of all, I would like to thank Prof. J.K. Satpathy, Head of Department of Electrical Engineering for his kind support, advice, and valuable discussions that are highly commendable.

I would like to express my sincere gratitude to my supervisor Prof. Paresh Govind Kale for his supervision, encouragement, and support that has been a key factor in the success of this project.

I would like to thank Vishal Minz for his help and support throughout my Thesis work.

Lastly, I would also like to express my gratitude to Mr. S.N. Mohanty, the developer of the 'SN Mohanty Solar power plant' for providing data related to the plant.

Lastly, I would also like to thank my family for their love and support and encouragement that inspired me in gaining confidence in myself.

Rakesh Kumar Tarai

Roll No. 214EE5495

Abstract

Solar energy is a potential resource for 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 plan through proper assessment of solar PV Energy potential. The study uses the estimate of the PV potential of an area under consideration using the PVGIS online software. The study divides the total geographic area of into a grid of ‘mxn’. The PVGIS evaluated the value of incident solar radiation and generated PV energy at central coordinate of each grid. The evaluation of energy potential for four cases (based on mounting and tracking) uses two critical parameters: annual incident Global radiation and annual PV Energy production. A methodology is presented to plot the rasterized maps of the solar energy potential. The study further discusses a case study of Odisha to show the usefulness of the proposed methodology to develop a district wise strategy for promoting the installation of grid-connected PV system.

The decision to install a PV plant depends on three major factors: the climatic and environment conditions of the location, the viability of commercial operations, and the government policies. Considering uncertain nature of geographical parameters development of a reliable model to predict the energy output of a plant-to-be installed becomes essential. The study proposes models that consider only two meteorological variables collected from 1195 locations of Odisha: total annual incident global radiation on the PV module and annual average air temperature. The thesis focuses on simplification at every stage of the development while validating the preciseness of the model. A case study of NIT Rourkela is considered to apply a various methods for the evaluation of PV potential. Again the current solar policy framework of India is reviewed along with the challenges the nation has to face for achieving the targets.

Key Words: PVGIS; PV potential; Estimation; Rasterized Maps; Odisha; Predictive Model; Validation; Solar Policy; JNNSM

Contents

List of Figures

List of Tables

List of Abbreviation

AM	Air Mass
CMSAF	Satellite Application Facility on Climate Monitoring
CSI	Clear sky Index
c-Si	Crystalline Silicon
FSFM	Further Simplified Model
FY	Full year
GHI	Global Horizontal Insolation
GIS	Geographical Information System
HRA	Hour angle
IAM	Incidence Angle Modifiers
ICI	Insolation clearness index
JNNSM	Jawaharlal Nehru National Solar Mission
LAR	Least Absolute Residuals
MNRE	Ministry of New and Renewable Energy
MPP	Maximum Power Point
NASA	National Aeronautics and Space Administration
NISE	National Institute of Solar Energy
NITI	National Institution for Transforming India
PR	Performance Ratio
PV	Photovoltaic
RMSE	Root Mean Square Error
SCADA	Supervisory Control And Data Acquisition
SERC	State Electricity Regulatory Commission
SFM	Simplified Model
STC	Standard Test Conditions
TOA	Top of Atmosphere

List of Symbols	Description	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}, T_a	Ambient Temperature	^0C
P, P_{inv}	Actual power of the module	kW
G	Global irradiance	kWh/m^2
K_T	Temperature coefficient of the module	$^0C/(W/m^2)$
δ	Declination angle	^{0}
α	Elevation angle	^{0}
Θ	Azimuth angle	^{0}
y	Power Temperature Coefficients	$\%/^0C$
T_{ref}	Reference Temperature	^0C
P_g	Generated Power	kWh
$P_{inv,nom}$	Nominal Power of the PV	kW

Chapter-1

Introduction to Basics on Solar Radiation

The Sun is an essential source of vitality close to our planetary system. Its temperature is very high more than twenty million° K. Nuclear fusion reaction at the core of the sun releases an extremely high amount of thermal energy which is called the solar energy. Because of the vast amount of energy of the sun, the solar energy is considered to be the best among all the renewable source of energy available on earth.

This amount of energy can be estimated by using Einstein's formula shown in Equation-1

$$E = mC^2 \approx 3.8\, x\, 10^{20}\, MW \quad (1)$$

Where, *m* is the mass lost from the source, and *C* is the speed of the light emitted from the source. This energy is transferred from the surface of the sun to all the other places in the space. The emitted radiation from the Sun or sunlight is the combination of all kinds of electromagnetic waves like infrared, ultraviolet rays, X-rays, and so on. According to the opinion of the Einstein, the speed of light is "The maximum speed attainable of anything except space". The speed of all kinds of electromagnetic waves in the vacuum is of approximately 3.0×10^8 m/s.

The average distance from the sun to the earth, by considering one orbital motion of the earth in a year is about 150 000 000 Km. Thus, it will take about 8 minutes for radiation from the Sun to get to Earth. When this radiation reaches earth, part of it gets absorbed by the planet's atmosphere (mostly due to the presence of ozone). After that, the remaining sunlight or solar radiation is blocked by clouds or reflects off other objects, making the radiation diffusive in nature. When the solar radiation is not absorbed, it becomes direct sunlight that is the mixture of bright solar light and thermal radiant heat that heat up the surface of the earth. Some amount of this heat stays at the surface while the rest is reemitted. Upon reaching the atmosphere, again part of it gets absorbed, and part of it passes through it. By this way, the absorbed radiation heat adds to the heat already there. This phenomenon is very familiar and known as the greenhouse effect that occurs due to the presence of the greenhouse gasses like CO_2, CH_4, NO_2, CFC, etc. Due to the presence of these gasses the atmosphere absorbs heat more than necessary and reduces the EM energy of the sun. The total of energy that the population of the earth uses over an entire year is less than the total solar energy reaching the surface of land in the interval of every hour.

All the solar-based devices like solar collectors, solar PV, and solar thermal devices are based on solar radiation. The overall performance of these kinds of devices depends solely on the total incident solar radiation at a given location and time. Thus, it is required to have a clear fundamental regarding the basic of solar radiation. The topic represents the significant about the characteristics and properties of solar radiation. Later we are going to discuss regarding the terrestrial solar radiation that will come in handy later.

1.1 Properties and Characteristics of Sun Light

The solar energy is radiated in the form of waves known as electromagnetic energy. The properties of the electromagnetic waves include frequency, wavelength, and propagation speed, which can be combined to create the following relation as shown in Equation-2.

$$C = \lambda . f \tag{2}$$

The propagation speed (*C*) of electromagnetic waves is a constant and equal to the speed of light in a vacuum. Thus, we came to a conclusion that frequency (*f*) is inversely proportional to wavelength (λ). Simply for each frequency there exist one, and only one wavelength. The diagram represented in the Figure 1 shows the typical wavelengths and corresponding frequencies of important spectra of solar radiation.

There are many vital characteristics of the incident solar radiation which are necessary for determining its interaction with a photovoltaic converter or any other object. The key aspects of the incident solar radiation are:

i. The spectral irradiance of the incident light;
ii. The total power density from the sun;
iii. The angle at which the solar radiation strikes a PV module
iv. The radiant energy from the sun throughout a year or day for a particular surface.

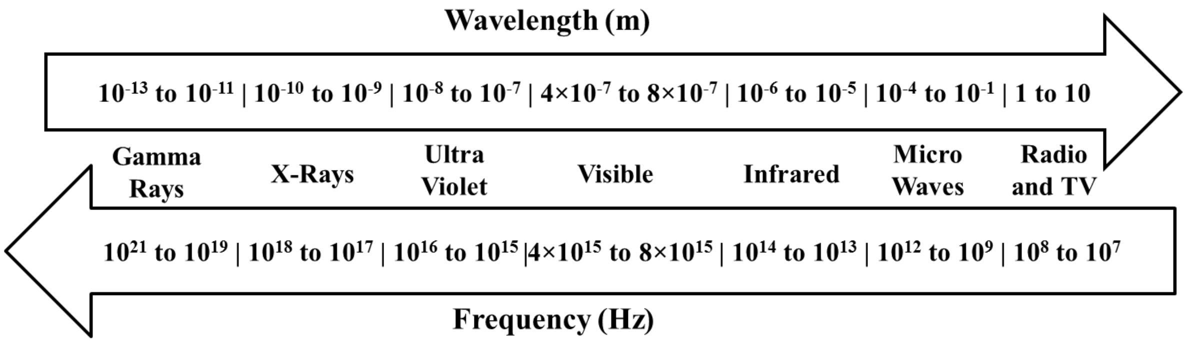


Figure 1 The electromagnetic spectrum of sunlight

1.1.1 Energy of photon

In the early 1800's Thomas Young, François Arago, and Augustin-Jean Fresnel indicated that light is made of waves by showing the interference effects. Thus, the description of light as a wave first gained acceptance. In late 1860, the light was viewed as part of the electromagnetic spectrum, however in 1900, and in 1905, Planck proposed that the total energy of light is made up of same energy elements. These energy elements are called quantum energy or quanta. In the lateral years Einstein, correctly distinguished the values of these energy elements while examining the photoelectric effect. Due to this contribution of research Planck and Einstein both won the Nobel Prize for physics and thanks to their work, light is now viewed as consisting of packets of energy, called photons.

These photons can appear as either wave or particle. This concept is called the *wave-particle duality* of the photon. The quantity of energy that a photon can store affects its color as shown in Figure 2. The storage of energy by a photon is inversely proportional to its wavelength. According to Plank:

$$E = \frac{hC}{\lambda} \tag{3}$$

Where E = energy of photon, and

h = Plunk's constant =6.626×10^{-34} joules

From the above relationship, it is concluded that for the higher energy of the photon, the wavelength is shorter and for the lower energy of the photon, the wavelength is greater.

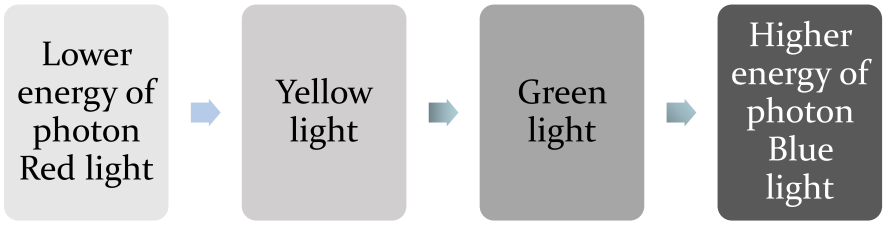


Figure 2 Energy levels of photon and change in its color

1.1.2 Photon flux

Photon flux is the measure of the number of incident photon per second per unit area. We know that the current produced by the solar cell is directly proportional to the quantity of the incident photon. Thus, it is an important aspect of radiation. It requires a small number of photons with the higher energy and a large number of photons with the lower energy to produce the same amount of current by a solar cell. The measure of this property is called power density that can be calculated by multiplying photon flux with photon energy (refer Equation-4).

$$H = \phi \times E \tag{4}$$

Where H is the Power density, and ϕ is the Photon flux

1.1.3 Spectral irradiance

Spectral irradiance is the function of the wavelength of the photon. It is denoted by the variable '*F*'. It is often needed during the analysis of the solar radiation because it gives the power density of the photon per given wavelength. Its unit is $W/m^2/nm$ and formulated in Equation-5.

$$F(\lambda) = \frac{H}{\lambda} \tag{5}$$

Figure 3 shows the estimated graph of the spectral irradiance vs. the wavelength with the data collected from Renewable resource data center [**1**]. The characteristic of the graph is closely similar to that of a black body. So we can say that the sun is equivalent to a black body as it absorbs all kind of radiation at its surface, and emits them depending on its temperature. The typical function of a black body is shown in Equation-6.

$$F(\lambda) = \frac{2\pi hC^2}{\lambda^5(e^{\frac{hC}{k\lambda T}} - 1)} \quad (6)$$

Where T is the temperature of the black body

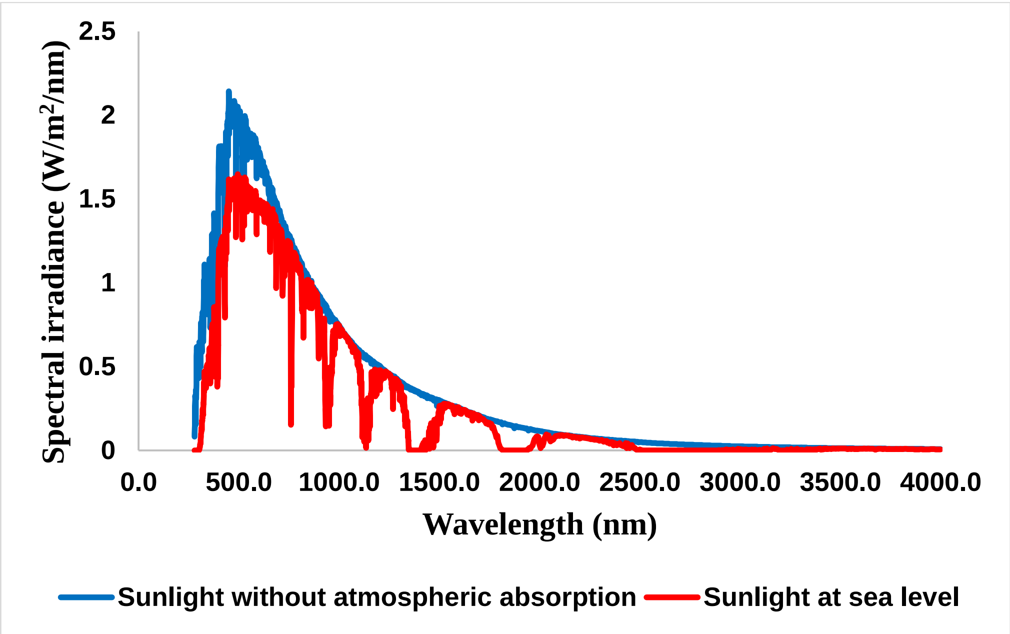


Figure 3 Spectral irradiance of the solar radiation

By integrating this function with respect to all the wavelength, the total power density can be estimated as shown in Equation-7;

$$H = 6T^4 \quad (7)$$

Where Ϭ is the Stefan-Boltzmann constant.

At the sun's surface, the total power density is the multiplication of the power density of a black body with the sun's surface area. However, at some distance from the sun, the total power from the sun is distributed over a larger surface area. So it can be said that the amount of solar irradiance on a body decreases as the body moves further away from the sun (refer Figure 4). Let the distance between the object, and the sun is D. Then the solar radiation intensity H_o incident on that object can be determined as;

$$H_0 = \frac{R^2}{D^2} H_{SUN} \quad (8)$$

Where *R* is the radius, and H_{SUN} is the total power density at the surface of the sun [**2**]

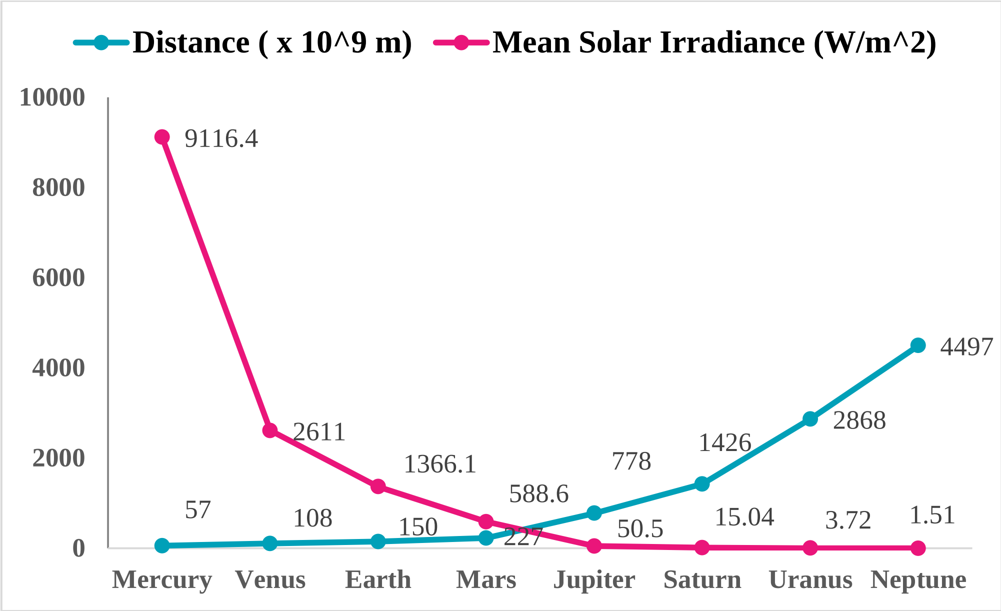


Figure 4 Comparison between the distance from the sun and mean solar irradiance of all the planets of solar system

1.2 Solar radiation at the surface of the earth

The variation of the solar radiation on the earth's surface is due to some common factors such as atmospheric effects (including absorption and scattering), change in regional climate due to clouds and pollution, the coordinate of the location, the season of the year and the time of day. Due to these factors, there arises some variation in the incident solar radiation at the surface of the earth like Variations in the overall power, Change in spectral content and the angle of incidence of the light, and Increase in the variability of the solar radiation at a particular location.

When the solar radiation reaches the atmosphere of the earth, it gets absorbed by various components of dust, gasses, and molecules. The gasses like carbon dioxide, ozone, and water vapor have very high absorption capability of the photons with high energy. Apart from absorption some amount of gasses gets reflected back to space. Figure 5 shows these effects of atmosphere with incoming solar radiation. The absorption capacity of the air significantly depends on the angle of incidence and path length of the radiation. When the sun is at overhead, the absorption capacity of the air becomes uniform that makes the incident ray appears to be white. Similarly for longer path length like during sunrise and sunset, the atmosphere absorbs the high-energy of the photon that makes the incident radiation seems to be red. The scattering of the light is called diffusive light. It is undirected by nature that's why it appears to be coming from any region of the sky. Due to this effect, the sky appears to be blue. Among all the incident radiations about 10% is scattered on a bright day.

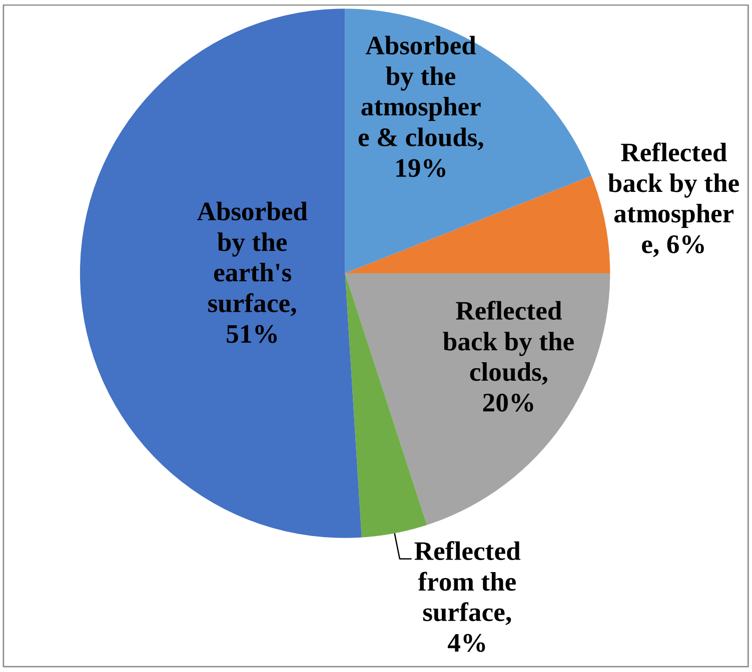
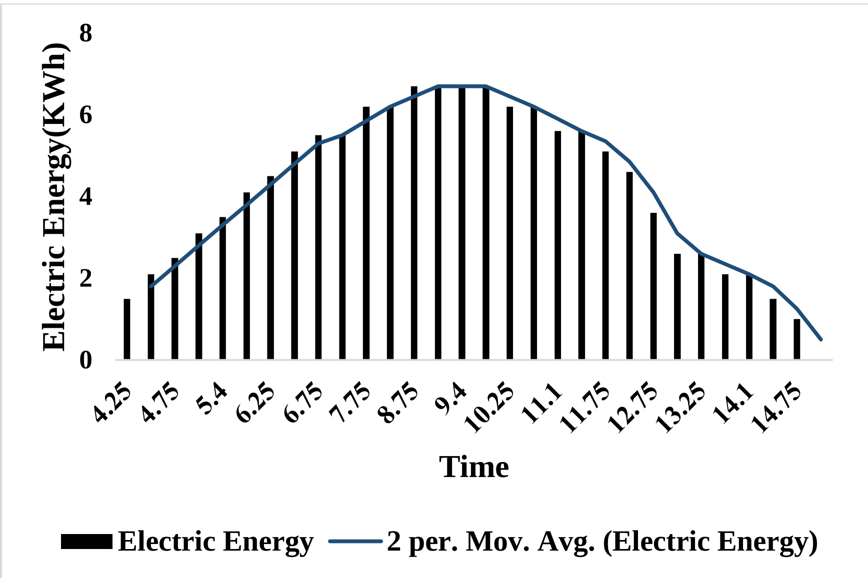
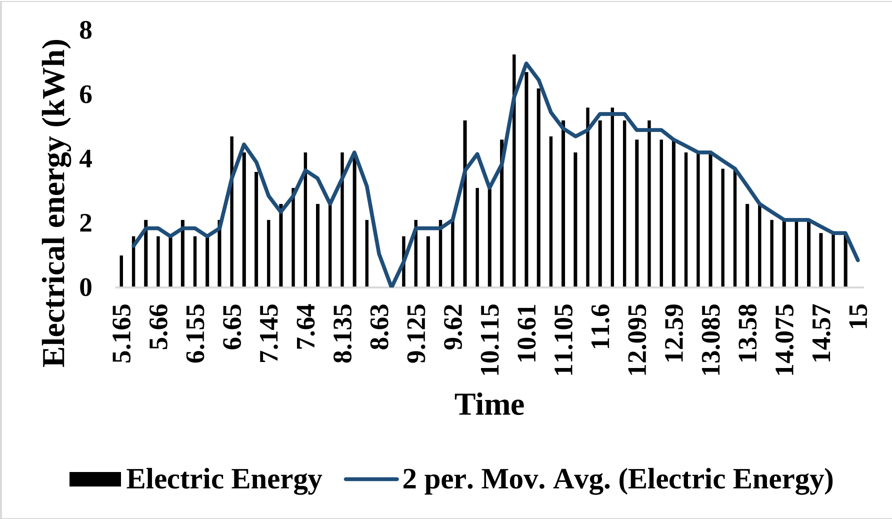


Figure 5 Typical absorption and reflection of solar radiation

The last effect of the atmosphere on incident solar radiation is because of the local variations in the environment. During a cloudy day, the incident power is severely reduced. An example of such data is shown in Figure 6.



(a)



(b)

Figure 6 relative output power from a photovoltaic system on (a) clear day, and (b) cloudy day

1.2.1 Air mass

The air mass is the shortest possible path length the solar radiation takes to reach a particular point on the surface of the terrain. It detects the degree of power reduction of the radiation. As per Figure 7 the path length of the radiation, when the sun is directly overhead from that point is taken as the reference value. Then the angle between both the path lengths is measured. The data can be used to evaluate the air mass as shown in Equation-9:

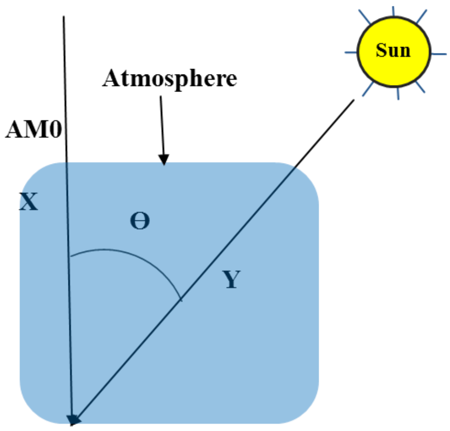


Figure 7 Determination of Air Mass

$$AM = \frac{1}{cos(\Theta)} \tag{9}$$

Where ϴ is the angle between both the paths. This calculation assumes the atmosphere to be ideal that is ignoring refraction of light, however in practical case there exists some refraction that leads to a new formula as shown in Equation-10 [**3**]:

$$AM = \frac{1}{cos(\Theta) + 0.50572(96.07995 - \Theta)^{-1.6364}} \tag{10}$$

Due to the enormous distance between the sun and the earth, the amount of solar radiation that extents outside of the atmosphere of the earth is quite small typically around 1367 W/m^2 (measured by taking average distance and perpendicular to the surface). This number is called as solar constant (*S*). It is also called as air mass zero (*AM0*) as it refers to the radiation outside the earth's atmosphere or air mass.

Due to the variation in the earth-sun distance over the years, the actual radiation reaching earth's atmosphere varies throughout the year. The change in solar constant with time over the year S_t can be given by the formula shown in Equation-11.

$$S_t = S\,(1 + 0.033cos\frac{360n}{365}) \tag{11}$$

Where n describes the nth number of the day of a year. The intensity of the direct solar radiation per each day is a function of air mass and can be estimated as shown in Equation-12.

$$I_D = 1.353 \times [(1 - ah)\,0.7^{AM^{0.687}} + ah] \tag{12}$$

Where a = 0.14, and h = location of height above sea level in km. Its unit is kW/m^2. The value 1.353 Kw/m^2 is the solar constant and 0.7 is taken as 70% of solar radiation is transmitted to earth. The value 0.682 is constant, and calculated by taking in to account the non-uniformity of the atmosphere. As the diffusive radiation is about 10% of direct one, so the global radiation can be estimated by the relationship shown in Equation-13.

$$I_G = 1.1 I_D \tag{13}$$

1.2.2 Declination angle

It is the angle created due to the tilt of the earth during its rotation around the sun. This angle varies seasonally, and its value ranges from 0° to $\pm$23.45° [**2**]. The rotation of the Earth around the sun and the change in the declination angle are shown in Figure 8. The seasonal variation of declination angle is provided in Figure 9. The formula for measuring the angle is shown in Equation-14.

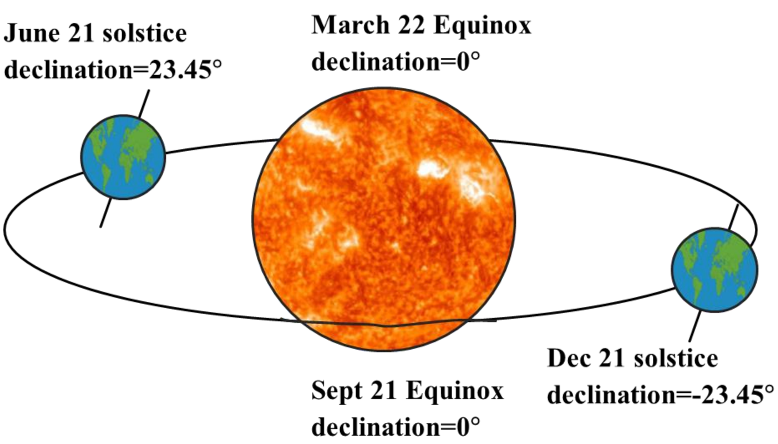


Figure 8 Revolution of earth and change in declination angle

$$\delta = 23.45° sin\left(360/365 \ (d + 284)\right) \quad (14)$$

Where *d* = day number of the year

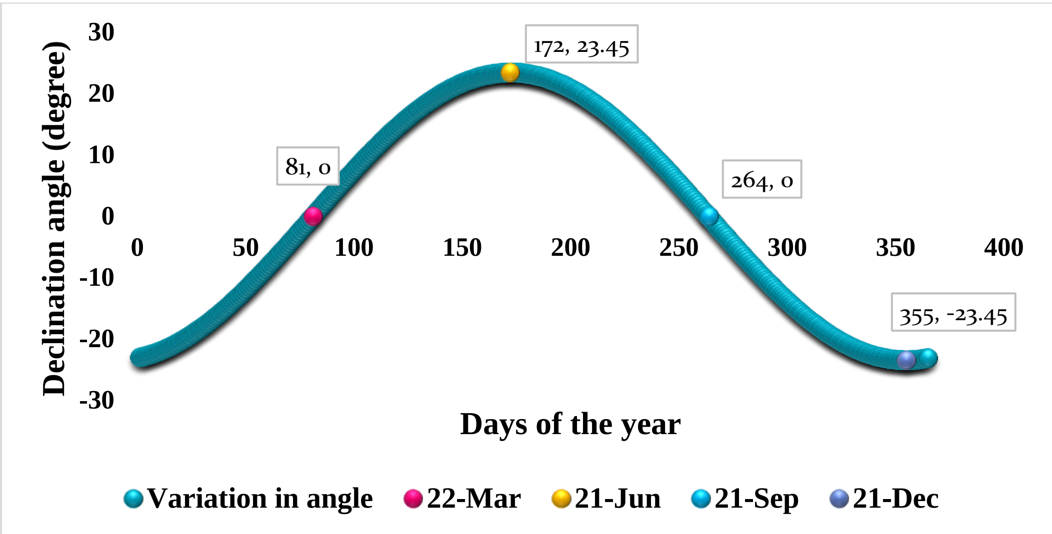


Figure 9 Variation of declination angle over the year

1.2.3 Elevation angle

The elevation angle is the angle formed between the angular height of the sun and horizontal surface. The maximum elevation angle (90°) occurs, when the sun is directly overhead. The minimum elevation angle (0°) occurs, during the sunrise and sunset. It depends on the latitude, location, and time of the year. Its value varies throughout the day. Figure 10 shows the evaluation of elevation angle with respect to the position of the sun. ϕ is the latitude value of the targeted region

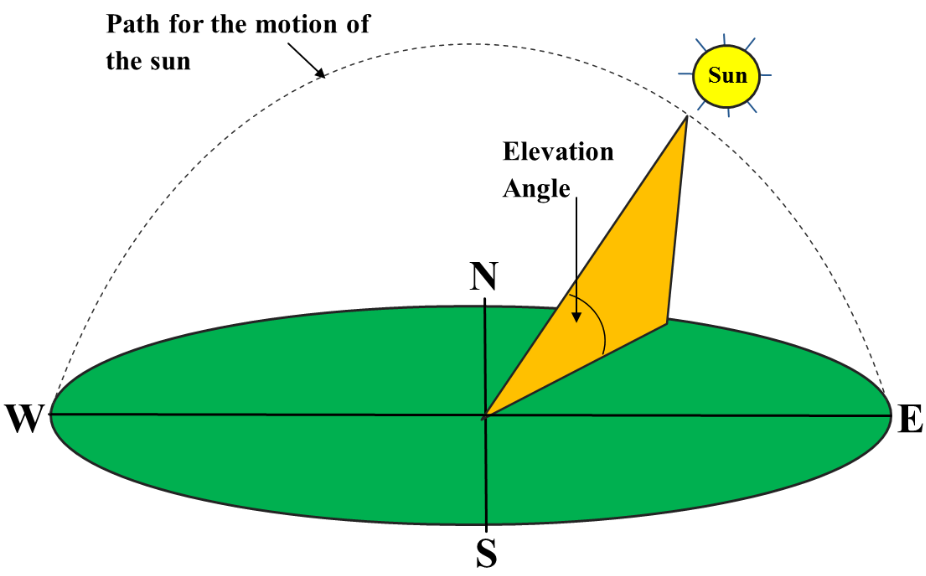


Figure 10 Determination of elevation angle with respect to the position of the sun

$$\alpha = sin^{-1}(sin\delta sin\phi + cos\delta cos\phi\ cos(HRA)) \tag{15}$$

1.2.4 Azimuth angle

The azimuth angle expresses the angle between the compass direction of incident sunlight and the compass direction of the incident sunlight when the sun is at the overhead. At sunrise, its value is 90° and at sunset, it is 270°. Similar to elevation angle it also depends on the latitude, and time of the year. Its value varies throughout the day [**3**]. Figure 11 shows the evaluation of elevation angle with respect to the position of the sun and north direction. By using declination angle, elevation angle and azimuth angle the sun's position throughout the day can be detected. The angle can be calculated by the formula shown in Equation-16.

$$\theta = cos^{-1}(\frac{sin\delta cos\phi - cos\delta sin\phi cos(HRA)}{cos\alpha}) \quad (16)$$

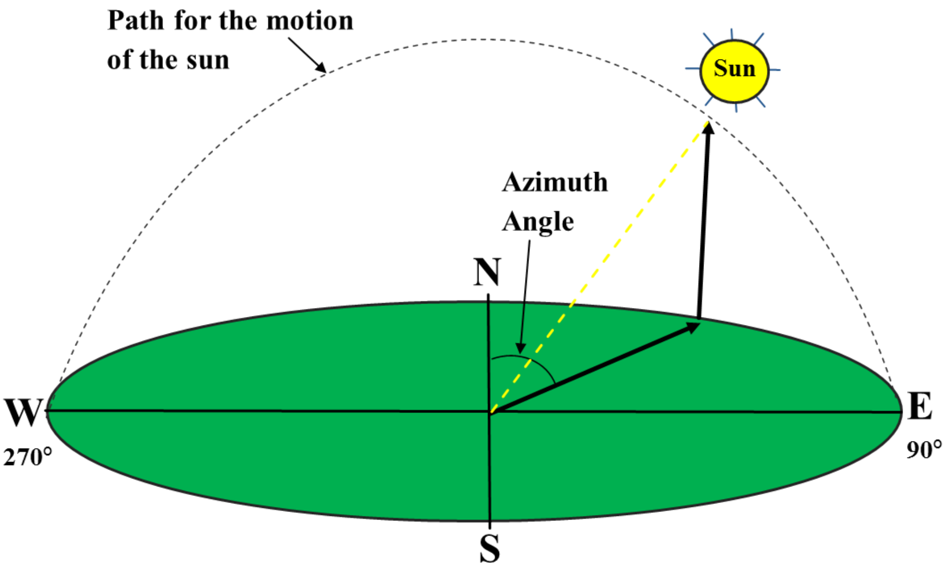


Figure 11 Determination of azimuth angle with respect to the position of the sun

1.2.5 Solar radiation on tilted surface

The incident radiation power on the solar PV module does not only depend on the power density of the radiation but also depends on the angle of incidence. The amount of solar radiation incident on the surface of the solar array is the function of the incident radiation that is perpendicular to the horizontal plane and the sun. Figure 12 shows the method to calculate the solar radiation falling on a tilted surface (S_{module}) with respect to the solar radiation measured on a horizontal surface ($S_{horizontal}$) or perpendicular to the sun ($S_{incident}$) [**3**].

According to the figure

$$S_{horizontal} = S_{incident}.sin\alpha \quad (17)$$

$$S_{module} = S_{incident}.sin(\alpha + \beta) \quad (18)$$

Where $\alpha = 90°-\phi+\delta$ and

$$S_{module} = \frac{S_{horizontal}.sin(\alpha + \beta)}{sin\alpha} \quad (19)$$

For a module at a random inclination and orientation the equation transforms to the formula shown in Equation-20;

$$S_{module} = S_{incident}.[cos\alpha.sin\beta.cos(\Psi - \Theta) + sin\alpha.cos\beta] \quad (20)$$

Where Ɵ is the sun azimuth angle and Ψ is the azimuth angle that the module faces.

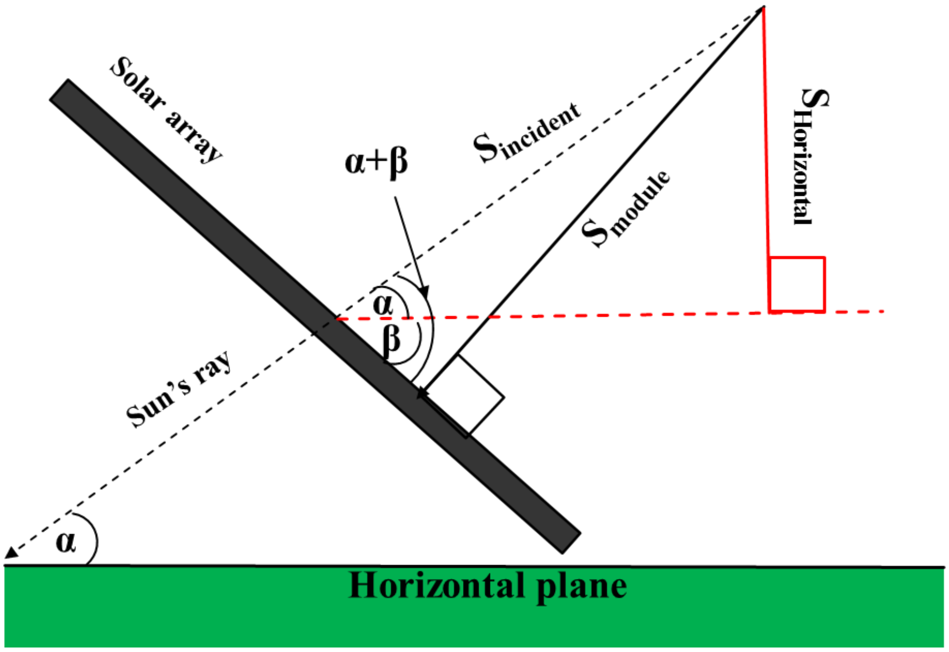


Figure 12 Analysis of the solar radiation incident on tilted surface

1.2.6 Solar insolation

Insolation is the measure of the total amount of solar energy a surface area receives during a particular period. Its unit is kWh/m^2. As per the place of the sun in the sky and the inclination of the surface of interest, the maximum value of the solar insolation can be calculated as the function of latitude, and day of the year. Figure 13 shows the annual Global Horizontal insolation (GHI) throughout the year for India. The data is collected from MNRE [**4**] , and the map is plotted with QGIS software.

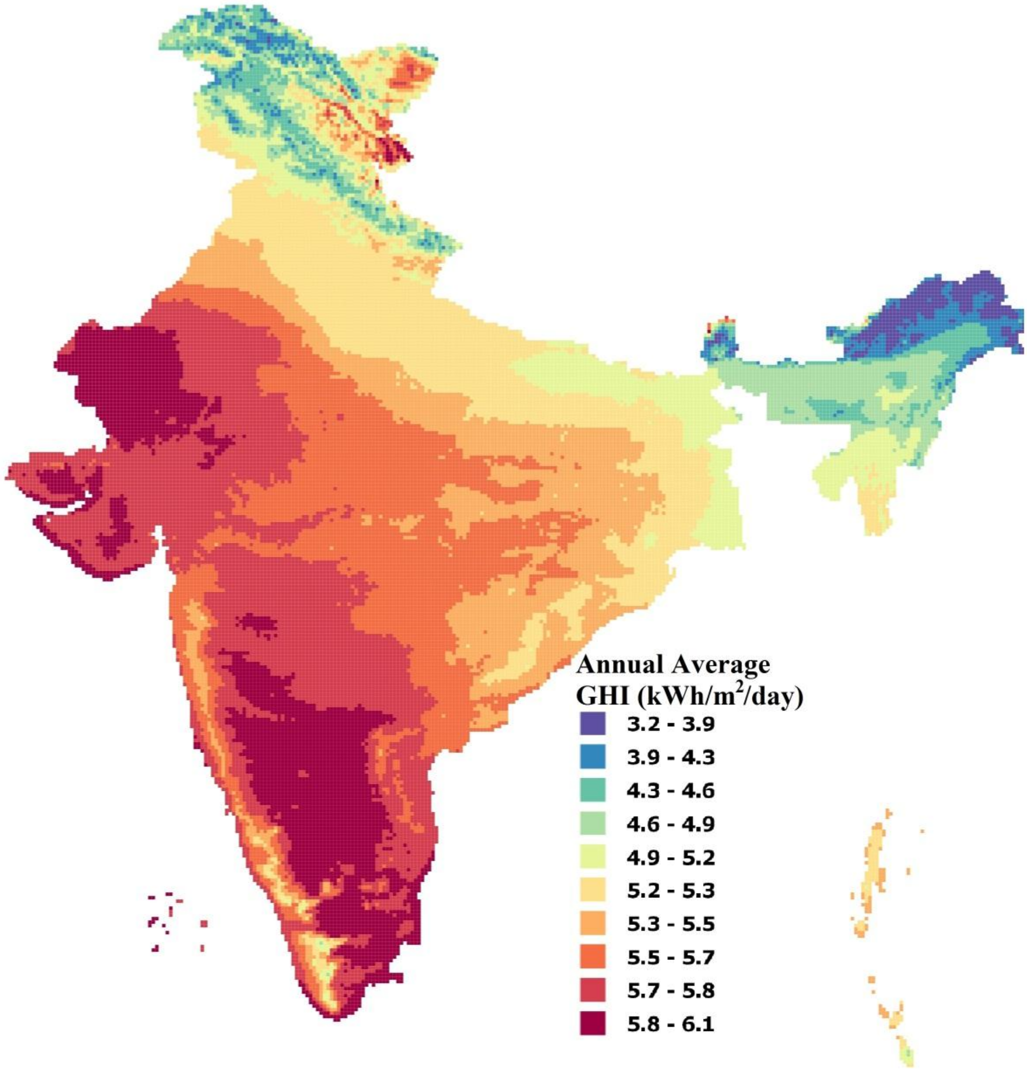


Figure 13 Global horizontal insolation exposures over India average over a year in $kWh/m^2/day$

1.3 Objective and Motivation of the Thesis

The state of Odisha has a tremendous potential for harnessing the solar power; however the state lacks proper strategy in the solar policy to evaluate the PV energy potential with precise details. The detailed estimation of state wise solar potential will help the policy developer or planners setting up the solar targets more accurately. Due Stochastic nature of the meteorological factors like sunlight and temperature, reliable methods are necessary that can predict the energy yield of the location accurately. The presented thesis provides various methods to identify the solar PV potential based on the parameters like radiation, temperature, land pattern, and energy yield. The thesis considers Odisha as a reference state to apply all the methods; however the methodology of the work can be applied to any state, county or a particular region.

The primary objective of the thesis is to evaluate, analyze, and identify the PV potential for the state of Odisha with the implementation of various methods. The study aims to emphasize on the estimation the annual PV energy yield of the state which is the most important and reliable parameter for the potential analysis. The methods provided in the thesis include an evaluation with satellite-based free online tools (PVGIS, SolarGIS, and PVwatts, etc.), methodology to create or plot rasterized maps for zonal analysis, and development of data predictive models for precise prediction. The work of the thesis intends to plot various rasterized maps with the methodology for Odisha and utilizing it to identify, verify, and evaluate the Solar PV Potential of the state. The mapping provides regional based overall structure of solar potential; however developing data predictive model can predict the PV energy yield, irrespective of the location inside the state. The model takes only two basic input parameters i.e. Radiation and temperature for predicting the output. Simplification and validation of the developed models are done phase by phase to forecast the results precisely and to check the reliability of the method. The study also targets to test the reliability of the developed models by verifying with the production data collected from the real solar power plant inside of Odisha. In the later stage, the study suggests the utilization of all the developed methods in making better policy framework for the states of India.

1.4 Outline of the Thesis

Chapter-1 is the core introduction regarding the solar radiation, its characteristics, and properties. The aim of the chapter is to gain basic knowledge about different kinds of terrestrial solar radiation and variation in their value with respect to the movement of earth and atmospheric conditions, and angle of the surface of the module.

Chapter-2 explains about the estimation of PV energy yield inside Odisha using PVGIS online tool. Using various collected potential parameters like temperature, radiation, PV energy yield, elevation, and land pattern a methodology is provided to plot the rasterized maps for the state of Odisha. The plotted maps are further analyzed to identify the potential regions inside Odisha for the implementation of solar power plants.

Chapter-3 provides a basic methodology to implement a simplified model to predict the PV energy yield with two necessary inputs i.e.: Radiation and Temperature. Initially, a simplified model is created that takes three input for the prediction i.e.: radiation, module temperature, and temperature coefficient. Later the model is simplified to take only two inputs for prediction. The validation of the model is provided on the real plant data collected from SN Mohanty solar power plant situated at Cuttack. A case study of NIT Rourkela is considered that explains the climatic conditions and prediction of PV energy yield inside NIT with various methods.

Chapter-4 is about the review of the current solar policy framework of India. Initially, the basic idea about the different act, plans, and national policies that affect the solar policy of the states is explained. The study of all the states in India that has implemented their solar power policy is discussed. The review of top ten countries in the world in the field of PV capacity is analyzed on India. Finally, the challenges for the Indian PV sectors to achieve the target are investigated on the target set by the Government.

Chapter-5 provides the concluding section with the discussion about the possible scopes for further research of the thesis work.

Chapter-2

Development of Rasterized Maps for the Assessment of PV Energy Potential of Odisha

Odisha, a state in India, located South of the Tropic of Cancer that is rich in Energy resources. Economic growth of Odisha depends on upon the utility of energy resources, majorly arising from coal and hydroelectric power which contributes 74.7% and 24% of the total electricity production [**5**]. The comparison between annual generation and an annual demand of electrical power is shown in Figure 14 [**6**]. As per the trend line the demand for electricity is increasing rapidly; however, the production is stagnant over 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 PV is 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 [**7**].

The objective of the chapter is to provide an alternate method to estimate and analyze the solar PV Energy potential in different parts of Odisha-based on the radiation, temperature, and other geographical data. All the required parameters are determined 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 chapter further discusses the usefulness of the proposed methodology to develop a strategy for promoting the installation of grid-connected PV system.

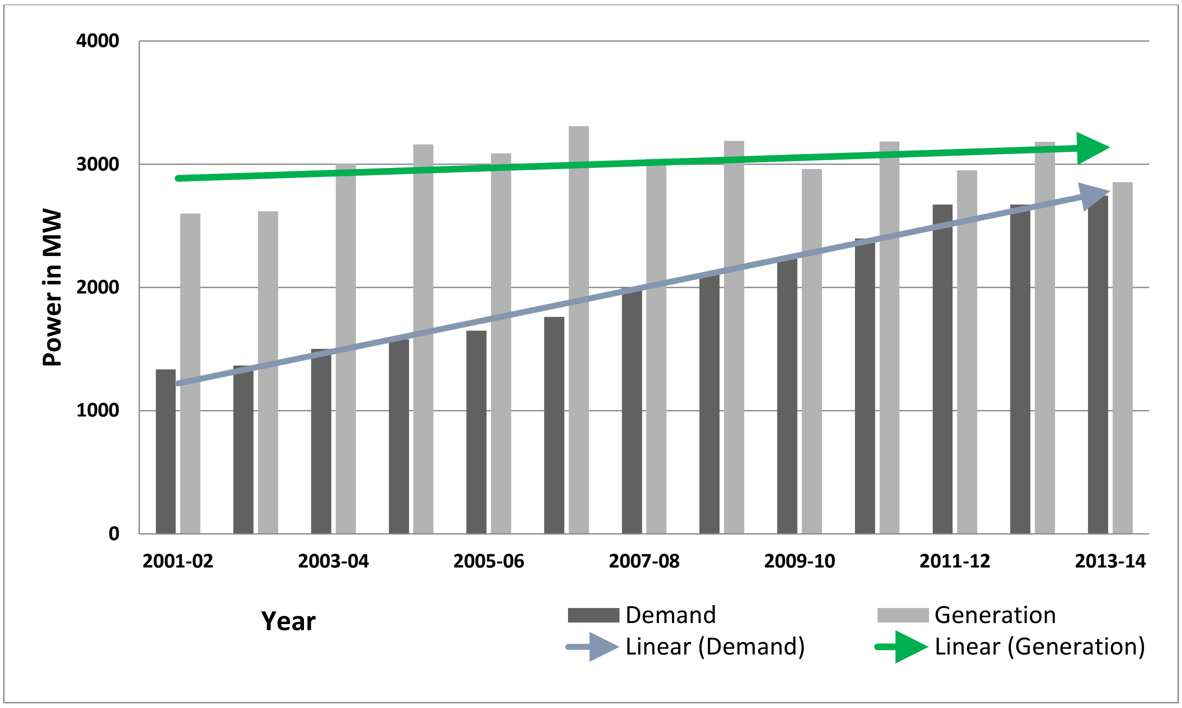


Figure 14 Annual demand and Generation of power in Odisha [6]

2.1 Geography of Odisha

Odisha is one of the twenty-nine states of India with a vast amount of natural resources. The states like West Bengal, Bihar, Andhra Pradesh, Madhya Pradesh, and ocean like the Bay of Bengal surrounds the land of Odisha. The location 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 155 707 km^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 [**8**,**9**]. The rasterized maps provided in Figure 16, Figure 17, and Figure 19 uses *Google My Map* [**10**], 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 [**11**]. The Methodology section provides the details about the method used for the division of area and plotting of maps. State wise Geographical and climatic parameter analysis of Odisha can be found in Appendix-I.

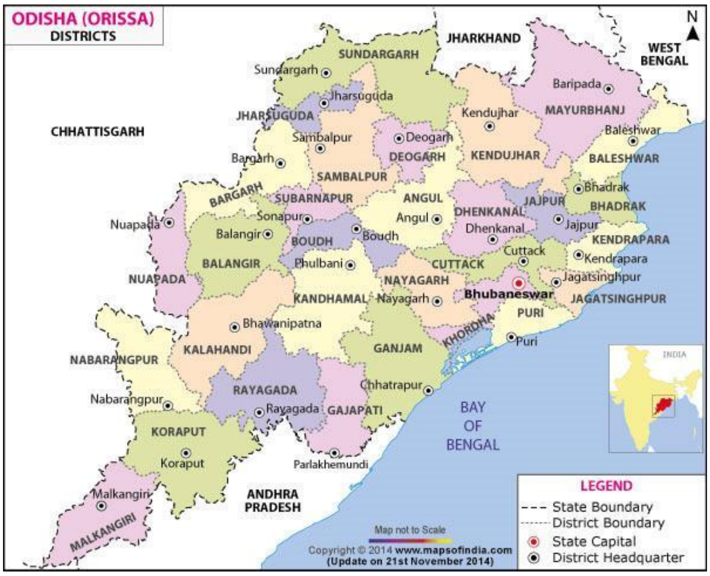


Figure 15 Political map of Odisha showing 30 districts **[**12**]**

The state of Odisha located on the eastern coast of the Indian peninsula is quite rich in natural resources. The state contains harboring dry and moist deciduous forests as well as mangroves with several rare and endangered floral and faunal species. Figure 16 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 Baitarani, reside 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 region of the state. Odisha also has plateaued and rolling uplands, which have the lower elevation that the plateaus [**8**,**9**]. Figure 17 shows the plotted elevation map of Odisha.

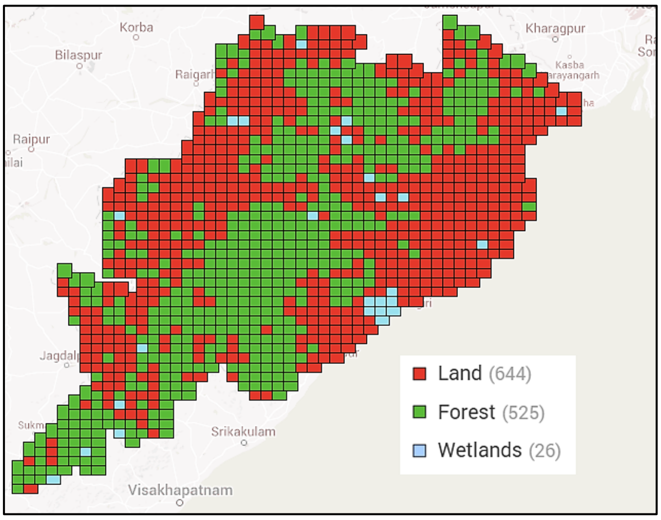


Figure 16 Distribution of Wetland, Forest, and Land cover of Odisha

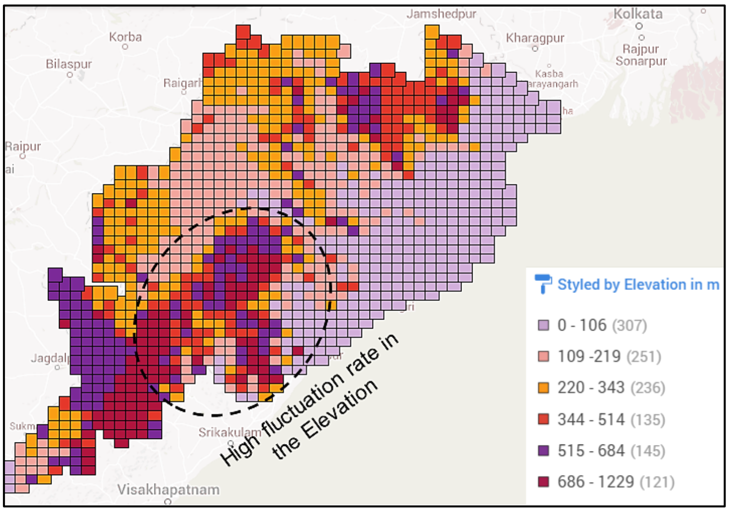


Figure 17 Elevation map of Odisha plotted by using data from Solar-GIS

2.1.1 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 part 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 square kilometres '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. Figure 18 shows the distribution of these forest covers on 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 [**13**].

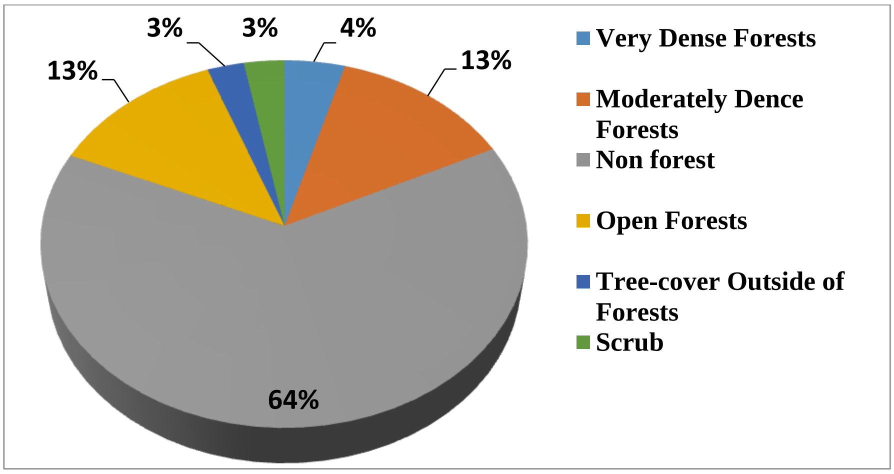


Figure 18 Distributions of forest cover in Odisha

2.1.2 Surface water resources

The land of Odisha depends largely upon monsoon for its water resources. The state contains an extensive network 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 [**9**,**14**].

The total capacity 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 [**15**].

2.1.3 Climate Details

Tropical monsoon weather represents the climate of Odisha. Searing hot summers with considerably high monsoon downpours and cold and pleasant winters mark the atmosphere 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 [**15**]. Odisha receives about 78 % of rainfall during the months of June and September [**9**]. The maximum temperature ranges between 35-40 ℃ and minimum temperature are between 12-14 ℃ [**16**]. The annual average air temperature data retrieved from Solar-GIS is plotted on the map of Odisha in Figure 19 [**11**].

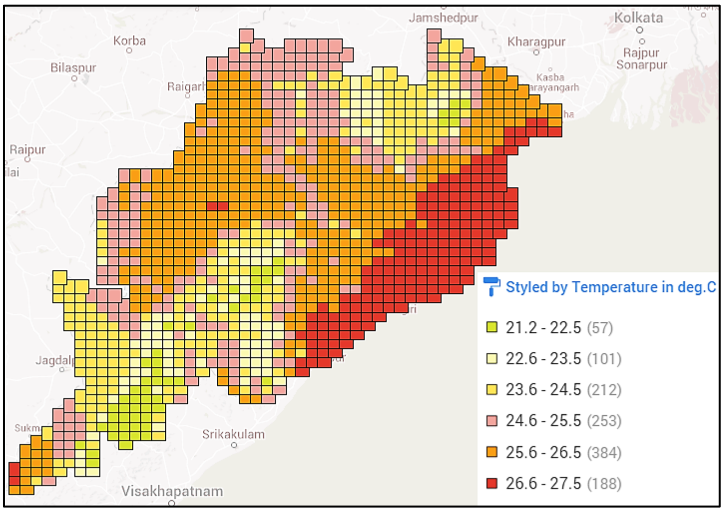


Figure 19 Average annual air temperature map of Odisha Plotted by using data from Solar-GIS

2.2 Estimation of PV potential with PVGIS Estimation tool

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 configuration 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 various 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 [**17**].

Howard O. Njoku [**18**] 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. [**19**], 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 [**20**,**21**,**22**].

The (Photovoltaic Geographical Information System) PVGIS is another solar-based online tool that evaluates the potential of PV production throughout the world [**23**,**24**,**25**]. It is a popular and free-to-use GIS-based online tool 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. PVGIS takes data on solar radiation to make estimates of the performance of PV systems and to do the other calculations possible [**26**]. A study presents a method to predict PV production in Concentrating Photovoltaic installations by using Global Horizontal Irradiation and the PVGIS database [**27**]. Another methodology uses the '*r.sun solar radiation model*' (provides the radiation data) and PVGIS estimation utility to estimate the PV potential [**28**,**29**]. The PVGIS is also used to compare output performance of fixed, one axis, and two-axis tracking PV system [**26**,**30**].

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 [**23**]. The database represents twelve years data of global radiation, measured using meteorological geostationary satellites and ground stations [**31**]. 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 [**32**]. 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 20, Use either top box (search box) or two bottom input boxes to provide information regarding the coordinate (latitude and longitude) details of the location [**32**]. PVGIS provides four kinds of calculation tools [**32**] which are PV Estimation tool, Monthly Radiation tool, Daily Radiation tool, and Stand Alone PV tool.

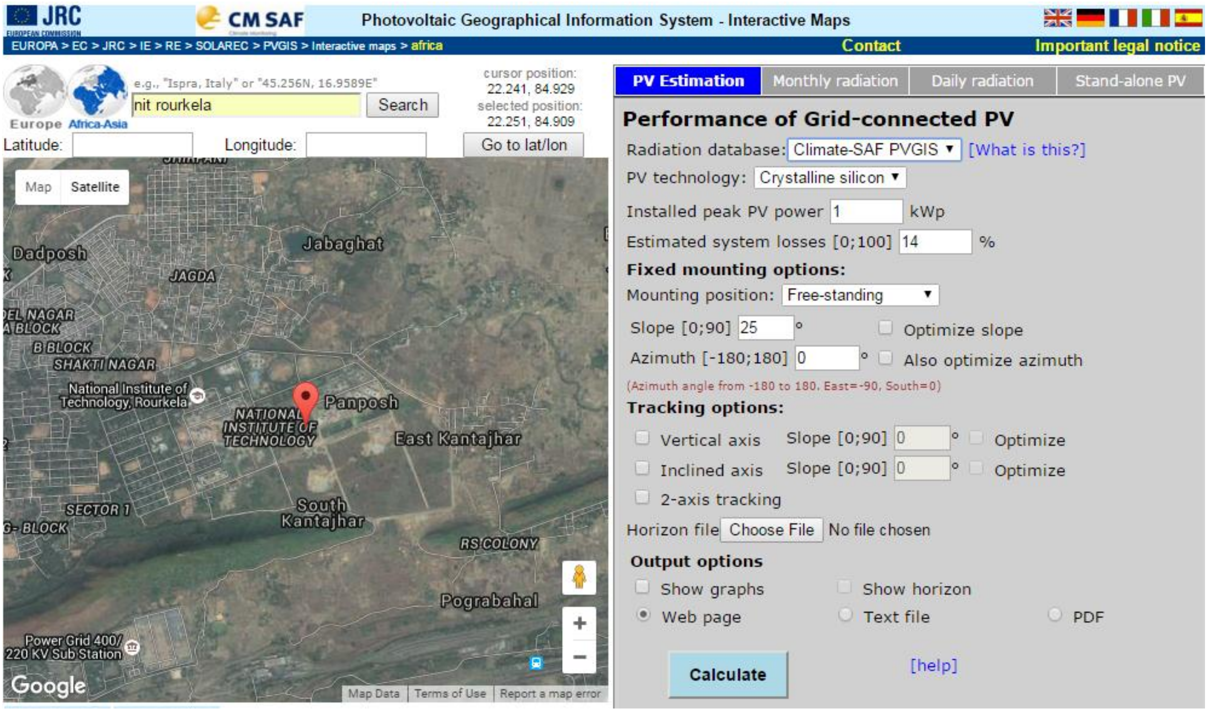


Figure 20 PVGIS interface **[**32**]**

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 are PV technology, Installed peak PV power, estimated system losses, mounting option, and tracking option.

2.2.1 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 varies on 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 [**32**].

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°C module temperature, 1.5 air mass, 1m^2 surface area, and 100% efficiency, the module produce a constant output power of 1KW [**32**]. The efficiency under STC can vary on 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

$$P_K = A \times eff_{nom} \tag{21}$$

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%, the user is free to provide the suitable value [**32**]. With mounting position option, the user can set the orientation of the fixed module as per need. 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 on the horizontal plane (in the range of 0° to 90°), 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 [**32**].

The user can choose from three different tracking options that allow the PV module to follow the movement of the sun [**32**]. 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 terrain 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 on ground. The study considers four cases, tabulated in Table 1 to be implemented considering the orientation and mounting option of the PV system to estimate PV Energy potential of Odisha.

Table 1 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

Table 2 Selected Inputs in the PV estimation tool of PVGIS

Parameters/attributes	**Value Setting**
PV technology	Crystalline silicon
Installed peak power	10 kW_p
System losses	14% (losses in cables, inverter, soiling, etc.)
Mounting option	Freestanding or building integrated
Inclination	25^0(non-tracking)
Azimuth	0^0 (for Southwards orientation of module)
Tracking	Two-axis tracking (when opted for)

2.2.2 The PVGIS energy rating method

The PVGIS energy rating method defines the formulation of the actual 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.

$$P = G' \times A \times eff(G, T_m) \text{ or } G' \times A \times eff_{nom} \times eff_{rel}(G, T_m) \quad (22)$$

Where; $G' = G/1000$;

$$T'_m = T_m - 25$$

$$T_m = T_{amb} + K_T G \quad (23)$$

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 $^0C/(W/m^2)$ and based on values referred from literature [**32**] for the building-integrated system it is 0.05 $^0C/(W/m^2)$. Equating eq. (21) and (22)

$$P = G' \times P_K \times eff_{rel}(G', T'_m) \quad (24)$$

The formula for estimating the relative efficiency (refer equation-25) 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.

$$eff_{rel}(G',T'_m) = 1 + k_1 \ln(G') + k_2 ln(G')^2 + k_3 T'_m + k_4 T'_m \ln(G') + k_5 T'_m ln(G')^2 + k_6 T'^2_m \quad (25)$$

Where k_1 to k_6 are the coefficients that can be found out by comparing the measured value of different PV technologies used [**32**].

2.2.3 Uncertainties in Data and Calculations

Uncertainties in Data and Calculations provided PVGIS; affect all the measurements and calculations done in the PVGIS to estimate the energy production. There are four kinds of uncertainties that majorly influence 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 [**31**] 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 on 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 [**32**].

2.3 Methodology for plotting the rasterized maps

The method of 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 21 X1 and X2 represent the minimum and maximum latitude position, and Y1 and Y2 define the minimum and maximum longitude location respectively. For Odisha, the range is selected from 17.811N to 22.568N in latitude and 81.431E to 87.495E in longitude.

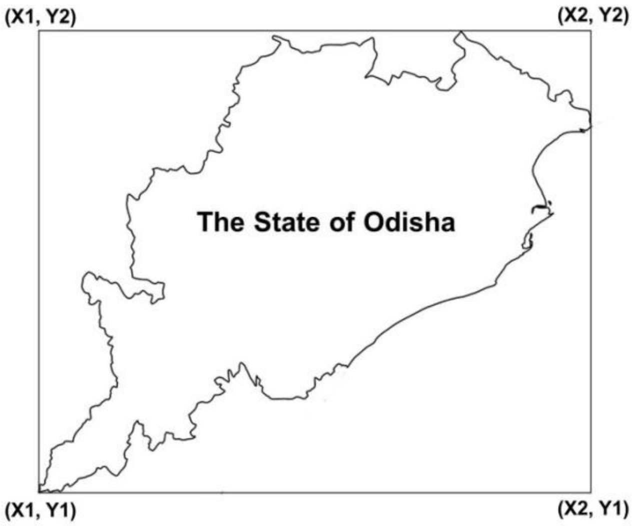


Figure 21 indicating the coordinates that define the total area of Odisha

2. *Dividing the area under study:* Figure 22 divides the designated area into m×n equal and square grids. 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 is 4.757N 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. The division of grid depends on the proportion ratio of the difference in the latitude and longitude. The proportion size ratio should always be compared with five (e.g. 5:10,) for 50 × 50 equal division, with ten (e.g. 10:4) for 100 × 100 equal division. When the difference between the horizontal and vertical proportion size is one or less, the division of grid should be equal on both the sides of the field. For example, when the proportion ratio is around 5:6, the division of grid should be 50 × 50. If the difference between the horizontal and vertical proportion size is more than one then, the division of grid should be unequal on both sides of the field. For example, when the proportion ratio is around 5:10, the division of grid should be 50 × 100.

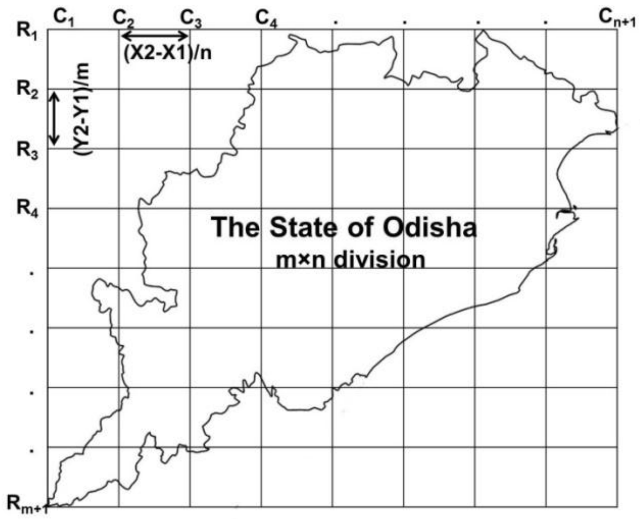


Figure 22 Division of Odisha into m×n squarish grids

3. *Defining the center point of corner grid area:* Step 3 sets the new value of longitude and latitude. Placing each coordinate at the midpoint of each grid is necessary. In Figure 23 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 defines the above purpose;

$$(New\ latitude)_{max} = (latitude)_{max} - (increment\ in\ latitude \div 2) \quad (26)$$

$$(New\ latitude)_{min} = (latitude)_{min} + (increment\ in\ latitude \div 2) \quad (27)$$

$$(New\ longitude)_{max} = (longitude)_{max} - (increment\ in\ longitude \div 2) \quad (28)$$

$$(New\ longitude)_{min} = (longitude)_{min} + (increment\ in\ longitude \div 2) \quad (29)$$

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

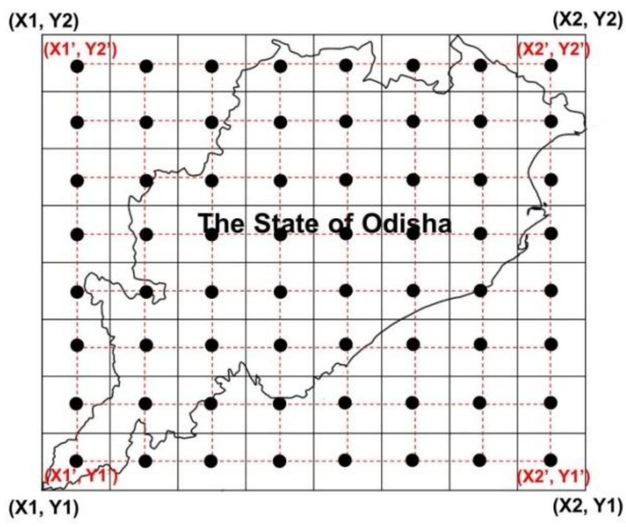


Figure 23 defining the center points of corner grid area

4. *Removing unwanted region:* Step 4 removes all 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 in Figure 24.

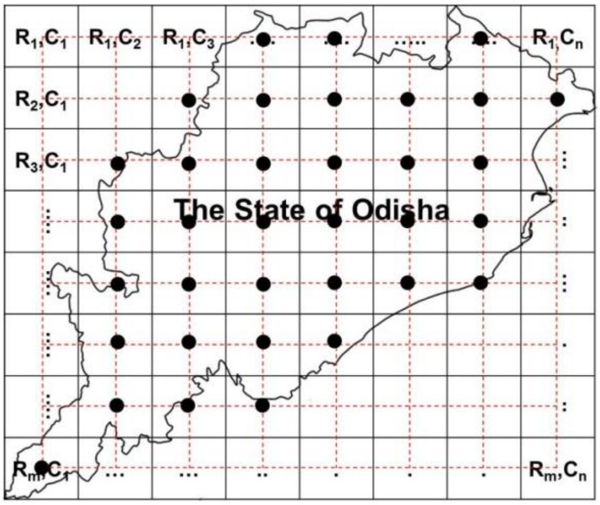


Figure 24 defining each grid into rows and columns

With the row and column data, all the required coordinates can be found by using the equation 30 and 31. The unwanted coordinates are removed from the analysis shown in Figure 25. All the formulated coordinates are saved in the Excel format for further processing.

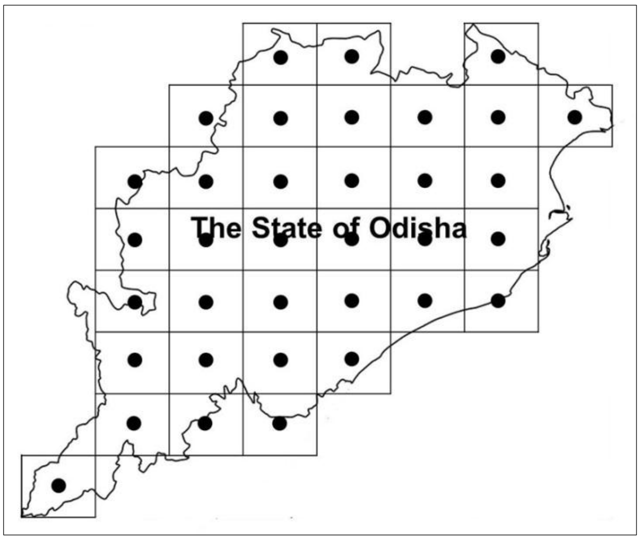


Figure 25 Removal of unwanted regions of Odisha

$$longitude = (New\ longitude)_{min} + [(column\ no. -1) \times increment\ in\ longitude] \quad (30)$$

$$latitude = (New\ latitude)_{max} - [(row\ no. -1) \times increment\ in\ latitude] \quad (31)$$

Some error in estimation may arise due to the squares lying on the boundary of the state. The error can be reduced by lessening 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 (refer Appendix-III). The user can get coordinate-wise temperature, elevation, and land cover data from the SolarGIS [**11**]. The newly acquired parameters with respect to coordinates are updated in the Excel file before plotting the map.

6. *Preparing the final rasterized map:* Google My Maps [**10**] 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 tool creates symbols and colors, eight in the current case, depending on the range of the data. The interface of Google-My Maps for plotting rasterized maps is shown in Appendix-II.

2.4 Results and Discussion

The procedure described in the earlier section is used to produce the various maps of the output parameters for all four cases that define the potential of PV production using the PVGIS PV estimation tool. The suggested methodology can be applied to any region, small or large to plot the rasterized maps. The PVGIS and SolarGIS give information in a numerical format for only one place at a time; however, the methodology provides 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 19 denotes more fluctuation in average air temperature data in the southwest region compared to the rest of Odisha. The cause of the variation in temperature is attributed to the presence majority of forest-land and change in elevation due to the presence of hilly region. Forest-land should be ignored from the potential region for plant establishment for important reasons such as cause for deforestation, an imbalance in the ecosystem, 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 26 displays 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 [**32**]. An inclination 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. The azimuth angle of 0^0 is provided as an input 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 27 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 26 and Figure 27 indicates the improvement of estimated radiation values (1820-2180 kWh/m^2 to 2140-2850 kWh/m^2) due to the addition of two-axis tracking system.

Figure 28 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 the presence of mountains primarily affects the PV energy output (Figure 17). The range of PV production is in between 1300 kWh/kW_p to 1550 kWh/kW_p. Similarly, Figure 29 shows the estimation of the total annual PV energy generation for case-II, a system with two-axis tracking. The range production of PV energy shows improvement (1510 kWh/kW_p to 2030 kWh/kW_p) compared to the case-I due to the involvement 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 shoreline 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 module that 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 30 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 integrated type mounting position (refer Figure 31). For the building-integrated structure, having higher temperature coefficient (K_T), the total production range decreases to 1400-1880 kWh/kW$_p$. With two-axis tracking the produced output value depends on the effect of global radiation more, so the distribution of color ranges in map plotted in Figure 27 is almost similar to the map in Figure 31.

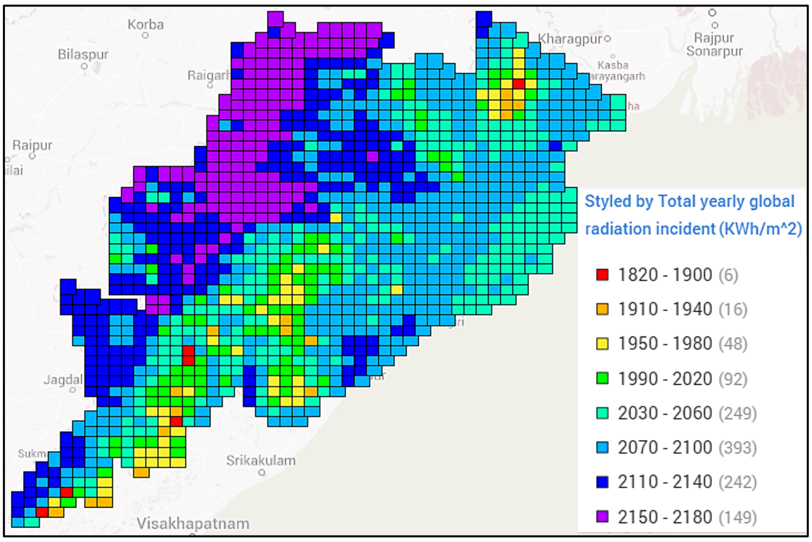


Figure 26 Total Yearly Global Radiation map of Odisha plotted for case-I and case-III

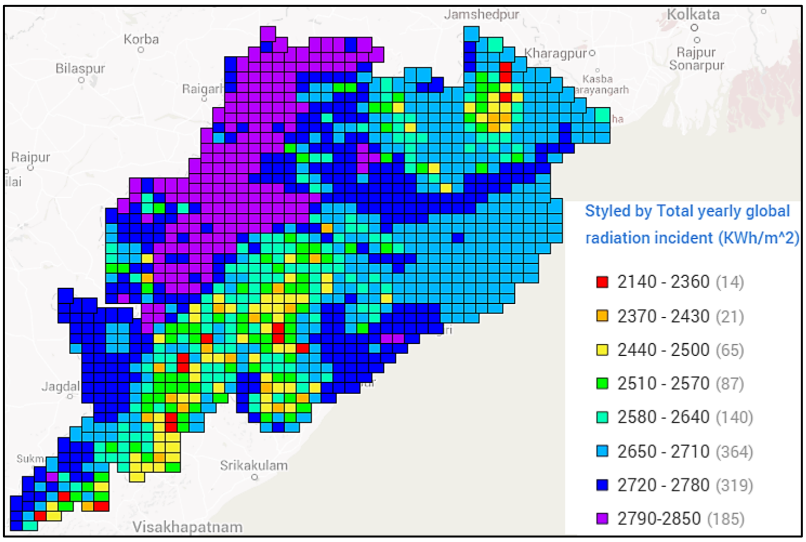


Figure 27 Total Yearly Global Radiation map of Odisha plotted for case-II and case-IV

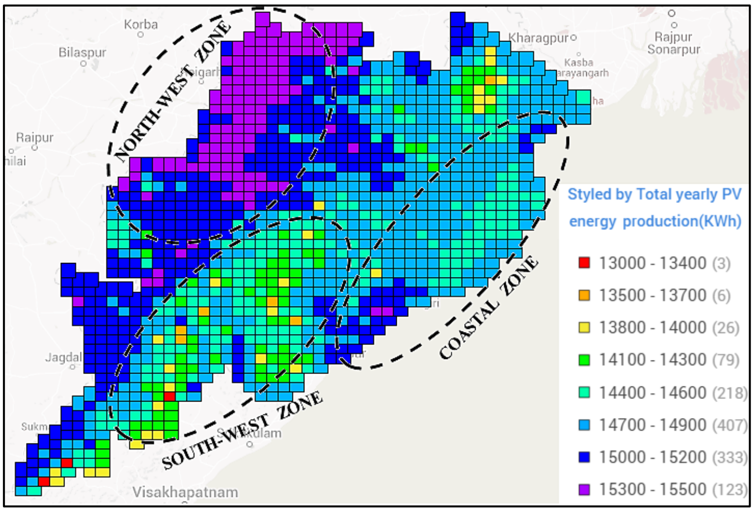


Figure 28 Total Yearly PV Energy Production map of Odisha plotted for case-I

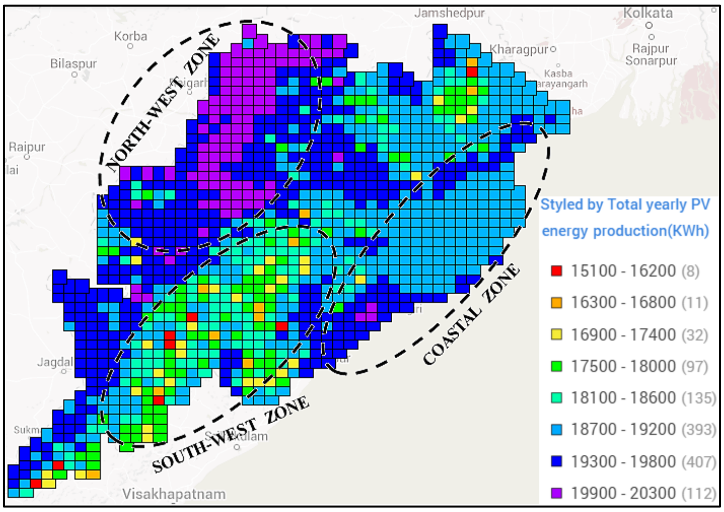


Figure 29 Total Yearly PV Energy Production map of Odisha plotted for case-II

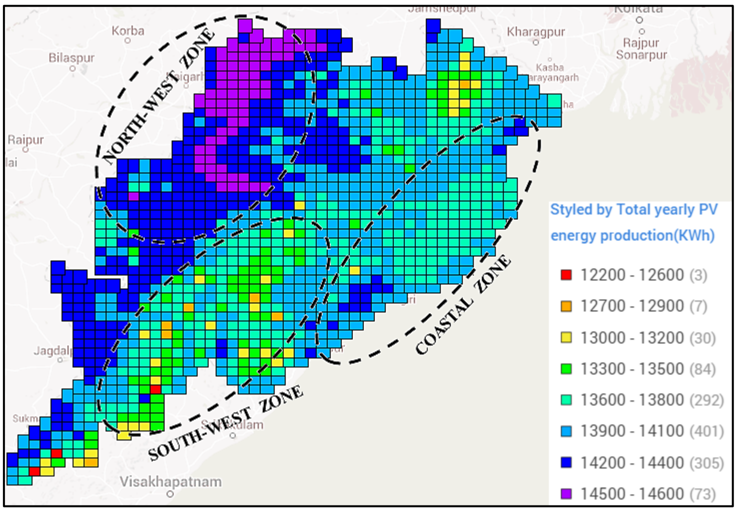


Figure 30 Total Yearly PV Energy Production map of Odisha plotted for case-III

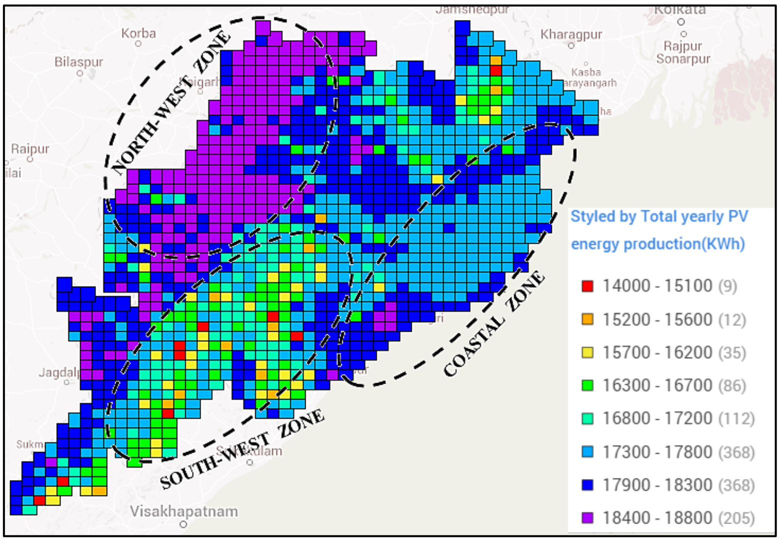


Figure 31 Total Yearly PV Energy Production map of Odisha plotted for case-IV

The whole 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 3 represents the overall analysis of the plotted PV production in Odisha. The estimation of 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 in Table 3 is the product of the number of square blocks in the estimated zone with the area of each square (130 km^2). The comparison of the actual area of the defined zones with the estimated one establishes an average error of 11.4%. The percentage of the area of the low potential zone is very less (0.16% and 0.25%) compared to other zones that show the higher production capability of PV Energy in Odisha. The distribution of area for the medium potential zone (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 potential zone 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 zone consists of mostly the urban region 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 creates a significant disadvantage while planning the installation 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 the higher rate of change 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 potential zone 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 high in 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 make northwest region perfect for establishing new and large PV plants.

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, Sundargah	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, Sundargah	Kandhamal, Angul, Boudh, Deogarh, Gajapati, Ganjam, Kendujhar, Kalahandi, Koraput, Malkangiri, Puri, Mayurbhanj, Rayagada, Nayagarh, Sambalpur, Nuapada, Sundargah	–
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, Sundargah	–	Khordha, Cuttack, Nayagarh	Balangir, Deogarh, Sambalpur, Subarnapur, Sundargah	–	**–**

Chapter-3

Development and Validation of Simplified Predictive Models

The economic viability of the solar PV systems in the energy market depends on the system installation cost, the output of the plant, availability of the land, public awareness, and government policies. The energy production of a PV plant depends on the climatic conditions, which are unpredictable, for the location. Thus, the prediction of the output of proposed PV plant for a short term (for a day) and long term (for month and year) beforehand comes in handy for the owners and planners.

The annual PV energy production is estimated with PVGIS software from 1195 different locations in Odisha. The annual global radiation and air temperature are collected from PVGIS and SolarGIS [**11**] respectively. The chapter deals with the development of a simplified model to predict the energy production of the PV system to be installed for the state of Odisha. The first model takes only three input variables while predicting the output response of the PV system. Later the model is simplified to a second one which requires only two input values to estimate the expected output energy production. The aim of the chapter is to analyze the preciseness of both the model's forecast for Odisha on simplification at every stage of the development.

3.1 Factors affecting the performance of PV module

The factors influencing the performance or the output production of PV module can be categorized as environmental, technological, and structural. The environmental factors include location, soiling and snow effect, temperature effect, and low insolation effect. The technical factors are module technology, inverter efficiency, and tracking option. The structural factors mainly comprise mounting option and size of the module. The PR can characterize the performance of a PV system. The performance ratio can be measured using global monitoring. The significance of this indicator is limited to a worldwide impression of the performance, as there is no way to identify improperly operational components.

The performance or the output production of PV module depends on various factors that may be environmental or geometrical in nature. The technical factors like module technology, inverter efficiency also affects the performance of the module. All the losses in the production due to the above factors can be expressed in a single factor called Performance ratio (PR).It is a crucial parameter that gives details regarding the performance and reliability of the PV plant, independent of its location. It is the ratio between actual outputs PV to theoretical output PV of the system. It depends on the solar radiation factors and orientation of the PV module. The variation of Performance ratio (refer Appendix-VI) with respect change in tilt and azimuth angle of the module is shown in Figure 32 which is for tropic regions. The plant efficiency is high when performance ratio is high. Typically the PR value for a good plant stands within 70% to 80%. It is estimated by using the following formula that gives the various important factors affecting the PR ratio of the PV Plant [**20**].

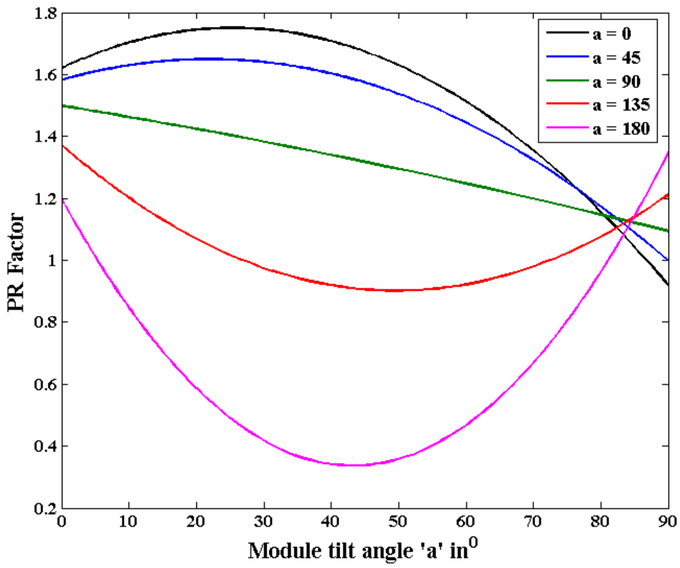


Figure 32 Variation in PR factor with respect to change in azimuth and tilt angle of the PV module **[**33**]**

$$PR = k_{\theta}.k_{Q}.k_{BI}.k_{\gamma}.k_{w}.k_{s}.\eta_{inv} \quad (32)$$

The equation-33 is based on analytical method formulas that are used to estimate the instantaneous PV production or for an extended period [**20**]. The formula takes into account all the main factors that affect the performance of PV power plants. Figure 33 describes the effect of PR ratio on the energy yield of the System.

$$P = PR.P_{k}.\frac{G}{G_{STC}} \quad (33)$$

Where E_{PV}, is the electric energy generated by the PV plant in the analysis period (kWh). P_k is the Nominal power measured at standard test conditions (kW). H_T is the total solar irradiation on the modules plan (kWh/m^2), and G_{STC} is the solar irradiance in standard test conditions. Y_F is the final yield that represents the ratio between total PV production and nominal power. Y_R is the reference yield that represents the ratio between total global radiation incident on PV to radiation at STC. PR is the performance ratio of the plant and ratio between Y_F and Y_R [**34**,**35**].

$$Y_F = \frac{E_{PV}}{P_k} \tag{34}$$

$$Y_R = \frac{G}{G_{STC}} \tag{35}$$

$$PR = \frac{Y_F}{Y_R} \tag{36}$$

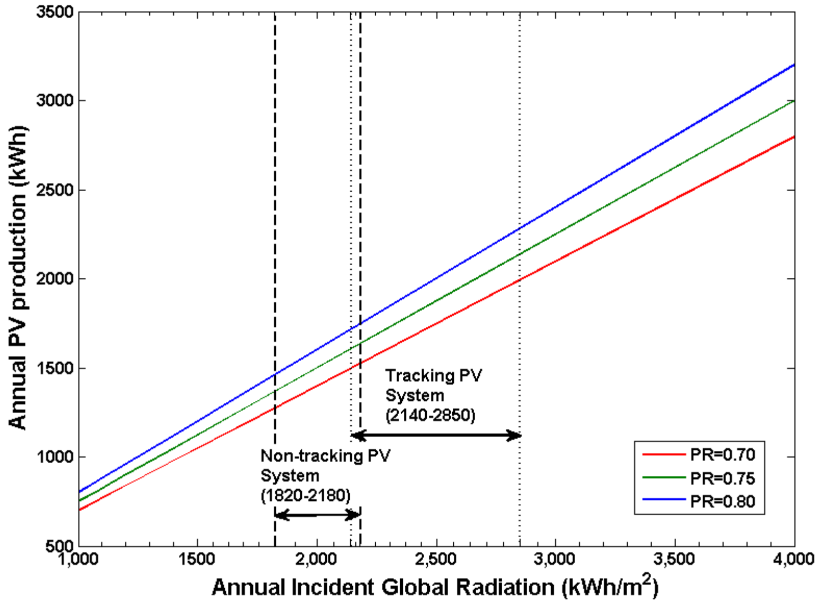


Figure 33 Estimation of PV production on change in PR ratio with analytical method

3.1.1 The optical reflection reduction factor (k_θ)

The optical reflection reduction factor defines the losses in the PV production due to an extremely unusual angle of incidence of solar radiation on the vertical plane. The radiation incident on a solar module with a particular angle of incidence is reflected wholly or partially from the surface. This factor is also called as Incidence Angle Modifiers (IAM or k_θ). The optical effects reflected in the IAM function depends not only on PV materials properties but also PV geometry. This phenomenon occurs not only for direct radiation but also with diffuse radiation. Although in general the reflection loss is usually quite low, however under unfavorable conditions the production decreases up to several percentages [**36**]. The effect of IAM on a change in incidence angle is shown in Figure 34 and equation 37. Here b_0 and c are constants.

$$k_\theta = 1 + b_0\left(\frac{1}{\cos(\theta)} - 1\right)^c \tag{37}$$

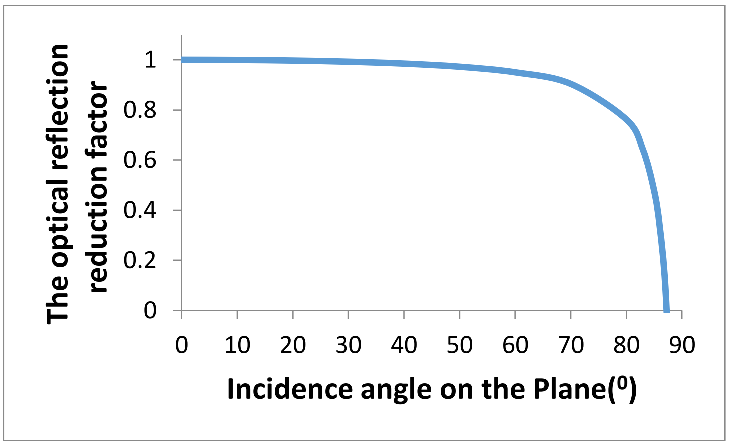


Figure 34 Variation in The optical reflection reduction factor on Longitudinal Incidence angle

3.1.2 Quantum efficiency reduction factor (k_Q)

It is the factor that implies the reduction in PV production due to the recombination effect. The factor represents the ratio between the amount of carriers composed of the solar cell to the number of photons of a particular energy falling on the solar cell. It is the function of wavelength or energy [**37**]. Figure 35 shows variation in the factor with a change in wavelength of the solar radiation.

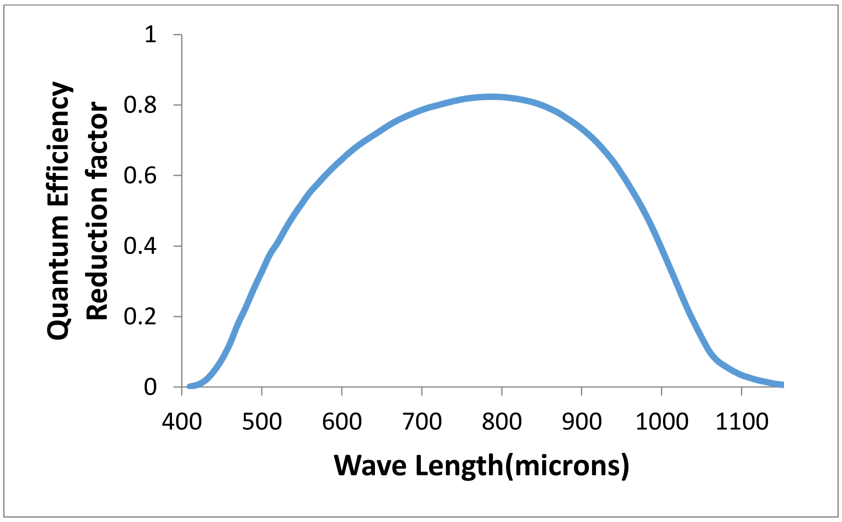


Figure 35 Quantum efficiency reduction factor on wavelength of the radiation

3.1.3 Low irradiance reduction factor (k_{BI})

At low light levels, the current through the solar cell decreases, and the equivalent resistance of the solar cell begins to approach the shunt resistance. This effect increases the net current flows through the shunt resistance. This power partial loss due to shunt resistance is called low irradiance reduction factor (k_{BI}). During sunrise and sunset or cloud coverage in the daytime, the incident radiation is very less approaching the power dissipation more closely. Due to this reason, the PR value is lower than usual [**38**]. When insolation goes below 1 kW/m^2, both open-circuit voltage and MPP voltage UMPP decrease; as a result, solar cell efficiency decreases with diminishing insolation. The effect of irradiance factor called GF with respect to change in tilt and azimuth angle of the module is plotted in Figure 36.

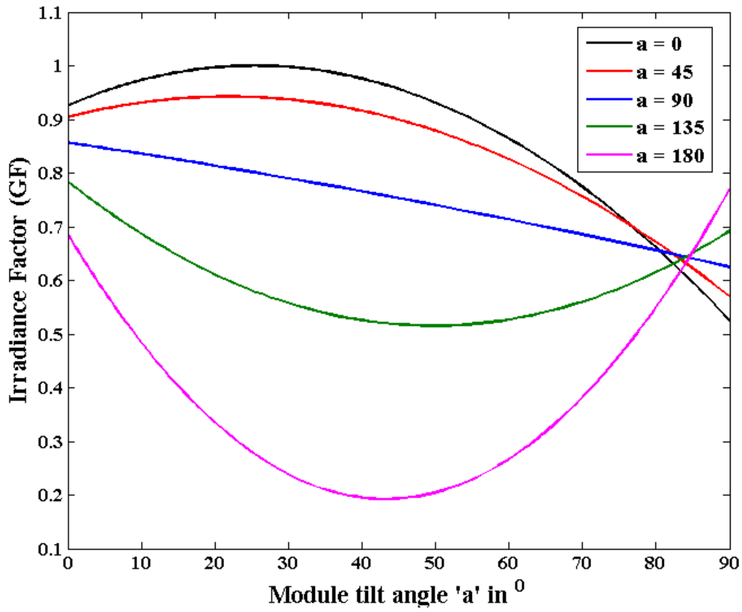


Figure 36 Change in irradiance factor (GF) with respect to change in azimuth and tilt angle (refer Appendix-VI)

3.1.4 Module temperature reduction factor (k_γ)

Performance and effectiveness of a solar cell depend on, upon the module temperature of the PV. As the temperature increases the loss in power generation is also increases. At low temperature, a PV module is more efficient. For example, the PV module is cold during cloudy weather and sunrise in winter. In these conditions, a full solar irradiation incident on the PV module operates very efficiently. After a particular time, the temperature of the PV module increases, and the efficiency decreases. Module temperature reduction factor can be calculated by using the equation 38. The value of *y* is typically around 0.35 %/^{0}C [**34**,**39**]. Figure 37 shows the variation in the factor on temperature coefficient and global radiation.

$$k_y = 1 - 0.01y[T_a - T_{ref} + \left(\frac{NOCT - 20}{800}.G\right)] \tag{38}$$

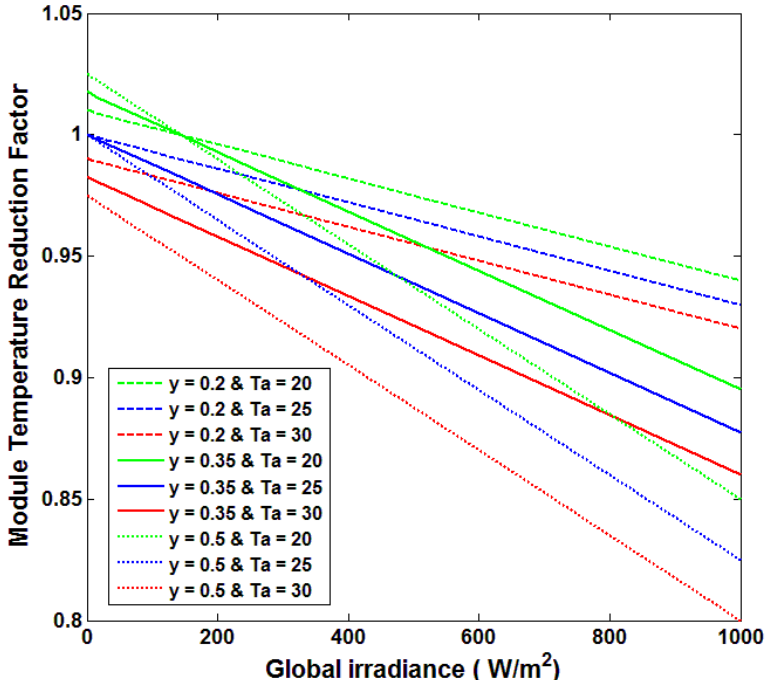


Figure 37 Variation in Module temperature reduction factor with variation in y, T_a, and G

3.1.5 Wiring losses reduction factor (k_w)

Power generated in PV plant passes through cables and other equipment to reaches at the end users. During the transmission, wiring losses occurs due to the cable resistance. It is also called ohmic or resistance losses. Wiring losses reduction factor is the measure of those DC and AC wiring losses. This factor depends on upon the resistance of the wire (R) and current (I) flowing in it [**40**].

$$k_w = \frac{P_g - I^2.R}{P_g} \tag{39}$$

3.1.6 Soiling reduction factor (k_s)

The deposition of dust, dirt, pollen and other environmental contaminants on PV modules, also known as PV module soiling. The effect of soiling results in the reduction of incident solar irradiance that reaches the semiconductor junctions of the module. The factor that represents the impact of losses in power generation due to soiling is called Soiling reduction factor. It is the third most important environmental factor determining the output of a PV power plant. Dust and snow are the major factors for soiling losses. Average annual energy losses due to soiling are typically in the range 3-6% [**41**]. However, some studies describe the annual soiling losses to be as high as 14%, monthly soiling losses to be as high as 20%, and short-term soiling losses to be as high as 30%.

3.1.7 Inverter conversion efficiency (η_{inv})

An inverter is the most important component of a grid connected PV system as it interfaces the module with the grid. It converts the output DC power of the PV module to suitable AC power with a conversion efficiency called the Inverter conversion efficiency (refer Figure 38). The highly efficient inverter results in high PR values. The other primary task of the Inverter is to operate at maximum power point and to inject AC to the grid [**42**,**43**].

$$\eta_{inv} = (aPLR^2 + bPLR + c).\log(PLR.10^3 - d) \tag{40}$$

$$Where\ PLR = \frac{P_{inv}}{P_{inv,nom}}$$

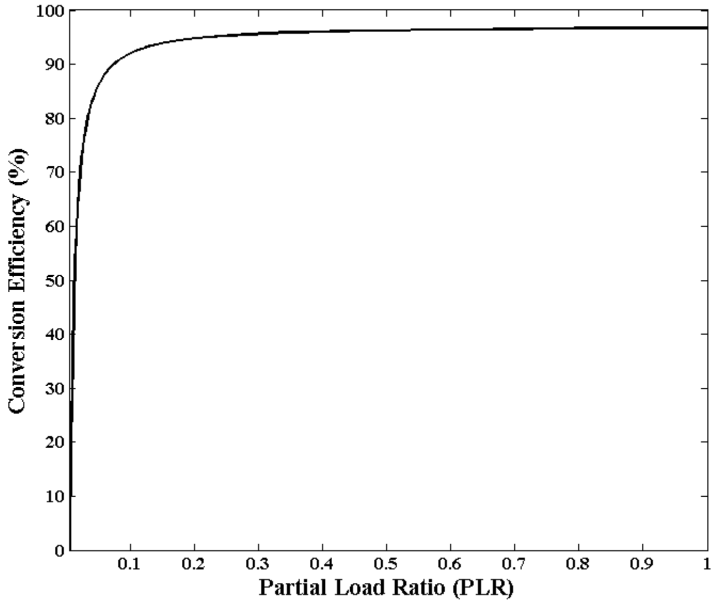


Figure 38 Inverter conversion Efficiency with respect to change in partial load ratio

Figure 38 shows the effect of PLR on the efficiency of the inverter (refer Appendix-VI). The European efficiency is a useful comparative tool to compare the performance of the inverters at the different operating point. The general form of the effectiveness regarding weighted conversion efficiency is as follows;

$$\eta_{euro} = \sum_{i=5,10,20,30,50,100} k_i \eta_{i\%} \tag{41}$$

Where $\eta_{i\%}$ represents the efficiency of the inverter at $i\%$ of rated power of the inverter. k_i is the corresponding weights provided to different operating conditions. The values of k_i are 0.03, 0.06, 0.13, 0.1, 0.48 and 0.2 respectively [**42**,**43**].

3.2 Methodology and Development of the model

Various predictive models reported use different methods or algorithms to predict the energy production of a PV system. Huang C. et al. [**44**] proposed an EP algorithm to predict the power output of the PV array by adjusting the fill factor, with an acceptable R^2 parameter under sunny (99.79% and 99.08%) and cloudy (99.59% and 99.62%) conditions for two experimental stations considered. Another study by Steffen R.E. et al. examines six independent variables (Installation capacity, shading, longitude, latitude, seasonal climatic variation, and orientation) to calculate system output using a regression model (R^2 ~ 0.832) for grid-connected PV systems [**45**]. Cameron C.P. et.al propose and evaluates the system accuracy of SAM (Solar advisor model) which predicts the energy production precisely [**46**]. The SAM model comprises of the radiation model (within 2% error), inverter model (within 1% error), and module performance models (within 5%, 10%, 4%, 11% absolute error). A short term power forecasting model, developed by Monteiro C. et.al, for PV Plants named Historical Similar Mining (HISIMI) provides a normalized RMSE of 10.14% during evaluation of the plant output [**47**].

The models those uses software simulation environment for predicting energy output are also reported by some researchers. A case-study shows the use of APROS Simulation showing the error of 2% to 7% of the measured value [**48**]. Aste N. et.al presents a long-term prediction model by using TRANSYS and PVsyst software for Europe with R^2 value greater than 0.99 [**20**].

The models presented in this section use the PV production data obtained for 1195 locations in Odisha using PVGIS method, after normalized to per kW_p, to predict the outcome of PV plant [**32**]. The regression analysis by a robust least square method using Matlab curve fitting tool provides the coefficients of the functions for the proposed models.

The plotted 3D graphs show the distribution of the range of PV electricity production for all kinds of combination of the input parameters.

3.2.1 Methodology to generate the Model

The initial phase of the model development identifies and collects all the main influencing factors that affect the performance of PV module. The parameters affecting the performance of PV module are mostly the climatic and technical in nature. The climatic factors are stochastic in nature and has more influence on the performance of the PV module. Among all the climatic factors global radiation and the ambient temperature is chosen as the input parameters of the model. Similarly, temperature coefficient is selected as the response parameter for the models. By using different PV production evaluation methods, the PV production output is estimated for the various selected location.

With these collected parameters and response, a simple model named simplified model (SFM) is created that takes three input parameters for the prediction of the annual PV production of the plant. Among the among the three parameters two are variables: Annual incident global radiation and Annual average air temperature, and one is a constant (temperature coefficient). The annual average air temperature is converted into differential module temperature inside the model that is the actual input variable. The SFM is again simplified and another model named further simplified model (FSFM) is created. The FSFM takes only two input variables (Annual incident global radiation and Annual average air temperature) for the prediction. The comparison of both the models is done simultaneously to analysis various cases and study the deviation in results.

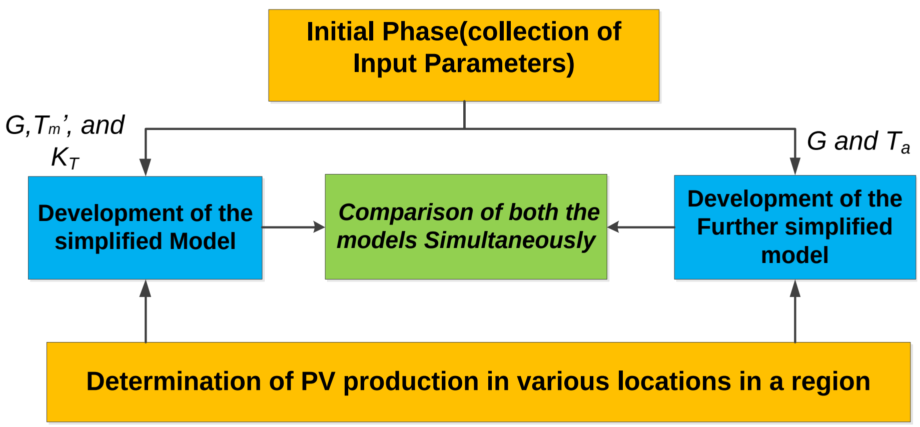


Figure 39 Methodology to implement the SFM and FSFM

3.2.2 Simplified model (SFM)

The SFM is the modified Output function of PVGIS energy rating method. The estimated output of the model is independent of any other influencing factors except for three input parameters: global radiation, air temperature, and temperature coefficient. Model converts air temperature to differential module temperature defined as the function of the average air temperature and incident global radiation. The proposed model equation for SFM, Based on PVGIS power estimation information [**32**] is described by equation (42) and equation (43).

$$\frac{P}{P_k}(G',T'_m) = G' + k_1 G' \ln(G') + k_2 G' ln(G')^2 + k_3 G' T'_m + k_4 G' T'_m \ln(G') + k_5 G' T'_m ln(G')^2 + k_6 G' T'^2_m \quad (42)$$

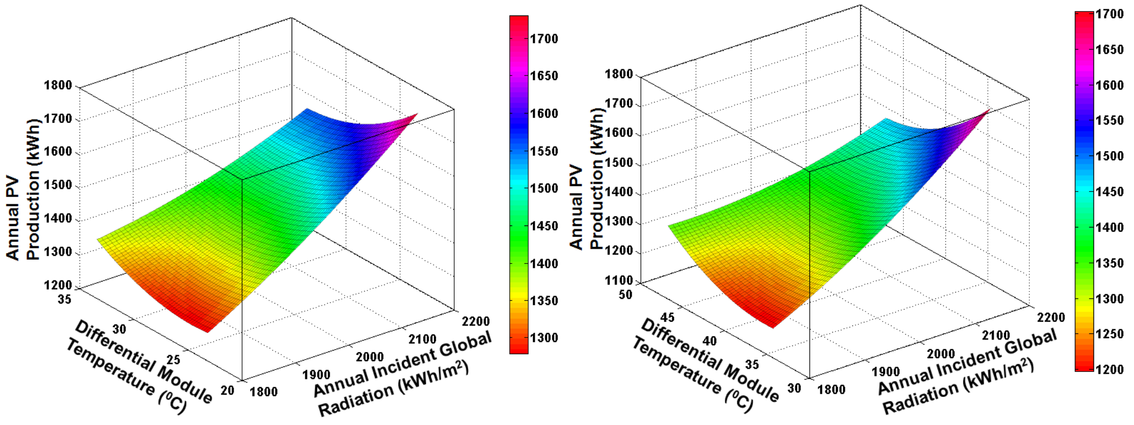
$$T_m{}' = T_a + K_T g - 25 \quad (43)$$

Where, $G'(= G/1000)$ is the total incident global radiation for the year in kWh/m^2, $T'_m(= T_m - 25)$ is the differential module Temperature in ^{0}C, and g is the average incident global radiation per hour in kW/m^2. Table 4 presents the input and output parameters provided to SFM with their value ranges. As indicated in the table the ranges of annual Incident Global radiation is equal for both the mounting option, however, different for both the tracking methods. The range of input value for the differential module temperature changes for each tracking and mounting option.

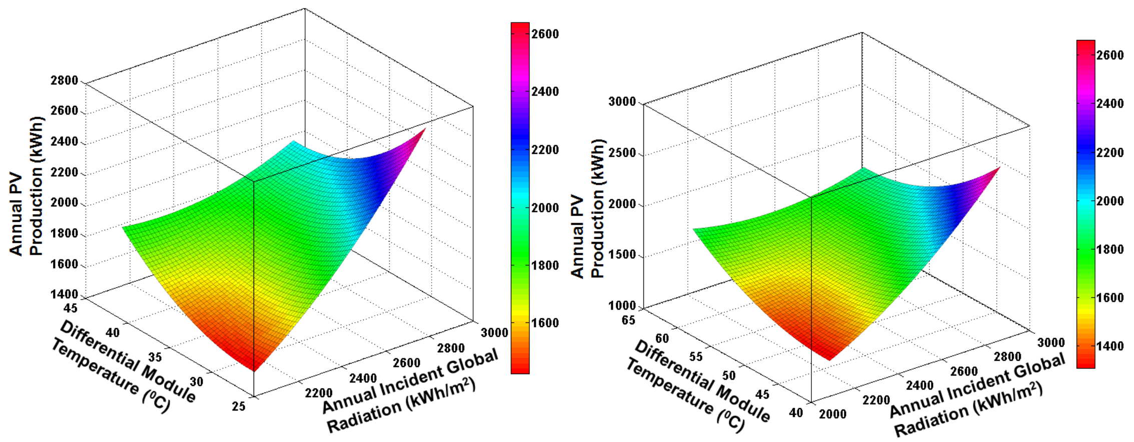
Table 4 Range of the input parameters provided to SFM and plant output

Input parameters range for SFM	**Non-Tracking PV system**		**Tracking PV system**	
	Freestanding	*Building Integrated*	*Freestanding*	*Building Integrated*
Annual Incident Global radiation (kWh/m^2)	1820-2180		2140-2850	
Differential module temperature (^{0}C)	22.44-33.93	33.69-47.41	27.06-43.59	40.28-61.21
Temperature Coefficient (^{0}C/ (W/m^2))	0.035	0.05	0.035	0.05
Plant production kWh	1220-1550		1400-2030	

The 3D plot provided in Figure 40 shows a comparison of the fitting response of the developed SFM for various mounting and tracking options. As the temperature coefficient of the building-integrated mounting is higher compared to freestanding, the module gets heated more quickly. The increase in cell temperature in the building-integrated structure accumulates further temperature losses that reduce the production. The production of the freestanding structure is higher (indicated by comparing blue or higher color region in both the graphs) than the building-integrated structure. The implementation of the tracking option increases the incident radiation on the module that raises the production of the module. The increase of radiation considerably increases the cell temperature of the module.



(a) Non-tracking Freestanding Model (b) Non-tracking Building Integrated Model



(c) Tracking Freestanding Model (d) Tracking Building Integrated Model

Figure 40 Comparison of Fitting response of SFM for various tracking and mounting options

Fitting of the non-tracking model uses Least Absolute Residuals (LAR) with Trust-Region [**49**], a type of robust least squares method. The Robust least squares method utilized for the fitting of the Two-axis tracking model is Bisquare method with Levenberg-Marquardt [**50**] algorithm. Fitted model coefficients presented for four types of model are tabulated in

Table **5**. These six coefficients can be used in the SFM equation to estimate the predictive response of the model. The RMSE value is around 1.2 kWh for non-tracking and 7.1 kWh for tracking model. The R^2 parameter is around 0.99 for all the system that indicates a very close to the response parameter estimated in PVGIS method. The closeness of the predictive response of the non-tracking model is better than tracking model.

Table 5 Results of fitting of data for SFM

Fitting parameters / System	**Non-Tracking PV system**		**Tracking PV system**	
	Freestanding	*Building Integrated*	*Freestanding*	*Building Integrated*
K_1	-1.784	-2.989	-2.828	-3.879
K_2	0.2405	0.4067	0.3759	0.5192
K_3	2.452	2.564	2.482	2.322
K_4	-0.5927	-0.6123	-0.5689	-0.5311
K_5	0.03481	0.03526	0.03111	0.02884
K_6	0.0007039	0.0006302	0.000885	0.0006489
RMSE	1.179	1.242	6.977	7.257
R^2	0.9989	0.9987	0.9918	0.9902

3.2.3 Further Simplified model (FSFM)

FMSM use only two inputs: annual incident global radiation and annual average air temperature decreasing the dependents to three fitting parameters. FMSM, given by equation (44) uses the annual average air temperature value directly instead of differential modular temperature. The values for various input and output parameters are tabulated in Table 6. The range of input values for annual incident global radiation and Plant production remains same for both the model.

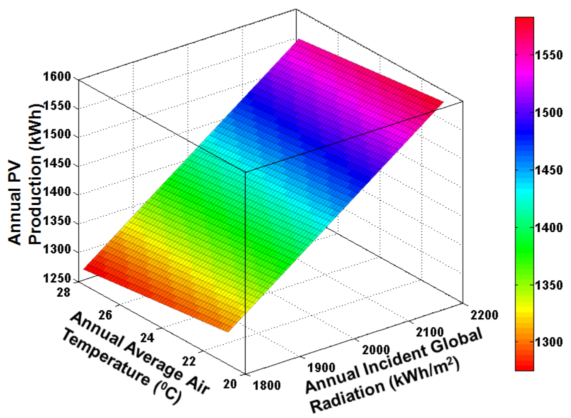
$$\frac{P}{P_k}(G', T_a) = aG' + bT_a + c \tag{44}$$

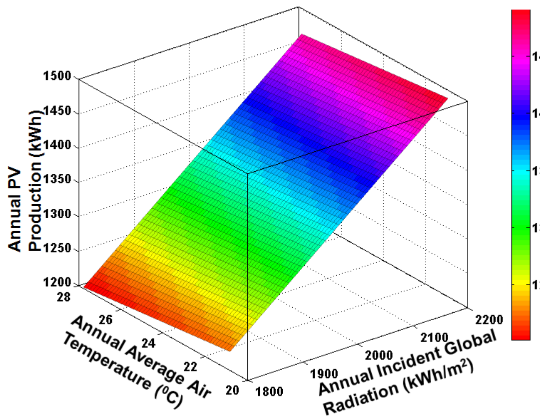
Table 6 Range of the input parameters provided to FSFM and plant output

Input parameters range for FSFM	**Non-Tracking PV system**		**Tracking PV system**	
	Freestanding	*Building Integrated*	*Freestanding*	*Building Integrated*
Annual Incident Global radiation (kWh/m^2)	1820-2180		2140-2850	
Annual Average Air temperature (^0C)	21.2-27.5			
Plant production kWh	1220-1550		1400-2030	

The 3D graphs provided in Figure 41 shows a comparison of the fitting response of the developed two-axis tracking FSFM for various tracking and mounting options. As the proposed model is a linear model, the decrease in PV production for the building-integrated mounting can be indicated by comparing the range of the Z-axis data of the plot. Unlike the previous model here the change in the range of the production does not affect the color pattern of the plot. Implementation of tracking raises the production of the PV significantly.

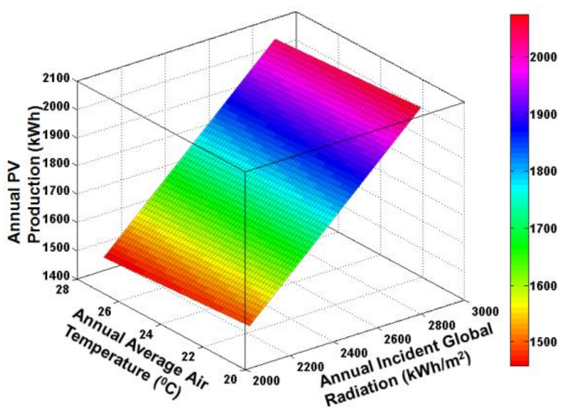
Fitting of the FSFM uses Bisquare method with Levenberg-Marquardt algorithm for both the development tracking and non-tracking model. The results of the fitting for four kinds of the model are shown in Table 7. The number of the model coefficient for the FSFM is half of the SFM. The RMSE value is around 5.5 kWh for non-tracking and 7.7 kWh for tracking model. The R^2 parameter for the tracking model is around 0.99 and for the non-tracking model is 0.98. The closeness of the predictive response of the tracking model is better compared to the non-tracking model.

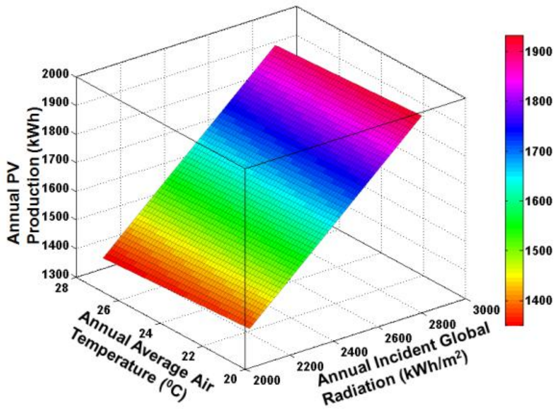




(a)

(a)Non-tracking Freestanding Model (b) Non-tracking Building Integrated





(c) Tracking Freestanding Model (d) Tracking Building Integrated Model

Figure 41 Comparison of Fitting response of FSFM for various tracking and mounting options

Table 7 Results of fitting of data for FSFM

Fitting parameters / System	**Non-Tracking PV system**		**Tracking PV system**	
	Freestanding	*Building Integrated*	*Freestanding*	*Building Integrated*
a	0.7015	0.6655	0.7433	0.7049
b	-4.269	-3.664	-5.031	-4.503
c	129.3	103.4	34.06	-8.927
RMSE	5.519	5.413	7.612	7.774
R^2	0.9768	0.9756	0.9902	0.9887

3.3 Analysis and Comparison of the Developed Models

To understand the preciseness of both the model the comparison of the results of both the models for tracking options and mounting options simultaneously is necessary. Initially, the input parameters of both the models should be equalized before proceeding with the comparison. The differential module temperature parameter can be replaced with annual average air temperature in the SFM by using the equation (43).

A single Simulink block named 'PV System', as shown in Figure 42, compares the results of both the models for tracking options and mounting options simultaneously. The user can set two input parameters: G and T_a with various tracking and the mounting option in the source block to estimate the outputs. The user can set two input parameters: G and T_a (for both the models) with various tracking and the mounting option to evaluate the outputs. Figure 9 represents the mathematical block model inside the mask of the PV system which represents the model equation. Within the climatic condition of Odisha, the prediction of both the model within the radiation and temperature range of Odisha is close to each other. For the verification of the above theory, the comparison of the prediction between the two models is plotted by considering different operating conditions. In the first comparison, the temperature is kept constant, and the effect of variation of radiation is studied. In the second comparison, the radiation is kept constant, and the effect of a change in temperature is investigated.

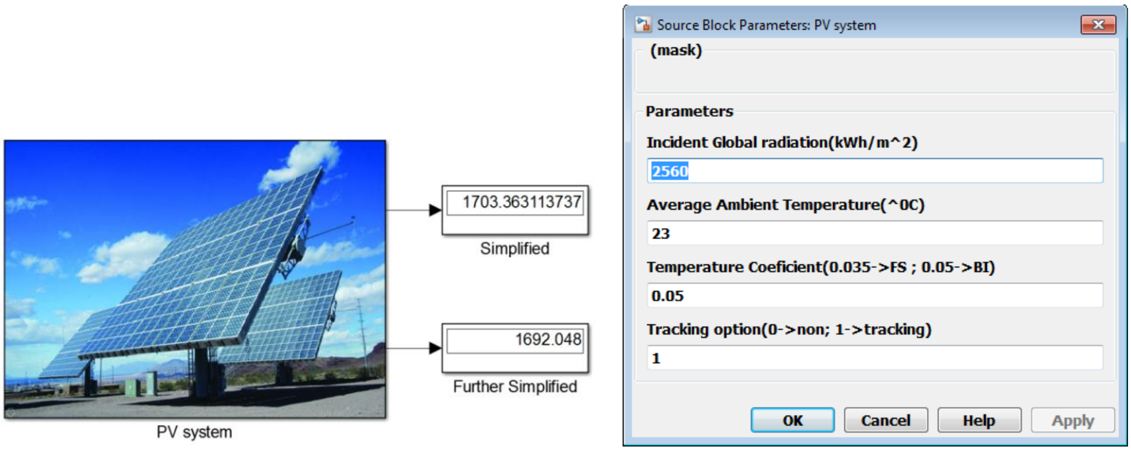


Figure 42 The representation of all the models into a single block generated using Simulink and Block parameters of the PV system.

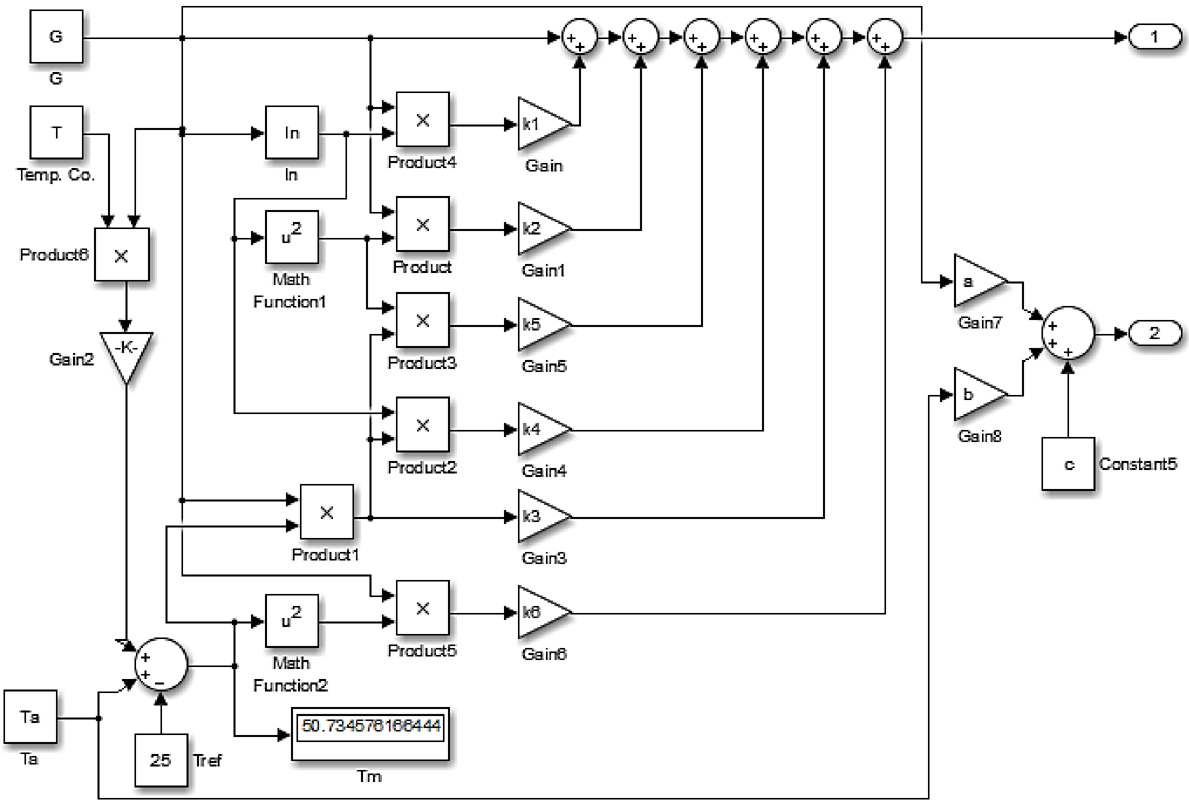


Figure 43 Depiction of the mathematical model inside the block

The comparison of the generated output for a Non-tracking and Two-axis tracking PV system on variation in radiation is shown in Figure 44 and Figure 45 respectively. By keeping the ambient temperature constant at 25^0 C, the PV production is predicted for both the models. The model equation for both the models becomes in the equation (45) and equation (46).

$$\frac{P}{P_k} = \sum_{n=1}^{3} G'^{n} \left(k_{1n} \ln(G') + k_{2n} \ln(G')^2 + k_{3n}\right)\Big|\, k_{13} = k_{23} = 0 \text{ (SFM)} \qquad (45)$$

$$\frac{P}{P_k} = a_1 G' + b_1 \text{ (FSFM)} \qquad (46)$$

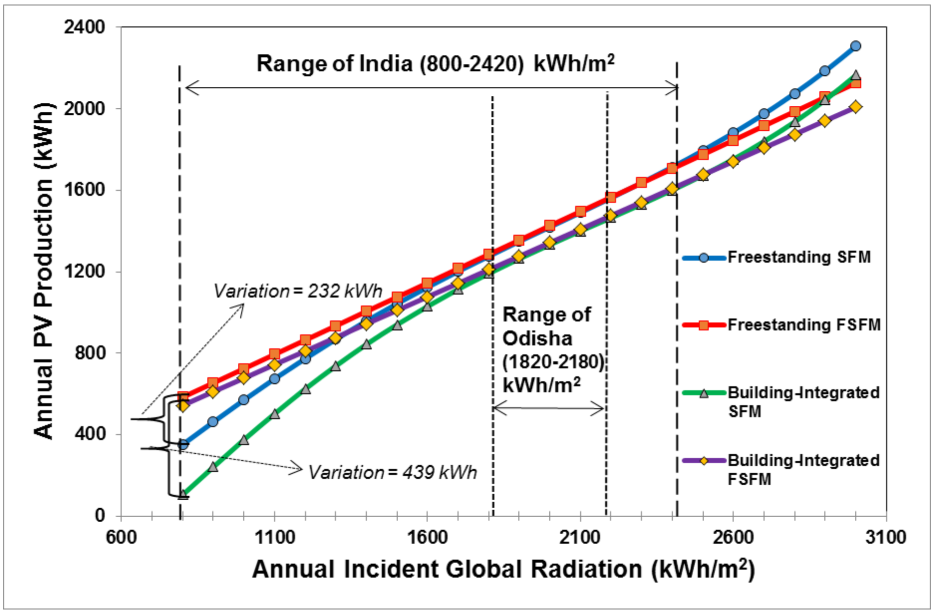


Figure 44 Comparison of the generated output for a Non-tracking PV system on variation in radiation by keeping the ambient temperature constant at 25^0 C

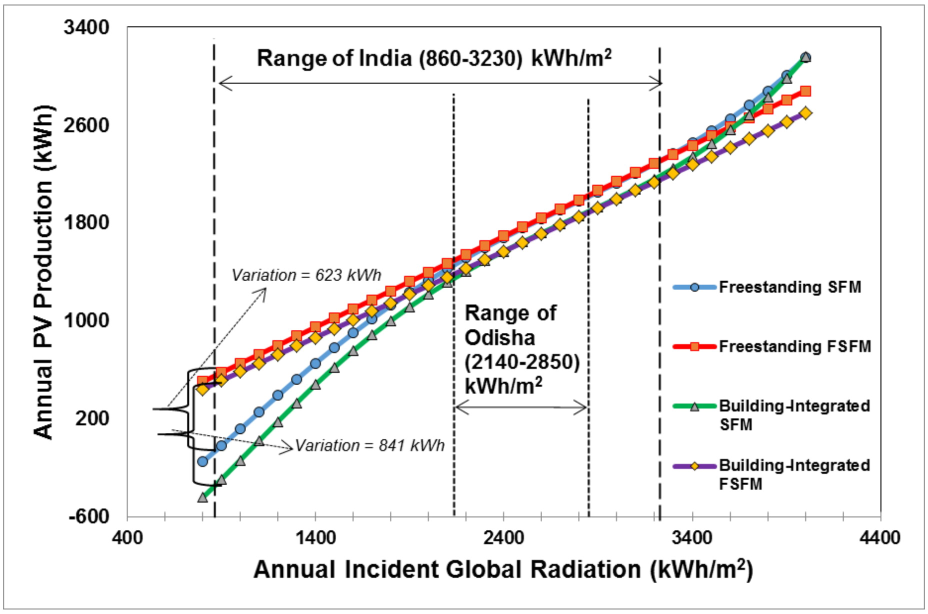


Figure 45 Comparison of the generated output for a Two-axis tracking PV system on variation in radiation by keeping the ambient temperature constant at 25^0 C

The estimated PV production is linear for the change in radiation while the temperature remains constant. As the radiation data is within the climatic condition of

Odisha, the error of prediction between the models decreases. Outside the region of Odisha, the difference between the predictions gradually increases. In the lower radiation boundary of India, a distinction between the prediction for the non-tracking and tracking setting of both the models are 232 kWh, 623 kWh (Free-standing) respectively and 439 kWh, 841 kWh (Building-Integrated) respectively. The difference in prediction for the building-Integrated system is more than the freestanding one. In the lower bounds of radiation, the sensitivity of the building-integrated system increases. As the prediction value for SFM becomes negative in the lower regions (refer Figure 45), it justifies the inaccuracy of the SFM to be more beyond the operating area of Odisha.

Similarly, the comparison of the generated output for a non-tracking and two-axis tracking PV system on variation in ambient temperature is shown in Figure 46 and Figure 47 respectively. The radiation is kept constant at 2000 kWh/m^2 and 2500 kWh/m^2 for non-tracking and two-axis tracking model respectively. The respective model equation is given by equation (47) and equation (48).

$$\frac{P}{P_k} = k_x T_a^2 + k_y T_a + k_z (\text{SFM}) \tag{47}$$

$$\frac{P}{P_k} = a_2 T_a + b_2 (\text{FSFM}) \tag{48}$$

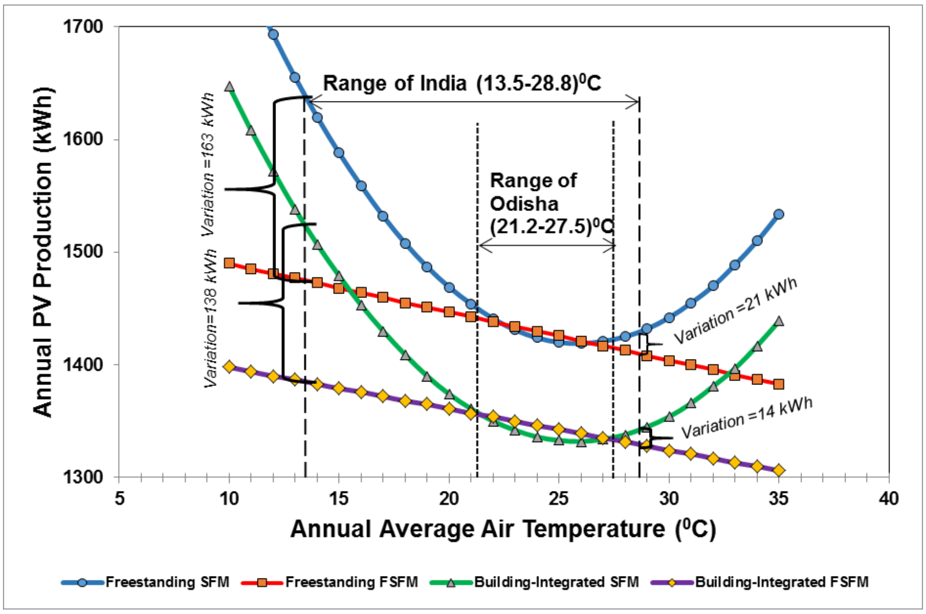


Figure 46 Comparison of the generated output for a Non-tracking PV system on variation in the ambient temperature by keeping radiation constant at 2000 kWh/m^2

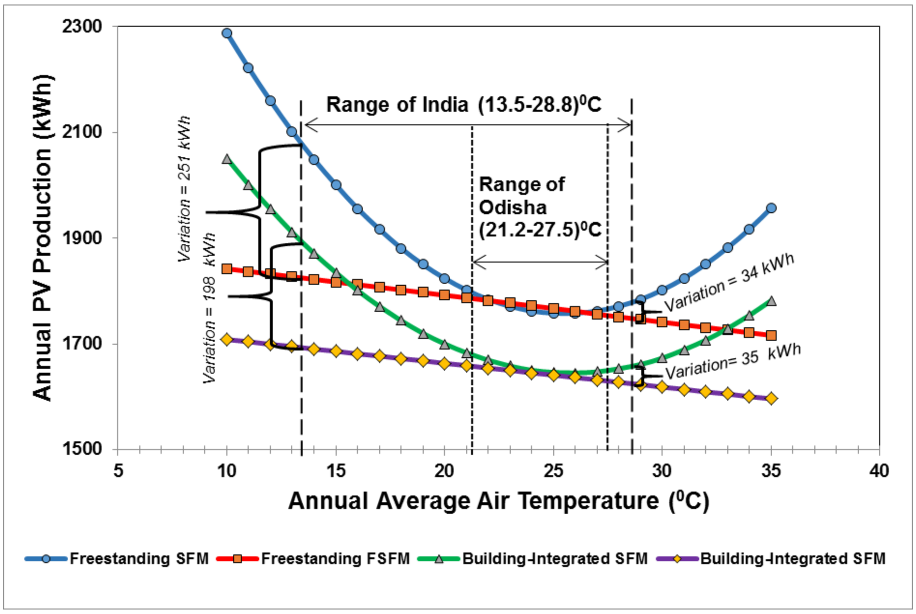


Figure 47 Comparison of the generated output for a Two-axis tracking PV system on variation in the ambient temperature by keeping radiation constant at 2500 kWh/m^2

The characteristic of the plot for the SFM is parabolic in nature however the FSFM gives a linearly decreasing plot. Within the climatic condition of Odisha, the error in prediction of both the model reduces, whereas, outside the region of Odisha, the error between the predictions gradually increases. In the lower radiation boundary of India, a distinction between the prediction for the non-tracking and tracking setting of both the models are 163 kWh, 251 kWh (Free-standing) respectively and 138 kWh, 198 kWh (Building-Integrated) respectively. In those conditions, the error in prediction for the building-Integrated system is less than the freestanding one. Again the error in prediction becomes more in the case of variation in the radiation rather than the change in temperature of the PV module.

3.4 Validation of the model

Odisha host eleven major solar PV power plants which are connected to the grid, seven out of six plants use c-Si modules while others produce power using thin film modules. (refer Figure 48). The first solar power plant (REHPL Balangir Solar Power Project) of Odisha commissioned in 2011 under the JNNSM situated at Balangir [9]. Seven power plants have been visited and from 5 plants data are successfully collected. As the model works only for c-si technology, data from thin film plants are not used for the validation purpose. The section is to analyze the preciseness of both the model's forecast for Odisha by validating the response with respect to the generation and weather data collected from SN Mohanty solar power plant which runs with c-Si modules. From SN Mohanty solar plant maximum 3 years of data (2013-15) is obtained which is used as the data for validation.

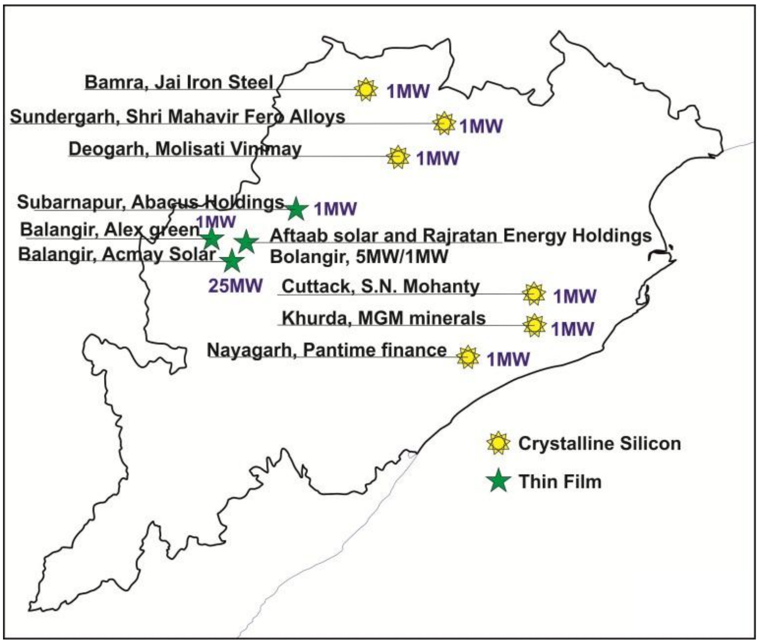
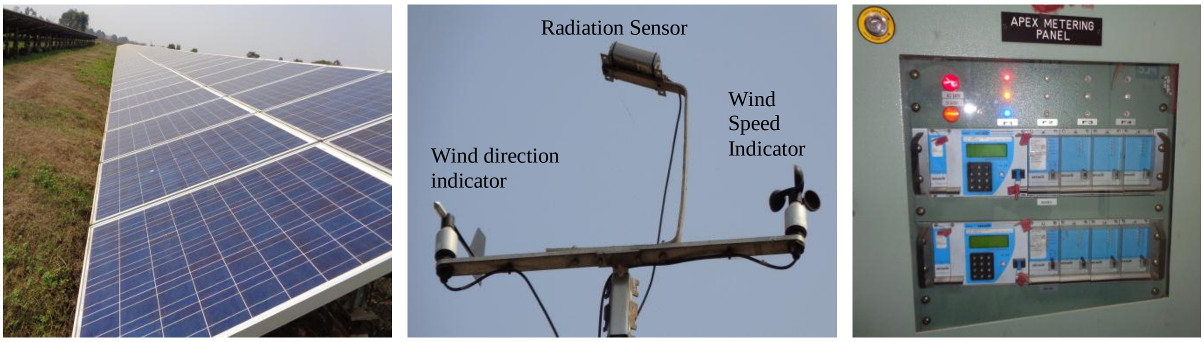


Figure 48 Location of the commissioned MW-scaled, grid connected Solar PV Power Plants throughout the region of Odisha

SN Mohanty solar power plant developed by SN Mohanty and established by Tata BP solar uses c-Si technology for power production. The power plant was commissioned on 23rd august 2011 near Patapur village, in Cuttack district of Odisha. The capacity of the power plant is 1MW produced through around 4300 panels, with each panel rated 230 Wp. Freestanding mounting is implemented in the modules of the plant. The plant uses two inverters each with a capacity of 500 kW. An SCADA system is implemented to record all the plant production related data while a weather monitoring station records all the weather related data, refer photographs shown in Figure 49. For validation of the developed models, all the SCADA data was collected for three years is successfully obtained from the plant. Data included generation data (generated power, generated Energy, Voltage, current, plant on time, grid outage), weather data (ambient temperature, incident direct radiation, wind speed, module temperature). The term grid outage denotes the time in which the grid is down that may be due to failure or low radiation, considered throughout the period of on duration of the plant. Plant on time denotes the operating period of the plant (not the production period) for a day. Out of all the three-year data collected, data analysis for the year 2014-15 is discussed here.



(a) (b) (c)

Figure 49 a) SN Mohanty Solar Power plant, Cuttack (Odisha) b) Weather monitoring station c) Metering panel

The average energy production and radiation of the plant for the year 2014-15 were 3269 kWh/day and 3877 Wh/m^2. Out of the 365 days of the calendar year, 12 days of radiation and 20 days of ambient temperature data found missing due to failure and data-recording error of the SCADA system as shown in Figure 50. Grid outage occurred in the plant frequently which reduced the energy yield of the plant. The maximum hours of grid outage were recorded on 27th May in which the production of the plant was down for 12 hours. From 3rd to 10th October, major failures in SCADA system occurred for which only the temperature and radiation are found to be missing from the record. There are cases of records of erroneous data (19th January and 14th December) for due to the error in the SCADA system which shows a significant increase in the plant on duration. Odisha is a cyclone prone area and almost every year the cyclone hits the state. On 12th Oct 2014 and from 12th to 14th Oct 2013, the operation of the plant was halted due to the major cyclone occurred in the eastern part of Odisha where the plant is located. The average on-time of the plant for the last three year is 11.16 hours, out of which 1.42 hours is attributed to the grid outage.

The energy yield of the plant typically follows the irregular pattern of the radiation. In the rainy season and in overcast conditions the radiation incident on the module becomes small. The cloudy condition significantly reduces the plant output, and torrential rain halts the plant operation from time to time. From the month of June to August in 2014, the energy production of the plant becomes weak mostly due to the rainy season. The average daily ambient temperature around the plant varies from 28 ^{0}C to 39 ^{0}C for the year of 2014. As the temperature and radiation data are proportionally correlated, the parameter affects the plant production indirectly. However, higher value in ambient temperature significantly raises the PV module temperature and reduces the production of the plant. The durations of operation of the plant become greater in the season of summer (April-August) due to increasing in sun hours. On 22nd May, the plant operates for 12.88 hours which is maximum for the year.

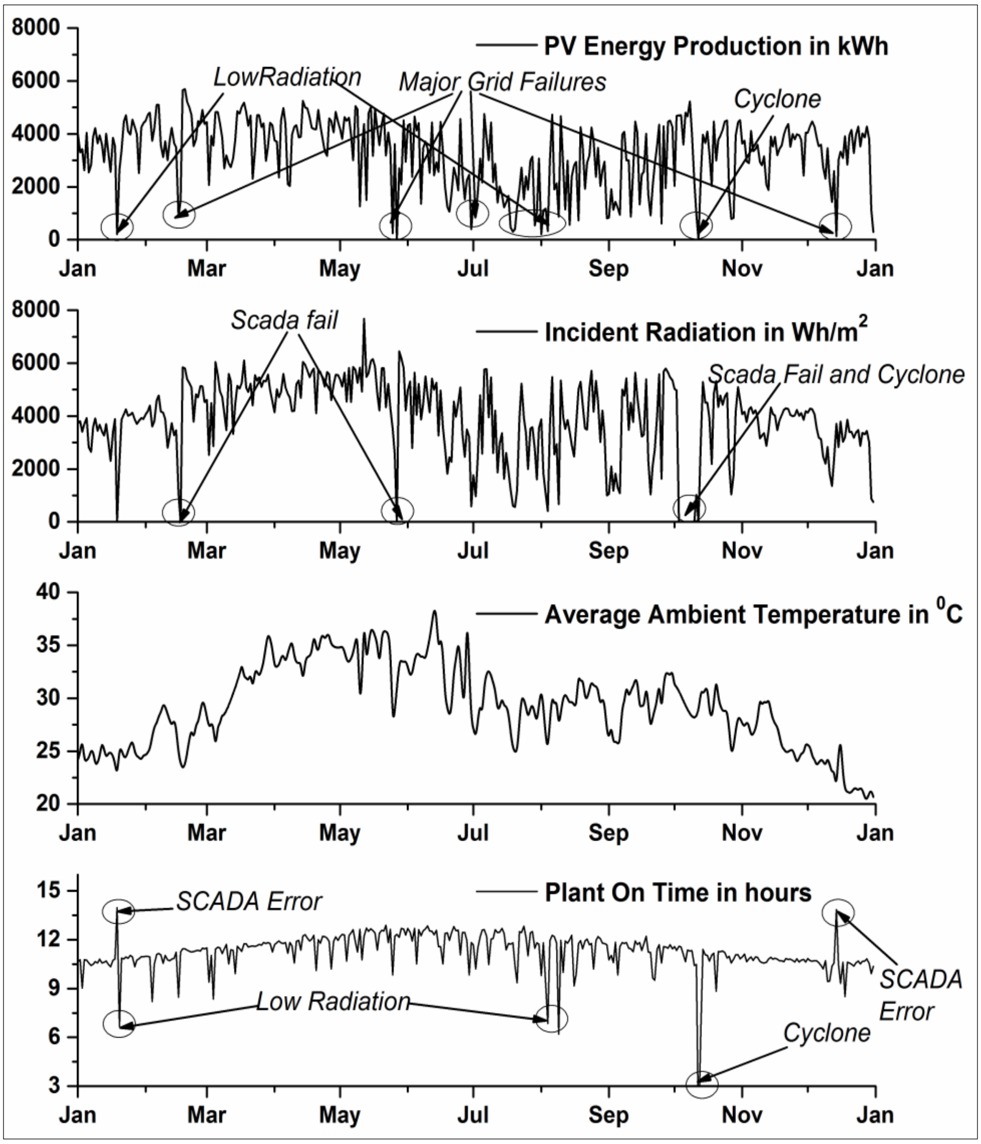
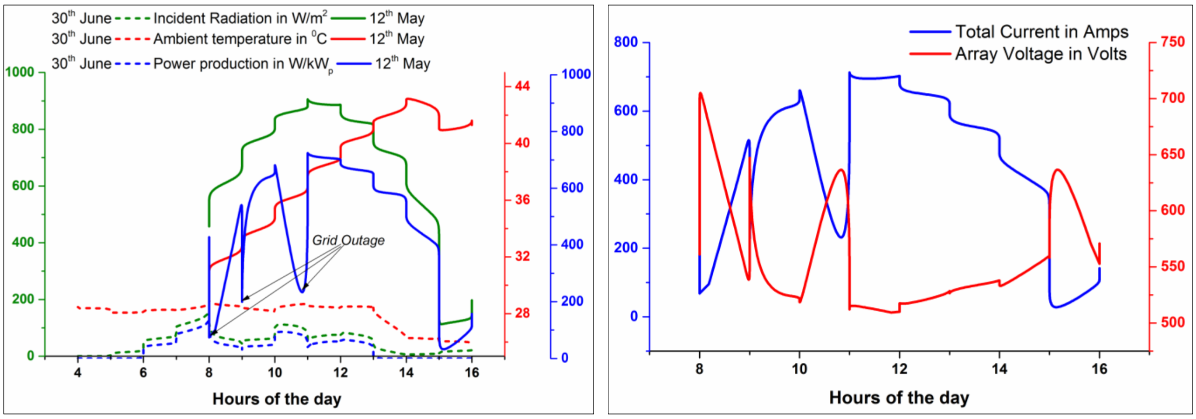


Figure 50 Analysis of the data collected from the SN Mohanty power plant for the year of 2014-15

The daily analysis of the plant for a bright sunny weather and a typical overcast condition are analyzed to check the behavioral characteristics of the plant in optimal and pessimal weather conditions. On 12th May 2014, the total radiation of 7684 Wh/m^2 was recorded, which was maximum for the year. Figure 51 shows the array voltage and current profile of an inverter for the day, 12th May. On the day, the plant was operated for 12.22

hours with around 8 hours of data being recorded (SCADA failure) out of which 1.75 hours were from the grid outage. The linear pattern of increment in temperature from 30.1 ^{0}C to 43 ^{0}C evidences the weather to be bright sunny. During the overcast conditions, like as shown for 30th June, the total radiation 580 Wh/m^2 was measured. The duration of operation of the plant for the day was 11.83 hours with 3.87 hours of the grid outage. Due to overcast condition, there is no periodic variation of temperature observed. The average temperature for the day was 27.9 ^{0}C. The effect of radiation on the production of the plant is clearly visible in the in Figure 51 (a). As shown the pattern output production of the plant proportionally trails the incident radiation except the duration of the grid outage.



(a) (b)

Figure 51 (a) Analysis of the plant in typical overcast conditions (30th June 2014) and on bright sunny weather conditions (12th May 2014) (b) typical analysis of array voltage and total current of the inverter on 12th May 2014

The analysis and comparison of the three years data collected from SN Mohanty 1MW power plant at Cuttack with the predictive results of the model are as shown in Table 8. The error displayed by the two models (SFM, and FSFM), relative to the expected energy output from the plant, lies in the range of -2.89 to -3.75 % and 0.37 to 1.56 %. Factors like lack of grid connectivity (transmission line failure, RMU tripping, low voltage, and grid failure), a failure of the SCADA (data-recording) system to record the temperature and radiation data, harass weather conditions (cyclone, torrential rains) and lower incident radiation than average expected radiation is responsible for the error.

Table 8 Analysis of the SN Mohanty solar Power plant data for the validation of the model (D/G-Direct/Global)

Year	**Grid outage time (hours)**	**Plant ON time (hours)**	**Incident Radiation D/G (kWh/m^2)**	**Annual Avg. Ambient Temperature (°C)**	**Generated Energy per kWp (MWh)**	**Prediction of the model (MWh)**		**% Error**	
						SFM	*FSFM*	*SFM*	*FSFM*
2013-14	580.38	4036.9	1467/1728	29.2	1.221	1.267	1.216	-3.75	0.37
2014-15	500.35	4103.7	1415/1667	29.1	1.193	1.227	1.174	-2.89	1.56
2015-16	479.15	4075.3	1463/1724	29.5	1.226	1.269	1.212	-3.53	1.10

The analysis and production for the year of 2015-16 are optimal as no cyclone and missing data with relatively less amount of grid outage time is present. The negative error of the SFM indicates the optimistic nature of the model while the positive error of FSFM indicates the pessimistic behavior. Although the prediction of the plant does not consider the parameters like grid failure time (a subset of grid outage), plant off time (due to a cyclone or inclement weather) still the prediction gives a reasonably accurate response. As tabulated in Table 8, even if the value of incident radiation is more in the year 2013-14 compared to 2015-16, due to additional grid outage hours the production is lower. As the grid outage doesn't affect the prediction of the models, the reduction in the power production increases the error of SFM and decreases the error of FSFM. Even if the plant on time is highest in 2014-15 compare to another year, still the radiation is lowest due to the absence of recorded data for the radiation (SCADA failure). As the radiation data affects the model prediction directly, the prediction of the model decreases. The reduction in the model prediction forces the positive error to increase and negative error to decline in 2014-15. Although the FMSM works on only two inputs, still the proximity of prediction is better than the SFM.

3.5 A case study for NIT Rourkela

The study provides the prediction of the PV energy yield for the campus off NIT, Rourkela from three different sources i.e.: With online software tools, designed data Predictive Models, and in-house build software. NIT Rourkela is situated at the coordinate position of (22.251N, 84.909E) which is selected as the location input for the online software tools i.e.: PVGIS and PVwatts [**51**]. The model takes only annual global insolation and average air temperature data as the set points before the prediction. The meteorological inputs provided to the model are collected from the NASA. The software uses different analytical equations and methods while predicting the energy yield. The software takes the data for radiation and temperature from the monthly radiation tool of PVGIS and SolarGIS tool respectively. The study focuses on evaluating the three different predictions while addressing the impact of climatic weather conditions for the development of a real solar power plant inside the campus of NIT Rourkela.

3.5.1 Climatic parameter analysis

NASA provides climatic parameters like radiation, temperature (air, soil, and dew point), clear sky index, humidity, etc. for any desired location on Earth from the year of 1984 to 2004 [**52**]. All the required parameters like solar insolation, temperature, etc. are collected by NASA for the region of NIT Rourkela. 21 years average data of the parameters have been created to compare all the related meteorological parameters with each other for one year.

Figure 52 represents the similar data from NASA for various types of Insulations falling around NIT Rourkela. Top of Atmosphere (TOA) insolation represents the direct solar radiation falling outside the atmosphere of the earth (above NIT) which is the highest. Clear sky insolation (CSI) accounts for the radiation falling on the land with the absence of cloud or any atmospheric particles that block the path of the radiation. The CSI can be direct, diffuse or global. The solar radiation emitted, reflected, or received; per unit time in the downward direction is called as downward long-wave radiative Flux. Global horizontal insolation (GHI) is the horizontal radiation falling on the earth. In Figure 52, the value of direct CSI is highest compared to diffusive and GHI. On average around 16% of the direct is the diffuse CSI and 78.7% is GHI. Figure 53 shows a comparison between the Insolation clearness index (ICI) and clear sky ICI. The sudden dip in the value of ICI is due to the presence of dense clouds in the rainy season. Comparing GHI with Clear sky GHI throughout the year, one can see mostly a similar pattern of radiation; however the radiation decreases significantly from the day 165 to the day 270; which is because of the sudden dip in ICI.

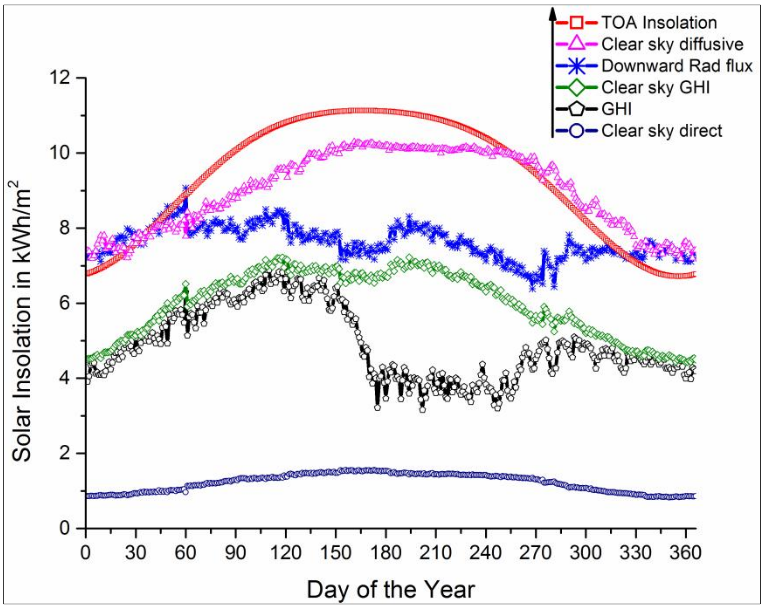


Figure 52 Analysis of various kinds of Insolation falling in the region of NIT Rourkela

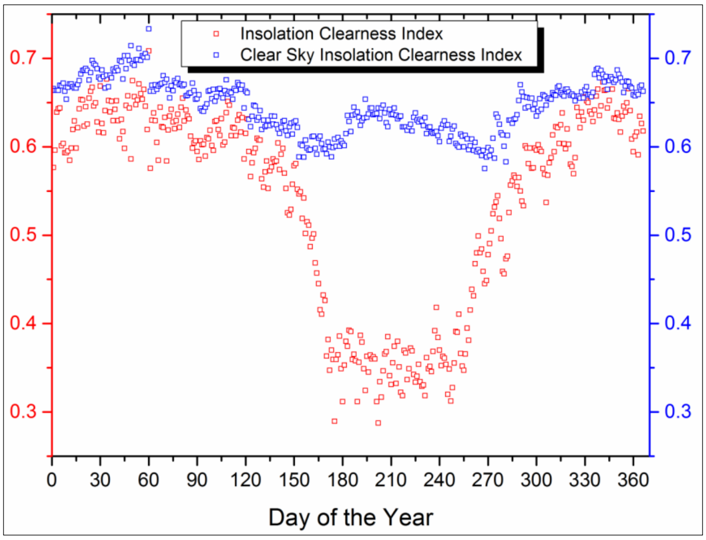


Figure 53 Comparison between ICI and Clear Sky ICI for NIT Rourkela

As Rourkela falls around the tropic of cancer, the temperature around is very high. From the Figure 54, one can see that the maximum air temperature in NIT Rourkela can be as high as 35^{0}C and minimum can be as low as 12^{0}C. The peak value of the temperature from the day 90 to 150 represents the season of summer. As per the data provided by NASA the average air temperature for NIT Rourkela for a year is 24.28^{0}C, where the average maximum is 28.51^{0}C and the average minimum is 20.23^{0}C. The data of the air temperature is measured at a 10m height from the surface of the earth. The average soil temperature around NIT Rourkela is 26^{0}C with a variation from 17^{0}C to 35^{0}C. The average dew point temperature in NIT Rourkela is 14.84^{0}C for a year.

In the case of implementation of tracking for PV system, the nature of variation of optimal tilt angle is provided in Figure 55. Inside the campus of NIT, the angle varies from -9^0 to 52^0 month-wise whereas the optimal tilt angle for the year is 27^0. The energy yield on the seasonal variation in optimal tilt angle shows an average production of 133.5kWh/month with a mean global radiation of 188.5kWh/m^2/month. From the month January to May and October to December the monthly energy yield is well above the mean value; however from the month June to September the prediction is below the mean value. The optimal azimuth for NIT is 0^0 which represents the southward direction. The comparison of monthly energy yield for NIT Rourkela only with the software tools is given in Figure 56. The value of energy yield for PVGIS and in-house build software is very close to each other. As per the plotted graph, all three methods follow the same pattern except in the month of November the PVWatts shows a sudden dip in yield compares to others.

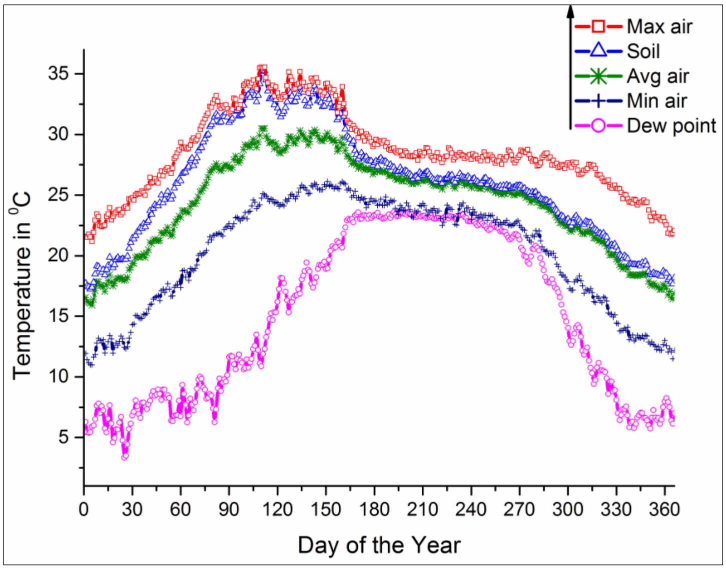


Figure 54 Comparison of various temperatures in the premise of NIT Rourkela

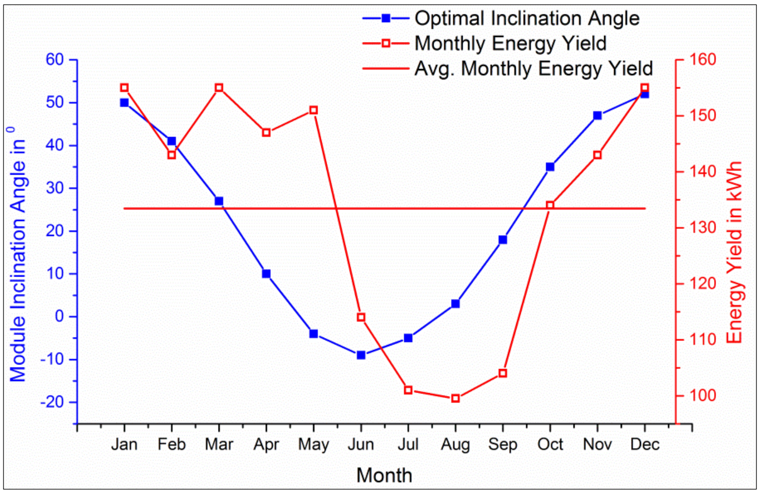


Figure 55 Variations in Monthly Energy Yield based on seasonal change in Optimal inclination angle

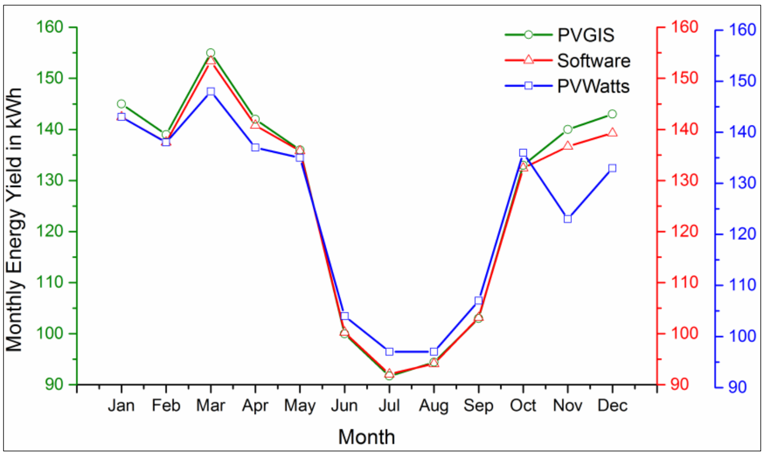


Figure 56 Comparison between monthly energy yields for NIT Rourkela with three different software

3.5.2 Estimation of PV energy yield

To estimate the PV energy yield inside the premises of NIT Rourkela three methods with various input parameters have been considered. Table 9 shows the results for the expected annual PV energy yield for the grid-connected PV system installed in the premises of NIT Rourkela. NIT Rourkela is situated at the coordinate position of (22.251N, 84.909E) which is selected as the location input. Estimation of PV Energy Production at NIT Rourkela Using PVGIS, PVwatts, and in-house build software is shown in Appendix-III, IV, and V respectively.

Table 9 Analysis of the PV Energy yield for NIT Rourkela by three different methods with the collected parameters from various sources for the period of one year (#-NASA; *-PVGIS inside NIT Rourkela; +-PVWatts; @- SolarGIS, **-PVGIS around Rourkela)

Methods		**Input of reference parameters**		**Yearly Output Energy Yield (kWh/kW_p)**
		Average Air Temperature for a year (^0C)	***Yearly Global Incident Radiation(kWh/m^2)***	
Online tools	*PVGIS*	No info	2140*	1520.00
	PVwatts		2084+	1498.00
Models	*SFM*	24.28#	1936.6#	1376.60
		24.9@	2140*	1520.70
			2084+	1480.53
	FSFM	24.9@	2084+	1484.92
			2140*	1524.21
		24.28#	1936.6#	1384.17
In-house build Software		24.9@	2146.68**	1507.96

The method that uses online tools and the in-house build software does not take any temperature or radiation data as input parameters for the estimation. Both the method receives the coordinate location as the primary inputs. The method of models can take various temperature and radiation as data for different predictions. For the selected area the average air temperature data is collected from two sources, i.e., SolarGIS and NASA. In the Online tools, no information about the temperature is provided. The software uses different analytical equations and methods while predicting the energy yield. The software takes the data for radiation and temperature from the monthly radiation tool of PVGIS and SolarGIS tool respectively. The global radiation data is collected from four sources i.e.: PVGIS at NIT Rourkela coordinate, PVWatts, NASA, and PVGIS with the coordinate around Rourkela.

All the predictions from the three methods depend on upon the incident radiation. As per the Table 9, the higher radiation data gains, the greater value of prediction and vice versa. As per Figure 56, the prediction of the software and the online tools are close to each other. The average output energy yield from the method of online tool is 1509 kWh where the software gives a prediction of almost 1508kWh. The in-house build software has its database for its input parameters. The output of the models depends on the input temperature and radiation. The prediction of the two models takes the combination of two average air temperature and three global incident radiation sources as input and predicts different output as per the selected combination. The prediction of the models with only the data collected from NASA is comparatively lower than other methods. However, the forecast of SolarGIS temperature and PVGIS or PVWatts radiation is closer to the other methods. Database of NASA is older than the PVGIS and PVWatts for which the radiation data shows lower value comparatively.

Chapter-4

Review of the current state policy framework of India

India, due to its geo-location near the tropic of cancer has the vast potential of solar energy. India receives a total per year average of Global horizontal insolation from 3.2 kWh/m^2 to 6.1 kWh/m^2 per day [**53**]. According to National Institute of Solar Energy (NISE), the total potential of the whole country is accumulated to be 748.98 GW_p [**54**]. As of 2016 the total Installed capacity for grid connected renewable power in India has reached 42.72 GW [**55**]. Figure 57 shows the distribution of grid-interactive renewable power capacity in India. In 2014 the solar power capacity in the nation consisted 9% [**56**] of the total capacity; however now it is increased to almost 16%, taking over the capacity of the small hydro, reaching the second highest capacity renewable power position in India. The energy policy framework of solar power in India is shown in Figure 58. The MNRE has decided to increase the total cumulative renewable power Install capacity in India to 175 GW by the end of 2022 [**57**].

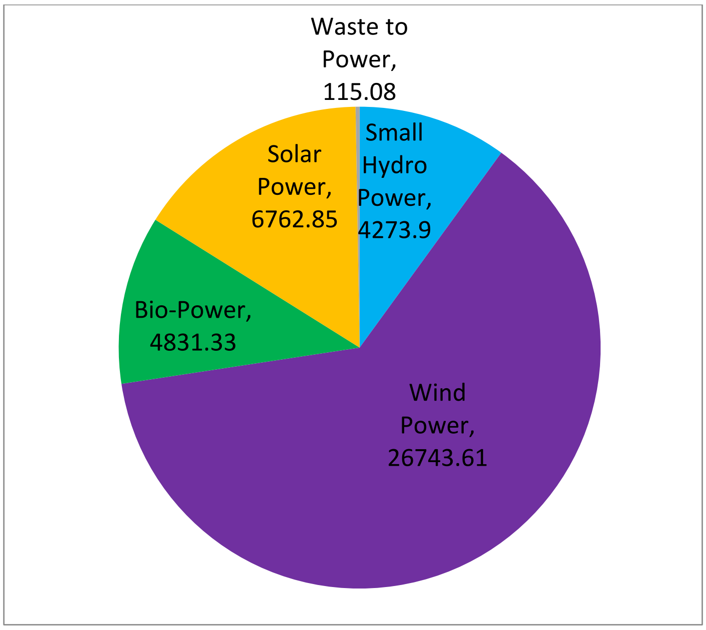


Figure 57 Distribution of grid-interactive Renewable power capacity of India in MW as on 31-03-2016 **[**55**]**

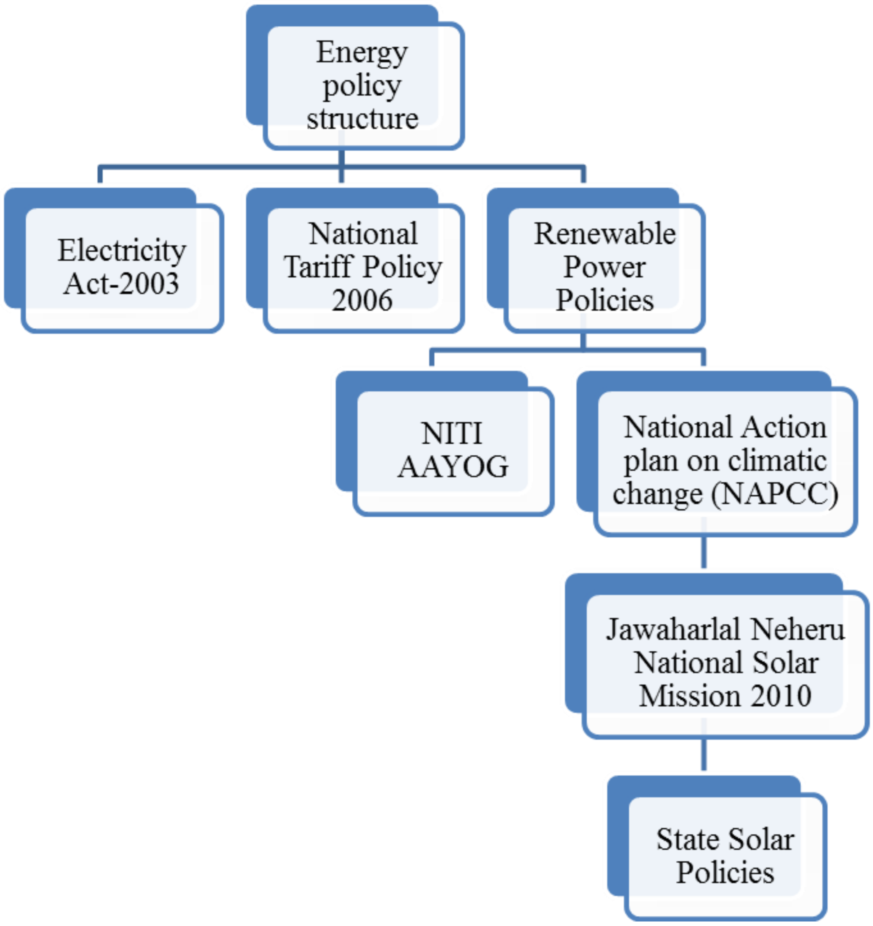


Figure 58 Energy Policy structure for solar power in India

4.1 Electricity Act-2003

The electricity act was set in 2003 to bring a reckon able revolution to the power sectors with new framework and development plans limiting the Government from any kinds of directive actions [**58**]. Apart from establishing laws for a generation, transmission, sharing and utility of electricity the objective of the act is to promote and rationalize electricity policies and tariff in the nation by establishing central electricity board of central and restructuring boards for each state. The act also deals with rural electrification, National tariff, and policy, precaution for theft of electricity and consumer protection. As per the act, one of the primary functions of the state commission is to promote generation and co-generation of power from renewable energy sources with facilities of intra-state transmission and wheeling.

4.2 National Tariff Policy 2006

The national tariff policy was started by the government of India in 2006 to increase financial feasibility of electrical sectors with attractive investments [**59**]. The objective of the policy is to provide electricity to all the consumers with sensible price by improving the competition, efficiency, and quality of operations. As per the plan multiyear tariff is implemented in the nation with availability based tariff being introduced at the state levels.

4.3 National Action plan on climatic change (NAPCC)

The NAPCC was implemented in 2008 [**60**] to tackle the effect of the change in the climatic and environmental related matters in India to attain sustainable growth, that fulfils monetary goals and ecological responsibilities. The policy replicates the assurance of the government towards the world, regarding the per-capita CO_2 emission, protection and enhancement of susceptible parts in the country. The NAPCC includes eight missions of which the major solar energy-related mission is the Jawaharlal Nehru National Solar Mission (JNNSM).

4.4 Jawaharlal Nehru National Solar Mission (JNNSM) 2010

The Government of India announced the Jawaharlal Nehru National Solar Mission (JNNSM) in 2010 to encourage the economic growth of solar power as well as to meet power challenges in India. The initial target of the mission was to install 20 GW capacity of solar power in three phases. The first phase contributes up to March 2013 aiming a target capacity of 1 GW, the second up to March 2017 and the third phase will continue until March 2022. The Batch-1 of the first phase of the mission aimed to target 150 MW solar PV installation [**61**]. The main objective of JNNSM is to enhance confidence in power developers and promote manufacturing in solar sectors of India.

The year wise exceptional growth of installed capacity of grid-connected solar Power in India with respect to its rival countries, after the implementation of the mission is clearly verified by the Figure 59. On 31st March 2016, the install capacity of commissioned solar power has reached 6.76 GW_p [**62**]. In the year 2015-16, India is able to meet all the renewable targets that are indicated in Figure 60. The target for the solar power was set to be

1.4 GW_p; however the nation was able to achieve more than twice of the targeted value reaching the installed capacity of 3.018 GW_p [**55**].

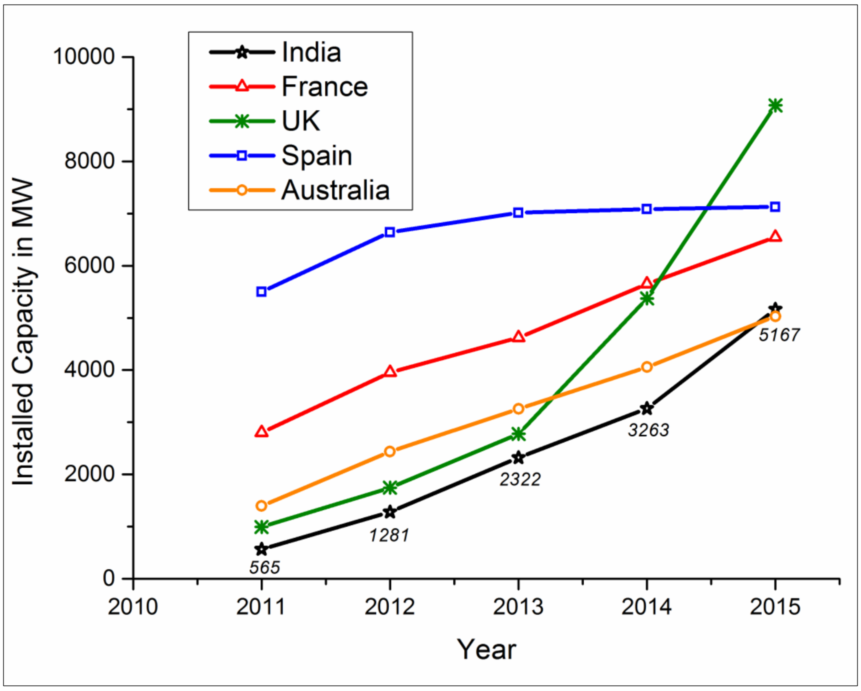


Figure 59 Comparison of the Year Wise Cumulative installed capacity of grid-connected solar Power of India with its rival countries (refer Table 15)

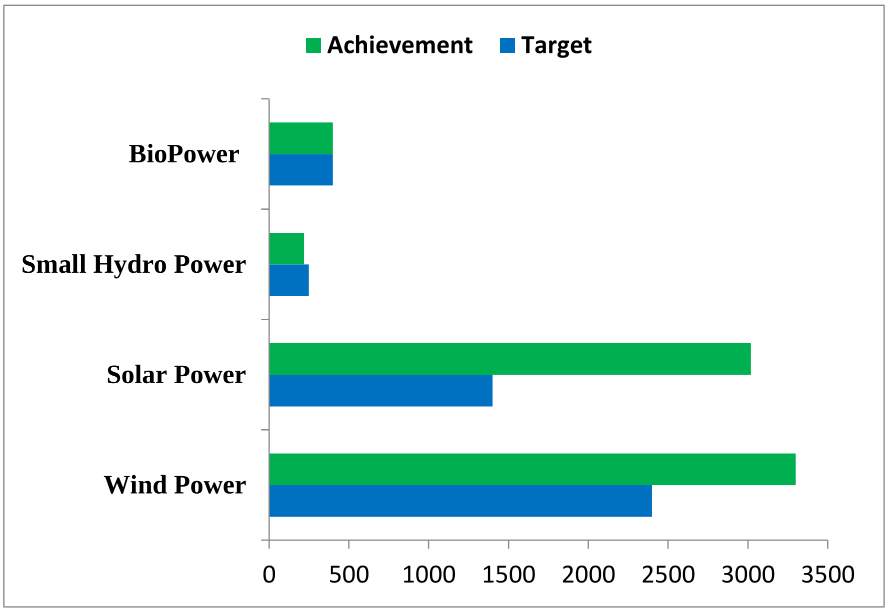


Figure 60 Target and achievements for grid interactive renewable power in India for the year 2015-16 **[**55**]**

4.5 NITI Aayog

The 60% drop in the price of solar PV from 2010 to 2014 [**63**] has driven need to revise the current solar target of India. Replacing India's 65-year-old planning Commission ('five-year plan') NITI Aayog was initiated on 1st January 2015 [**64**]. NITI Aayog focuses on technology up-gradation and capacity building for implementation of programs and initiatives in the country. The primary objective of the commission is to design strategic and long-term policy frameworks, initiatives and monitor their progress and efficiency. As per the renewable energy roadmap of the commission, the target of producing install capacity of 20 GW solar power by 2022 is increased to 100 GW [**65**]. The issue planning of grid and maintaining the system reliability in accordance with variability and uncertainty in the output of solar photovoltaic power plants is addressed by NITI Aayog.

The Central Electricity Regulatory Commission (CERC) of India, has declared the average cost of the module to be 0.59 US$ for Crystalline and 0.62$ for Thin Film. According to the solar tariff order, FY 2015-16 by CERC the total capital cost of Solar PV power projects for the year are Rs. 6.05 Cr/MW for solar PV power projects. The distribution of capital costs is shown in Table 10. The price of PV module is highest among all almost 55% of total cost. The commission has decided the generic tariff to be Rs.7.04 per kWh generation of solar PV power [**66**].

Table 10 Distribution of the normalized capital costs for solar PV projects in 2015-16

Essentials	Normalized capital cost in (Rs. Cr/MW)	% of entire Price
PV panels	3.32	54.9%
Land Rate	0.25	4.1%
Civil and overall work charge	0.5	8.3%
Mounting cost	0.5	8.3%
PCU (Power Conditioning Unit) price	0.45	7.4%
Cables, Transformers and Evacuation cost	0.55	9.1%
Preliminary and Pre-Operative Expenses	0.48	8.0%

4.6 Review of the state solar policies in India

Sixteen states in India have notified the state solar power policies or the draft of policies (refer Figure 61). Previously the nation has only one solar policy; however thanks to JNNSM after 2010 the solar policies were started blooming. The first solar policy in India is developed by the state Gujarat in 2009. Even now the four states have revised their policies and remade them as per their benefit. Uttar Pradesh is the first state to review and reproduced the solar power policy in 2013 among all the states in India. In the year 2012, five states have developed their own solar policy in India which is the highest up till now. In place of solar policy, the state of Maharashtra developed a consolidated renewable power policy in 2014 along with plans for solar power.

Regardless of the policy making all the states in India have started installing solar power in their region. Figure 62 shows the state wise installed capacity of commissioned solar power plants as of 31st March 2016. Rajasthan has the highest amount of capacity (1.27 GW) and potential (142.31 GW) of solar installed among all the states in India [**57**]. The state has implemented the solar policy framework by 2011 and yet to be revised. Gujarat holds the second position in the capacity of commissioned solar power with a cumulative installation of 1.12 GW throughout the state. The state has already revised its solar policy framework in 2015 and likely to grow more in the upcoming years.

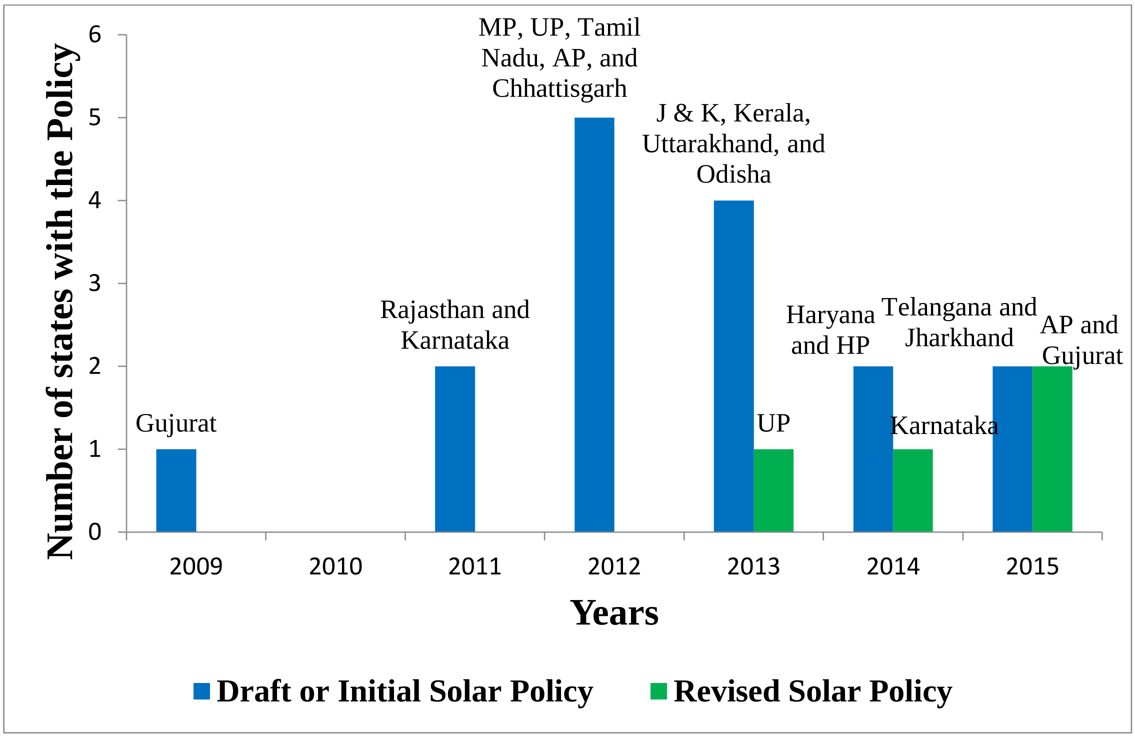


Figure 61 Implementation of the solar policy framework for the states in India up to 26-06-2015

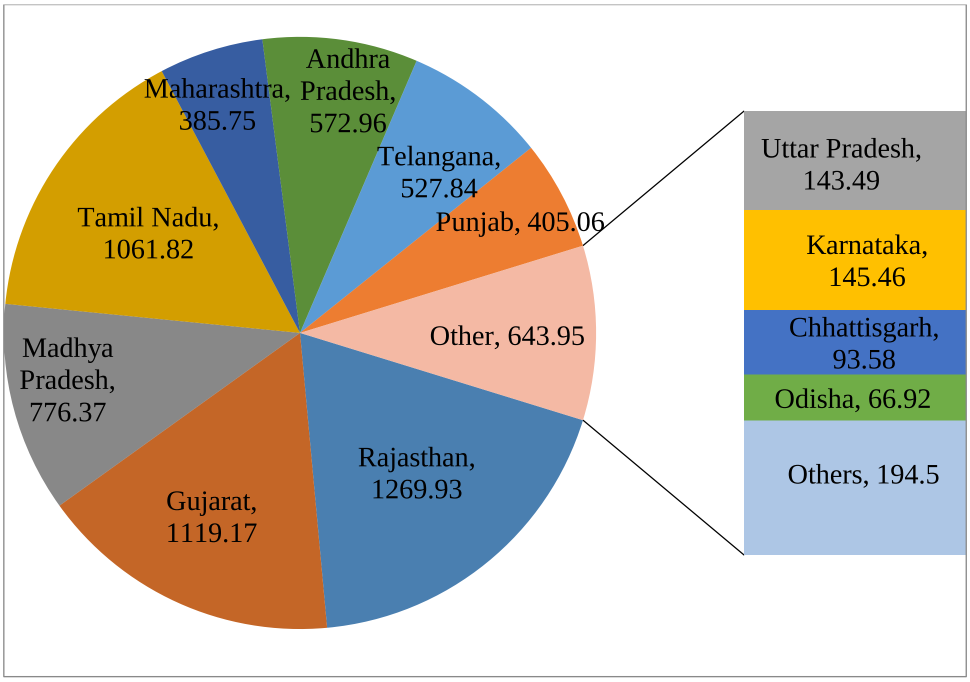


Figure 62 State wise install capacity of commissioned Solar Power plants as on 31-03- 2016 [62]

4.6.1 Common traits

The state solar policies of India comprise certain common objectives to improve the existing solar framework of the nation. The mutual aims are to promote and develop solar power, reduce dependency on fossil fuels, support productive use of barren, wasteland, and uncultivated lands, sponsor research, and development and create employment opportunities. Apart from this, the policies target to reduce energy cost while increasing the generation. The grid-connected solar PV infrastructure and framework of the states of India which has adopted solar policy plans are shown in table 1. Potential, radiation, capital cost, capacity, and targets to be achieved are compared state wise. Data for a minimum and maximum limit of capabilities is collected from state wise solar policy of all the sixteen states. According to the table, most amount of radiation falls in the state of Tamil Nadu that ranks third in the cumulative installed capacity of solar power. The lower amount of capital cost (5.86 Cr/MW) of a solar plant in the state has encouraged the government to set a target of 8.88 GW installation of solar power by the year of 2022.

Table 11 Comparison of solar infrastructure and framework of various states that have implemented their own solar policies

States with solar Policy framework	Range of the Global Radiation in kWh/m² [4]	Solar Potential in GW_p [62]	Net capital cost Cr per MW [66]	Minimum Install capacity limit for each plant in MW	Maximum Install capacity limit for each plant in MW	Cumulative Installed capacity by 2016 in MW [62]	Target to achieve by 2022 in MW [57]
Rajasthan	5.31-6.08	142.31	5.968	5	10	1269.93	5762
Gujarat	5.63-6.08	35.77	10	5	NA	1119.17	8020
Madhya Pradesh	5.47-5.78	61.66	10.25	0.025	100	776.37	5675
Tamil Nadu	5.78-6.08	17.67	5.86	NA	NA	1061.82	8884
Andhra Pradesh	5.12-6.08	8.65	NA	NA	NA	572.96	9834
Telangana	5.47-5.78	20.41	NA	NA	NA	527.84	-
Haryana	5.12-5.63	4.56	12.96	NA	NA	15.38	4142
Uttar Pradesh	5.12-5.47	22.83	NA	5	NA	143.49	10697
Karnataka	4.84-6.08	24.7	6.05	1	NA	145.46	5697
Chhattisgarh	5.31-5.63	18.27	10	NA	NA	93.58	153
Odisha	5.12-5.63	25.78	9	NA	NA	66.92	2377
Jharkhand	5.31-5.63	18.18	8.418	NA	NA	16.18	1995
Himachal pradesh	4.01-5.31	33.84	NA	NA	50	0.201	776
Jammu and Kashmir	3.25-6.08	111.05	6.05	1	NA	1	1155
kerala	4.84-6.08	6.11	10	NA	NA	13.04	1870
Uttarakhand	4.01-5.31	16.8	10	0.1	50	41.14	900

4.6.2 Overview of the policy framework of major States

Gujarat is the first state to implement their solar policy ever in India. The first draft of the policy was approved in the year 2009 [**67**], before the initiation of JNNSM. The state encourages the productivity of the solar power by defining and adding different features such as wheeling charges as per GERC (Gujarat electricity regulation commission), exemption from payment of electricity duty, relaxation from forecasting and scheduling, release of demand cut, authorizing renewable purchase obligation, open-access for third party sale, and conveying of state nodal agencies for ease of operation. The state has also implemented high feed-in tariff for a period of 25 years [**68**] (refer Table 12), grid connectivity and evacuation accommodations, etc. GERC was the first State Electricity Regulatory Commission (SERC) in the country to issue a comprehensive Tariff Order on 2010.

Table 12 Levelized tariff for MW and kW scale power projects from time to time decided as per GERC **[**68**]**

Plan		**Levelized Tariff (Rs/kWh)**		
		July 1, 2015, to March 31, 2016	***April 1, 2016, to March 31, 2017***	***April 1, 2017, to March 31, 2018***
Large Rooftop and MW-scale PV Power Plants	*Without AD (Accelerated Depreciation) Benefit*	6.77	6.30	5.86
	With AD Benefit	6.17	5.74	5.34
kW-scale PV Power Plants	*Without AD Benefit*	8.42	7.83	7.28
	With AD Benefit	7.64	7.11	6.61

The state solar policy for Rajasthan was stated in 2011 [**69**] to meet the energy requirements for the state along with India. The goal of the policy is to develop a global hub of solar power of 10000-12000 MW capacity by contributing to long-term energy security in upcoming 10 years. Generating substantial direct and indirect employment opportunities in solar, Creation of skilled and semi-skilled manpower resources through training facilities are the primary objective of the state. Apart from that, the state wants to establish an industrial set-up involving both domestic and foreign manpower participation and create a solar center of excellence for research and development of recent technologies to accelerate the achievement of the grid parity. The Rajasthan Electricity Regulatory Commission (RERC) decides the various norm costs for the installation of grid-connected PV plant (refer Table 13). The competitive solar PV power bidding tariff rate of Rajasthan is Rs.6.45 per unit [**70**].

Table 13 Breakup for Capital Cost projections for PV projects in Rajasthan and Karnataka **[**70**]**

Essentials	**Capital Cost Norm for Karnataka (Cr/MW)**	**Capital Cost Norm for Rajasthan (Cr/MW)**
PV panels	3.32	3.26
Land rate	0.25	0.073
Civil and General Works	0.5	0.5
Mounting structure expense	0.5	0.5
PCU price	0.45	0.45
Cables, Transformers and Evacuation rate	0.55	0.55
Preliminary and pre-operative expenses	0.48	0.47
Others	NA	0.15(connectivity, evaluative, and transmission cost)
Total	**6.05**	**5.96**

The state solar policy of Karnataka, which working period falls within 2014 to 2021 targets a minimum solar generation of 2000 MW [**71**] (Grid Connected Utility Scale - 1600 MW; Grid Connected roof top 400 MW). To convert Karnataka as an investor friendly state and To encourage participation of Public and Private Sector to set up Solar Power based projects are the objectives of the policy. The electricity regulation commission of the state has decided a tariff structure of Rs 8.40 [**72**]per unit generation of solar energy. The capital cost norms for installation of solar PV plant is presented in Table 13.

The solar policy of Madhya-Pradesh (MP) has started on 2012 [**73**]to build a favorable atmosphere for setting up Solar Power projects. The state provides the incentives and benefits to the Private Sector in clear terms in order to encourage them to set up Solar Power based projects in the State. The electricity Commission has determined the levelized tariff as Rs. 10.44 and Rs. 10.70 per unit for 25 years for the sale of electricity from Solar PV Plants of more than 2 MW capacities and less than 2 MW capacities respectively [**74**].

The state Andhra Pradesh has laid down its five-year plan for policy implementation on 2015 [**75**]. The objective includes developing solar parks, solar-powered agricultural pump sets, and encouraging developers to set up solar power projects, increasing employment opportunities, and promotion of distributed generation in the state. In the next five years, the state plans to increase its solar power capacity by 5000 MW (2500 MW of solar parks) to meet the growing energy demand. The Company wise upcoming tariff structure [**76**] of the state is provided in Table 14. The competitive solar PV power bidding tariff rate of Andhra Pradesh is Rs.6.49 per unit [**76**]of solar energy.

Up-gradation of the skills of the youth in the field of solar, promotion of environmental consciousness among all citizens, decentralization, and diversification of the energy range are the fundamental objective of the Haryana solar power policy. Being started on 2014 the policy targets installation of 100 MW capacity of MW Scale Grid connected Solar Power Project by 2017 [**77**]. The State shall encourage and facilitate Independent Power Producers to install solar power plants for captive use or for 3rd party sale or sale of solar power on Average Power Purchase Cost to the DISCOM under REC (renewable energy certificate).

Table 14 Tariff structure of AP in upcoming years for Central, Eastern, Northern, and Southern Power Distribution Company **[**76**]**

Particulars	Companies	2014-15	2015-16	2016-17	2017-18	2018-19
33kv (Rs./kVA/Month)	***Central***	7.37	12.12	12.95	12.93	13.78
	Eastern	13.46	10.98	11.38	11.80	12.22
	Northern	7.08	13.52	14.48	15.19	16.20
	Southern	7.66	15.51	15.39	15.11	15.17
11kv (Rs./kVA/Month)	***Central***	140.40	185.82	205.14	219.61	232.79
	Eastern	240.15	232.39	247.55	262.96	279.50
	Northern	181.09	241.99	260.57	277.99	297.20
	Southern	164.61	220.82	227.14	232.26	240.68

Tamil Nadu has implemented the solar power policy of on 2013 to project the state as an energy hub. The target of the policy is to generate 3000MW of solar energy and to achieve grid parity by 2015 [**78**]. TANGEDCO (Tamil Nadu Generation and Distribution Corporation) decided the rate of solar power tariff rate for the state as Rs 7.01 per unit [**79**] of solar PV projects without AD benefits. The main objectives of the state policy of Uttar Pradesh are to provide an appropriate investment climate to private sectors in the development of solar power and building of capacity to initiate and sustain the efficient management and use of newer technologies. Being started on 2013 the policy targets an installation of 500 MW of Grid connected solar power plant by March 2017 [**80**].

The state of Odisha has implemented the first draft of a solar policy on 2013 [**7**]. The plan aims to create performance testing facility in OREDA (Orissa Renewable Energy Development Agency) for various types of solar PV and thermal systems with their components. Chhattisgarh has introduced its solar policy framework on 2012 which is valid up to 2017 [**81**]. Encourage innovative projects on solar, creating a favorable environment for the development of solar manufacturing capabilities, and universalization of access to clean energy falls within the objective of the state. The state also targets to achieve the solar power generation capacity between 500MW to 1000MW by march 2017.

Similarly, the state of Himachal Pradesh (2014) [**82**], Jharkhand, Telengana (2015), Jammu and Kashmir [**83**], Kerala [**84**], and Uttarakhand (2013) have recently started their solar power policy. Promotion of the JNNSM and MNRE schemes creation of an environment for availing the benefits under clean development mechanism (CDM) encourage solar-based projects are some of the objectives of the policy. The policy target of the state Jharkhand is to increase solar power generation to 2650 MW by the year of 2020 [**85**].

Telangana aims to harness the install capacity of solar to 500MW by 2017 and 2500 MW by 2030 [**86**] with no open access charges of wheeling. The policy of Uttarakhand aims to increase the install capacity of solar sector in the state to 500MW by 2017 [**87**].

4.7 The growth of the Solar PV market

In 2015, the PV market, with a 25% growth, broke numerous records and continued its worldwide expansion at 50 GW installation. After a limited development in 2014, the market restarted its evolution, almost everywhere, with all regions of the world contributing to PV growth for the first time. The total installed capacity at the end of 2015 globally amounted to at least 227 GW, which is ten times higher than in 2009. Now among the total electricity generation of the world, 3% is covered by solar PV [**88**]. As per the Install solar capacity is shown in Table 15, currently, India's position is among top ten countries in the world.

4.7.1 Review of the world's growing PV frame

In today's world, the top most leaders of solar PV capacity countries are China, Germany, Japan, USA, and Italy with the total cumulative PV capacity of 43 GW, 39.6 GW, 33.3 GW, 27.3 GW, and 18.9 GW (refer Table 15) respectively. By the end of 2012, Germany shared the highest capacity of solar PV with generated 28 TWh of electricity up by 45% [**89**] over the previous year. In the year 2015, the nation gains the first position in PV per capita with the value of 491 Watt per capita. The country has a national target to reach solar PV capacity of 51 GW by 2020.

The Chinese government announced a policy for attracting the domestic solar PV companies as the minimum installed capacity is set as 10 MW per each installation [**89**]. In 2010, four of the world's largest five PV manufacturers were Chinese enterprises: Suntech, JA Solar, Yingli Green Energy and Trina Solar, with shares of 6.6%, 6.1%, 4.7% and 4.7% [**90**] of global cell production respectively. The National Energy Administration of China set a target of 50 GW by 2020 which is very much likely to be achieved. In 2015, the total installed capacity of solar PV became 15 GW [**91**] that ranked the country number one in PV market.

Table 15 Year wise Cumulative Installed capacity of the Top Ten solar countries in the World **[**91**]**

	Cumulative Installed capacity (MW)									
Year	**India**	**China**	**Japan**	**France**	**Germany**	**Italy**	**USA**	**UK**	**Spain**	**Australia**
2006	5	80	1708	15	2899	45	1099	14	180	61
2007	4	101	1919	26	4170	87	1439	18	750	73
2008	10	140	2144	80	6122	432	1618	23	3450	85
2009	12	284	2627	263	10566	1142	2086	27	3770	108
2010	37	864	3618	1030	17554	3475	3373	94	4653	402
2011	565	2934	4914	2803	25039	12778	5642	994	5501	1397
2012	1281	6501	6632	3953	32643	16425	7804	1747	6646	2435
2013	2322	18611	13643	4625	36337	18425	13365	2780	7016	3258
2014	3263	28061	23300	5654	38263	18615	19938	5377	7087	4057
2015	5167	43062	33300	6549	39636	18916	27317	9077	7132	5034

The Investment Tax Credit (ITC) is one of the critical policies in US solar energy market. It reduces tax liability for individuals or businesses that purchase qualifying solar energy technologies, encouraging investment and spurring growth in solar energy. In 2012, USA was ranked among top three countries in the world. In later years, it took over Italy by capacity; however the exceptional growth of China and Japan has ranked the USA as fourth in the world. Solar PV dominates in Italy's renewable sectors, due to real incentives and high solar radiation attracting developers from across the globe. The country targets to install 23 GW [**89**] of solar capacity by 2016which seems difficult seeing the PV growth in previous four years. In 2009, Japan restarted its new solar policy through which more than 99% of PV systems were installed in grid-connected systems, distributed applications, and residential PV systems. The government of Japan aims to achieve 28 GW and 53 GW installation of solar PV by the end of 2020 and 2030 [**89**] respectively.

4.7.2 Challenges for Indian PV sector

The Government of India has decided to set a target of 100 GW of solar power capacity: 60GW of utility-scale projects and 40GW of rooftop solar by 2022 [**65**]. The upcoming year wise targets to achieve 100 GW of solar installation are shown in Figure 63. It is assumed that the previous 20 GW target of JNNSM will be accomplished on or before 2017. Looking at the accomplishments of the nation in solar sectors in last 5-6 years, so far the feasibility of the target is debatable. Currently, India has a total cumulative solar install capacity is 6.76 GW [**57**]. As per MNRE, more than 99% of today’s solar capacity of India is created in the last four years. In the year 2015-16 India has achieved 3 GW of the capacity of grid-interactive solar power still, there are issues relating to land, manufacturing, and technology. To reach the 100 GW target, the current capacity needs to be multiplied fifteen folds in next upcoming five and half years. Apart from state wise electricity regulation board, India has its own central regulation commission that tackles the technical, financial, and installation issues of the PV power plants in the nation. All the sixteen state solar policy of India supports the regulations provided by JNNSM and MNRE.

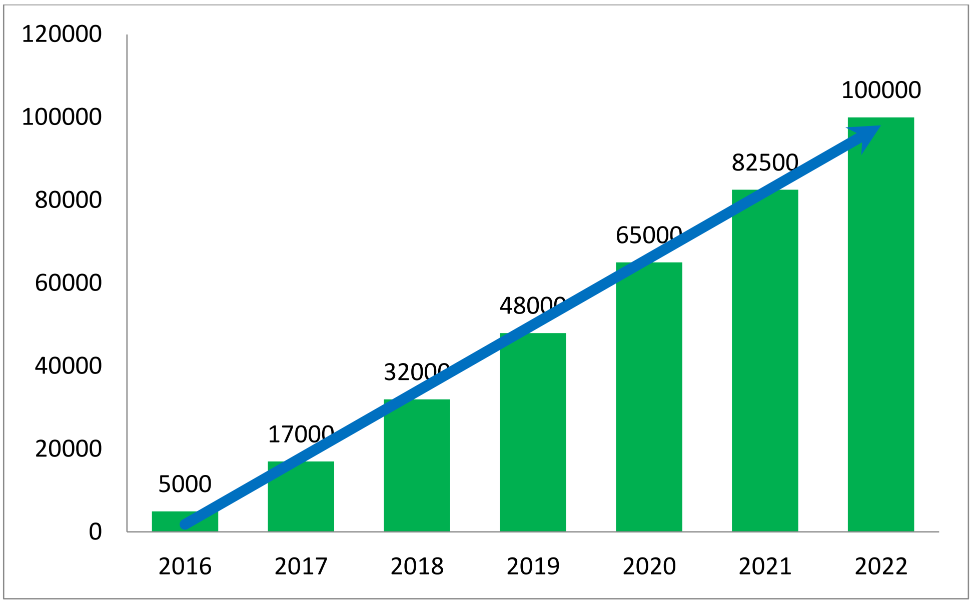


Figure 63 Upcoming target capacity of grid-connected solar PV of India [62]

The state wise potential expectation calculated by NISE does not include land pattern analysis. As the PV plant can only be installed on barren, waste lands, and rooftops throughout the region, suitable methods must be implemented to identify those parts. For example, the method of plotting and correlating the rasterized maps (chaper-2) for radiation, PV yields, and land pattern (waste land, forest, wetlands, etc.) could give the solar potential of each state much precisely. Solar models as provided in the chapter-3 can also be used to accurately predict the PV energy yield of any state location wise. The detailed estimation of state wise solar potential will help the policy developer or planners setting up the solar targets more accurately.

Chapter- 5

Conclusion and Future Work

In the thesis, 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 form of 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. 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 area of high potential zone increases when equipped with the two-axis tracking PV system. Considering PV potential, availability of land, presence of industrial area, and population density, northwest region of Odisha is qualified to construct new solar PV power plants.

In the later part of the thesis, an SFM is developed to take three input parameters and predict the output production of the plant if established in Odisha. Further, the SFM is simplified to FSFM, which takes only two input parameters to predict the output production. Each model considers different predictive response for various combinations of the tracking and mounting options. The prediction of both the models does not depend on the other influencing parameters that affect the performance of PV systems. Both the models show the fair value of the R^2 fitting parameter with RMSE value. As per the real-time plant data, the model predicts expected plant output with an average error of -3.4 % (SFM) and 1 % (FSFM). The prediction of the model does not take into account the factors like plant failure time, failure in data recording, and cyclone. The preciseness in the response for studied model is within Odisha; however it can be extended to any region under consideration with suitable corrections. To do so, refitting of the model to estimate model coefficients is required with newly collected data for the region under consideration. The implementation of the proposed model is simple, and the user can build own model to estimate the PV output for any location desired.

In the later stage, a case study of NIT Rourkela is considered to analyze the PV potential with different methods. Various climatic conditions of the site are explained with the 21 years average data collected from the database of NASA. The incident global radiation is typically high and varies between 1936 kWh/m^2 to 2140 kWh/m^2 inside the campus which indicates higher energy production. The value of average air temperature falls within 24^0C to 25^0 C that is optimal for the PV panels. The prediction from various methods shows that the yearly energy yield can be as high as 1524 kWh and as low as 1376 kWh. The predictions inside NIT Rourkela convey the large amount of power generation for the real solar power plant.

Scope for further Research

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 also be extended to other similar studies for a state like the potential 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 a higher 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. The methodology can be applied in the case for analysis of the energy production of standalone systems in a particular region. Correlating the rasterized maps for radiation, PV yields, and land pattern (waste land, forest, wetlands, etc.) could give the solar potential of each state much precisely.

Development of the models is very simple, and the predictions are accurate. The accuracy in the response of the model can be extended to the outside of the region of Odisha. To do so, refitting of the model is required with newly collected data from outside of Odisha. By following the same procedure as per section-2, new model coefficients can be found out that may justify the preciseness of the prediction of the model outside the climatic condition of Odisha. The detailed estimation of state wise solar potential will help the policy developer or planners setting up the solar targets more accurately.

Bibliography

[1] RReDC. Reference Solar Spectral Irradiance: ASTM G-173. [Online]. http://rredc.nrel.gov/solar/spectra/am1.5/astmg173/astmg173.html

[2] Chetan Singh Solanki, *Solar Photovoltaics: Fundamentals Technologies And Applications*.: Prentice-Hall of India Pvt.Ltd, 2011.

[3] Christiana Honsberg and Stuart Bowden, *Properties of Sunlight*.: http://pveducation.org/.

[4] MNRE. (2012) Ministry of New and Renewable Energy. [Online]. http://mnre.gov.in/sec/solar-assmnt.htm

[5] Ministry of Power, Government of India Central Electricity Authority, "All India Installed Capacity Of Power Stations," 2015.

[6] Department of Planning and Coordination Directorate of Economics and Statistics, "Odisha Economic Survey 2014-15," in *Power*. Bhubaneswar: Govt. of Odisha, 2015, pp. 6/1-6/30.

[7] Science And Technology Department, "Odisha Solar Policy," 2013.

[8] Govt. of Odisha. Government of Odisha Official Portal. [Online]. http://www.odisha.gov.in/portal/ViewDetails.asp?vchglinkid=GL012&vchplinkid=PL049

[9] National Institute of Disaster Management, "National Disaster Risk Reduction Portal,".

[10] Googlemaps. Google My maps. [Online]. https://www.google.com/mymaps

[11] GeoModel Solar S.R.O. (2010-15) SOLARGIS. [Online]. http://solargis.info/imaps/

[12] Maps of India. [Online]. http://www.mapsofindia.com/maps/orissa/orissa.htm#

[13] Planning and Coordination Department Directorate of Economics and Statistics, "Odisha Economic Survey 2014-15," in *Forestry and Environment*. Bhubaneswar, Odisha, India: Government of Odisha, 2015, pp. 3/1-3/60.

[14] Department of Water Resources, "Annual Report 2013-14," 2014.

[15] B. K. Pati, "Water Resources of Odisha: The Availability," in *Water Resources Of Odisha Issues And Challenges*. Bhubaneswar: Regional Centre for Development Cooperation, 2010, pp. 1-14.

[16] Ztransparency Technologies. Orissa Explorer. [Online]. http://odishaexplorer.com/climate.html

[17] A., Kurokawa, K., Otani, K., Enebish, N., Batsukh, G., Battushig, M., Ochirvaani, D. and Ganbat, B. Adiyabat, "Evaluation of solar energy potential and PV module performance in the Gobi Desert of Mongolia," *Progress In Photovoltaics: Research And Applications*, pp. 553-566, 2006.

[18] H.O. Njoku, "Solar Photovoltaic Potential in Nigeria," *J. Energy Eng.*, pp. 1-7, 2014.

[19] M.C., Gomes, N., Santos, T. and Tenedorio, J.A. Brito, "Photovoltaic potential in a Lisbon suburb using LiDAR data," *Solar Energy*, pp. 283-288, 2012.

[20] Aste N., Pero C.D., Leonforte F., and Manfren M., "A simplified model for the estimation of energy production of PV systems," *Energy*, vol. 59, pp. 503-512, September 2013.

[21] G., Remondino, F., Stevanato, G., De Filippi, R. and Furlanello, C. Agugiaro, "Estimation Of Solar Radiation On Building Roofs in Mountainous Areas," *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 38*, pp. 155-160, 2013.

[22] K.D., Katsikas, N.G., Psomopoulos, C.S. and Ioannidis, G.Ch. Mardikis, "An assessment and through analysis of the two major free photovoltaic software," pp. 992-998, 2014.

[23] T. Hulda, R. Mullerb, and A. Gambardella, "A new solar radiation database for estimating PV performance in Europe and Africa," vol. 86, no. 6, pp. 1803–1815, June 2012.

[24] M. Suri, T.A. Huld, and E.D. Dunlop, "PV-GIS a web-based solar radiation database for the calculation of PV potential in Europe," vol. 24, no. 2, pp. 55-67, 2005.

[25] M., Huld, T.A., Dunlop, E.D. Suri and H.A. Ossenbrink, "Potential of solar electricity generation in the European Union member states and candidate countries," vol. 81, no. 10, pp. 1295–1305, October 2007.

[26] M.S. Martin, C.A. Tristan, and M.D. Mediavilla, "Performance Indicators form Sun Tracking Systems A Case Study in Spain," vol. 6, no. 9, pp. 292-302, September 2014.

[27] F. J. Gómez-Gil, X. Wang, and A. Barnett, "Analysis and Prediction of Energy Production in Concentrating Photovoltaic (CPV) Installations," vol. 5, no. 3, pp. 770-789, 2012.

[28] J. Hofierka and J. Kanuk, "Assessment of photovoltaic potential in urban areas using open-source solar radiation tools," vol. 34, no. 10, pp. 2206–2214, October 2009.

[29] M., Huld, T.A., Dunlop, E.D., Albuisson, M. and Wald, L. Suri, "Online Data And Tools For Estimation Of Solar Electricity In Africa:The Pvgis Approach," pp. 1-4, 2006.

[30] T. M. Pavlovic and D. D., Radivojevic, A. R., Pavlovic, M. A. Milosavljevic, "Comparison And Assessment Of Electricity Generation Capacity For Different Types Of Photovoltaic Solar Plants Of 1 Mw In Sokobanja, Serbia," vol. 15, no. 3, pp. 605-618, September 2011.

[31] PVGIS radiation databases. [Online]. http://re.jrc.ec.europa.eu/pvgis/apps4/databasehelp_en.html

[32] Joint Research Centre European Commission. PVGIS. [Online]. http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en

[33] Caamaiio E. and Lorenzo E., "Modelling and Financial Analysis Tools for PV Grid-connected Systems," *Progress In Photovoltaics Research And Applications*, vol. 4, pp. 295-305, 1996.

[34] Kalykakis S, Papazoglou T.M Kymakis E, "Performance analysis of a grid connected photovoltaic park on the island of Crete," *Energy Conversion and Management*, pp. 433–438, 2009.

[35] Heinrich Haberlin, *Photovoltaics : System Design And Practice*.: Wiley, 2012.

[36] Horta P, Mendes J.F, Pereira M.C, Carbajal W.M Carvalho M.J, "Incidence Angle Modifiers: A General Approach For Energy Calculations," *Proceedings of ISES Solar World Congress: Solar Energy and Human Settlement*, pp. 608-612, 2007.

[37] PVeducation.org. [Online]. http://www.pveducation.org/pvcdrom/solar-cell-operation/quantum-efficiency

[38] Eikelboom J.A., van Zolingen R.J.C. Baltus C.W.A., "Analytical Monitoring Of Losses In PV Systems," *14th European Photovoltaic Solar Energy Conference*, 1997.

[39] J.A. Palyvos E. Skoplaki, "On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations," *Solar Energy 83*, pp. 614-624, 2009.

[40] C.W.A., Eikelboom, J.A., van Zolingen, R.J.C. Baltus, "Analytical Monitoring Of Losses In PV Systems," *14th European Photovoltaic Solar Energy Conference*, 1997.

[41] Littmann B, Caron J.R, Dunn L Gostein M, "Comparing PV Power Plant Soiling Measurements Extracted from PV Module Irradiance and Power Measurements," pp. 3004-3008, 2013.

[42] Raducu A., Sera D. and Teodorescu R. Valentini M., "PV Inverter Test Setup for European Efficiency, Static and Dynamic MPPT Efficiency Evaluation," *Optimization of Electrical and Electronic Equipment*, pp. 433-438, 2008.

[43] Pedersen J.K. , Blaabjerg F. Kjaer S.B., "A Review of Single-Phase Grid-Connected Inverters for Photovoltaic Modules," *IEEE Transactions On Industry Applications*, vol. 41, no. 5, pp. 1292-1306, 2005.

[44] Huanga MT, and Chenb CC Huanga CJ, "A Novel Power Output Model for Photovoltaic Systems," *International Journal of Smart Grid and Clean Energy*, vol. 2, no. 2, pp. 139-147, 2013.

[45] Suk S.J., Ahn Y.H., Ford G. Steffen R.E., "Modeling Energy Generation by Grid Connected Photovoltaic Systems in the United States," *Journal of Building Construction and Planning Research*, no. 1, pp. 39-44, 2013.

[46] Boyson W.E., Riley D.M. Cameron C.P., "Comparison Of Pv System Performance-Model Predictions With Measured Pv System Performance," *Photovoltaic Specialists Conference*, pp. 1 - 6, 2008.

[47] Santos T., Fernandez-Jimenez L.A., Ramirez-Rosado I.J. , Terreros-Olarte M.S. Monteiro C., "Short-Term Power Forecasting Model for Photovoltaic Plants Based on Historical Similarity," *Energies*, vol. 6, pp. 2624-2643, 2013.

[48] Aikala A., Weiss R. Ruuska P., "Modelling Of Photovoltaic Energy Generation Systems," *Proceedings 28th European Conference on Modelling and Simulation*, 2014.

[49] Hendawy Z.M., El-Shorbagy M.A. El-Sawy A.A., "Trust region Algorithm based on local search multi-objective Optimization," *First International Conference on Innovative Engineering Systems*, no. 12, pp. 207-212, 2015.

[50] Zhao Y., Hou K. Zhang L., "The Research of Levenberg Marquardt Algorithm in Curve Fittings on Multiple GPUs," *International Joint Conference of IEEE*, no. 11, pp. 1355-1360, 2011.

[51] NREL. PVwatts. [Online]. http://pvwatts.nrel.gov/India/index.php

[52] NASA. (2016) NASA Surface meteorology and Solar Energy: Daily Averaged Data. [Online]. https://eosweb.larc.nasa.gov/cgi-bin/sse/daily.cgi?email=skip@larc.nasa.gov

[53] Solar Energy center MNRE. India Solar Resource Maps.

[54] Solar R and D Division MNRE, "State wise Estimated Solar Power Potential in the Country," 2014-15.

[55] MNRE. (2015) Ministry of New and Renewable Energy. [Online]. http://mnre.gov.in/mission-and-vision-2/achievements/

[56] Chilakapati N., Saravana I.G., Bharata R.M.J., Asha R.M.A., and Varghese L.Z., "Renewable Power Generation Indian Scenario: A Review," *Electric Power Components and Systems*, vol. 43, no. 8-10, pp. 1205–1213, 2015.

[57] Government of India. (2012) Ministry of New and Renewable Energy. [Online]. http://mnre.gov.in/

[58] Ministry Of Law And Justice, "The Electricity Act, 2003," Legislative Department, New Delhi, 2003.

[59] The Gazette of India, "Tariff Policy," vol. 3, 2006.

[60] N. K. Sharma, P. K. Tiwari, and Y. R. Sood, "Solar energy in India: Strategies, policies, perspectives and future potential," *Renewable Sustainable Energy*, vol. 16, pp. 933-941, 2012.

[61] Government of India, "Jawaharlal Nehru National Solar Mission : Guidelines for selection of new grid-connected solar power projects," 2011.

[62] MNRE. (2012) Ministry of New and Renewable Energy. [Online]. http://mnre.gov.in/related-links/jnnsm/introduction-2/

[63] IRENA, "Renewable Power Generation Cost In 2014," 2015.

[64] Government of India. National Institution for Transforming India. [Online]. http://niti.gov.in/content/

[65] Aayog NITI, "Report on India’s Renewable Electricity Roadmap 2030," 2015.

[66] Central Electricity Regulatory Commission, "Determination of Benchmark Capital Cost Norm for Solar PV power projects and Solar Thermal power projects applicable during FY 2015-16," New Delhi, Petition No. SM/005/2015, 2015.

[67] Energy And Petrochemicals Department, "Gujarat Solar Power Policy-2009 and 2015," Government Of Gujarat , Gandhinagar,.

[68] Gujarat Electricity Regulatory Commission, "GERC Tariff Order No. 3," Gandhinagar, 2012.

[69] Energy Department, "Rajasthan Solar Energy Policy," Government of Rajasthan , 2011.

[70] Rajasthan Electricity Regulatory Commission, "Tariff Order FY 2015-16," Jaipur,.

[71] Karnataka Govt. Sec. Vikash Soudha, "Solar Policy 2014-2021," Government of Karnataka, 2014.

[72] Karnataka Electricity Regulatory Commission, "Tariff Order for Grid interactive MW scale Solar Power Plants FY16-18," Bangalore, 2015.

[73] Government of Madhya Pradesh, "Policy For Implementation Of Solar Power Based Projects In Madhya Pradesh," 2012.

[74] M.P. Electricity Regulatory Commission, "Tariff order for Solar Energy Based Power Generation in Madhya Pradesh," Bhopal, 2012.

[75] Energy, Infrastructure and Investment Department, "Andhra Pradesh Solar Power Policy," Government Of Andhra Pradesh , 2015.

[76] Andhra Pradesh Electricity Regulatory Commission, "Wheeling Tariffs For Distribution Business," Hyderabad, 2014.

[77] Renewable Energy Department, "Haryana Solar Power Policy," Haryana Government , 2014.

[78] Department of Energy, "Tamil Nadu Solar Energy Policy," Government of Tamil Nadu, 2012.

[79] Tamil Nadu Electricity Regulatory Commission, "Comprehensive Tariff Order on SOLAR POWER," 2014.

[80] U.P New And Renewable Energy Development Agency, "Solar Power Policy Uttar Pradesh ," Department of Additional Sources of Energy, Government of Uttar Pradesh, 2013.

[81] Chattisgarh State Renewable Energy Development Agency, "Solar Policy 2012-17," Government of Chattisgarh , 2012.

[82] Department of Non-conventional Energy Sources, "H.P. Solar Power Policy," Government of Himachal Pradesh, 2014.

[83] Department of Science and Technology, "Solar Power Policy for Jammu and Kashmir," Government of Jammu and Kashmir, 2013.

[84] Power Department, "Kerala Solar Energy Policy ," Government of Kerala, 2013.

[85] Department of Energy, "Jharkhand State Solar Power Policy," Government of Jharkhand, 2015.

[86] Government of Telangana, "Telangana Solar Power Policy," 2015.

[87] Government of Uttarakhand, "Solar Policy of Uttarakhand," Dehradun, 2013.

[88] International Energy Agency, "Snapshot Of Global Photovoltaic Markets," Photovoltaic Power Systems Programme, 2015.

[89] Bikash Kumar Sahu, "A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries," *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 631-634, 2015.

[90] Qiang Z., Honghang S., Yanxi L., Yurui X., and Jun S., "China’s solar photovoltaic policy: An analysis based on policy Instruments," *Applied Energy*, vol. 129, pp. 308-319, 2014.

[91] International Renewable Energy Agency, "RENEWABLE CAPACITY STATISTICS 2016," 2016.

Appendix

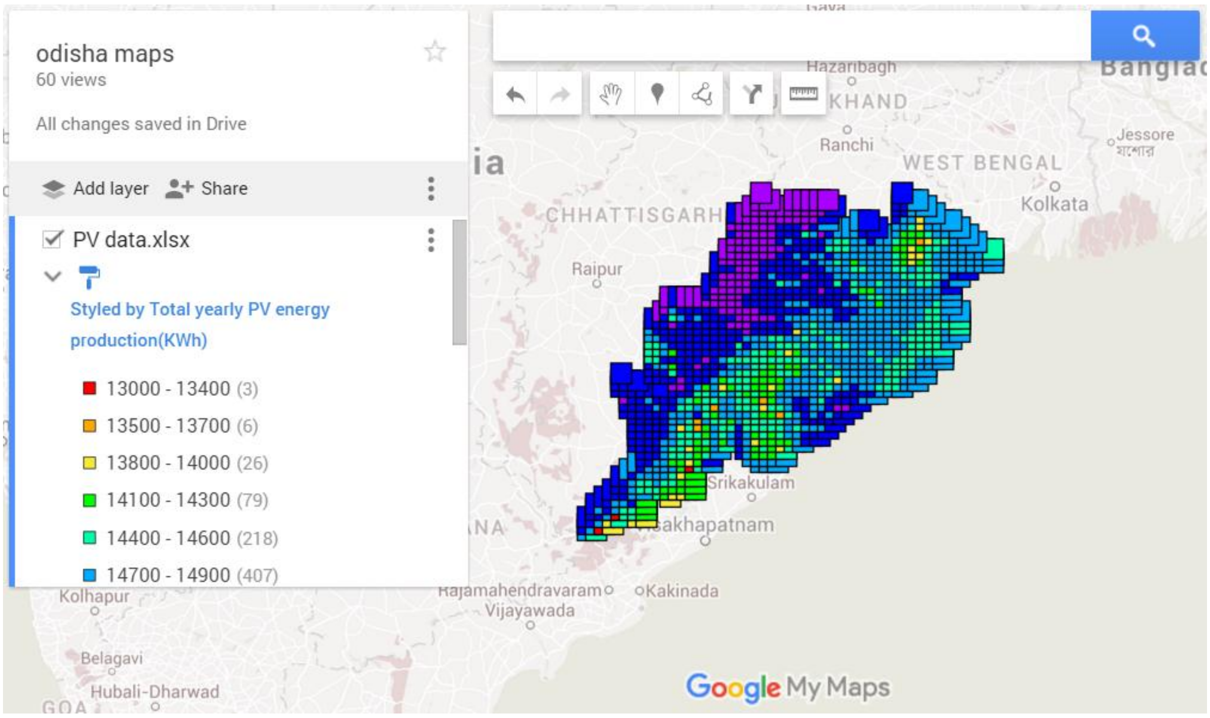
Appendix-I

State wise Geographical and climatic parameter analysis of Odisha

District Name	Area in km^2						Annual wind speed (km/hr)	Annual rainfall (mm)
	Total	*Forest*	*Mine*	*Wasteland*	*Wetlands*	*Major Dam*		
Anugul	6375	2716.82	7.263	663.48	251.755	388.424	11.25	1253.3
Balangir	6575	1543.85	12.079	540.28	8.26	8.45	4.58	1444
Balasore	3806	332.21	NA	110.78	168.095	1.278	4.92	1600
Bargarh	5837	1216.13	11.61	464.26	7.94	11.043	4.58	1398
Bhadrak	2505	97.07	NA	34.31	86.2975	32.956	4.92	1568.4
Boudh	3098	1277.17	0.291	359.51	0.63	1.241	9	1302.5
Cuttack	3932	787.9	5.392	337.98	28.8925	1.656	11.25	1351
Debagarh	2940	1560.22	NA	298.84	10.62	NA	8.33	1573
Dhenkanal	4452	1737.62	9.755	356.62	5.0625	18.864	11.25	1421.1
Gajapati	4325	2468.98	NA	1082.08	6.9425	NA	11.25	1295.6
Ganjam	8206	3149.9	24.676	1146.37	127.7975	45.823	11.25	1296
Jagatsinghapur	1668	132.92	NA	41.16	104.4	NA	11.25	1489.9
Jajapur	2899	725.27	61.710	250.32	14.075	123.117	4.92	1600
Jharsuguda	2114	202.44	5.4148	224.6	0	0.466	7.5	1456
Kalahandi	7920	2538.01	5.8953	888.43	1.94	6.207	2.1	1657
Kandhamal	8021	5709.83	NA	1084.36	4.2875	2.916	2.1	1592
Kendrapara	2644	248.05	NA	64.55	307.4825	NA	11.25	1435.1
Kendujhar	8303	3097.18	295.63	661.62	37.77	14.834	4.91	1800
Khordha	2813	618.67	1.1774	471.9	38.7225	1.574	11.25	1500
Koraput	8807	1879.53	66.422	1212.85	174	0.34	2.1	1430.5
Malkangiri	5791	3355.88	0.2333	1280.79	168.69	180.55	2.1	1594.6
Mayurbhanj	10418	4392.13	31.215	463.78	26.7125	1.941	4.91	1648.2
Nabarangpur	5291	2462.73	NA	856.37	7.44	466.322	2.1	1472
Nayagarh	3890	2080.97	0.1664	955.78	5.9425	6.079	11.25	1449.1
Nuapada	3852	1849.69	5.5219	517.48	16.26	23.837	2.1	1245
Puri	3479	137.1	NA	231.73	1175.2375	NA	11.25	1449.1
Rayagada	7073	2812.33	26.699	679.2	2.94	12.222	2.1	1640
Sambalpur	6624	3631.77	1.0069	577.67	627.94	777.885	11..25	1599
Sonepur	2337	415.78	1.1922	273.95	0	NA	4.58	1260
Sundargarh	9712	4957.32	173.58	526.24	62.65	60.66	7.5	1647.2
Total State	**155707**	**58135.47**	**746.94**	**16648.27**	**3478.78**	**2188.68**	**6.82**	**1482.25**

Appendix-II

Plotting of Rasterized Maps Using My Maps Google



Appendix-III

Estimation of PV Energy Production at NIT Rourkela Using PVGIS

Performance of Grid-connected PV

NOTE: before using these calculations for anything serious, you should read [this]

PVGIS estimates of solar electricity generation

Location: 22°15'3" North, 84°54'31" East, Elevation: 212 m a.s.l.,

Solar radiation database used: PVGIS-CMSAF

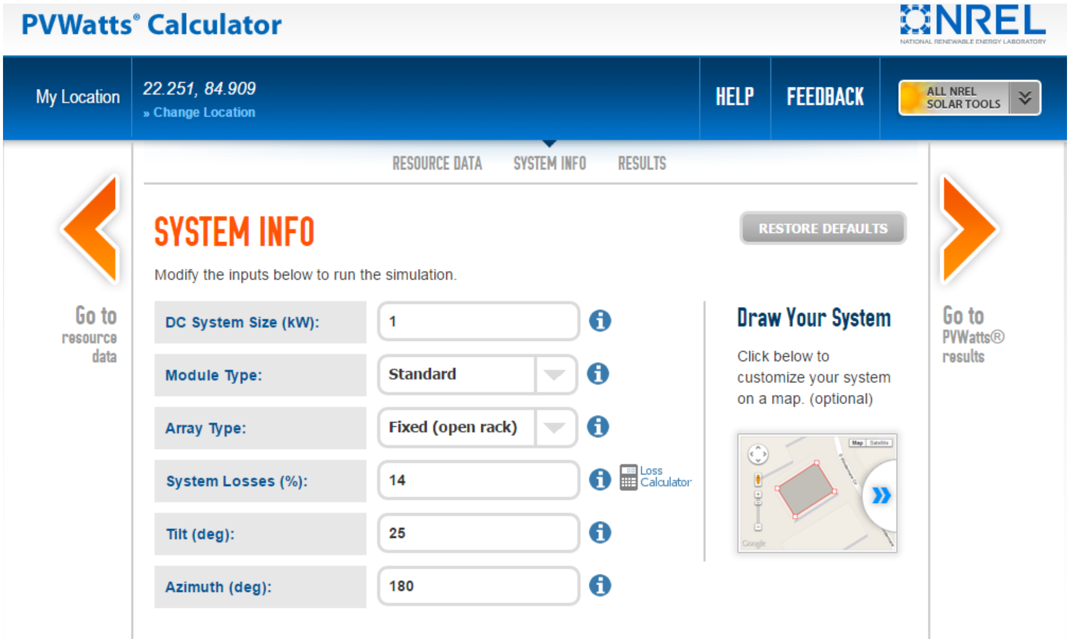
Nominal power of the PV system: 1.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 14.7% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.7%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 28.6%

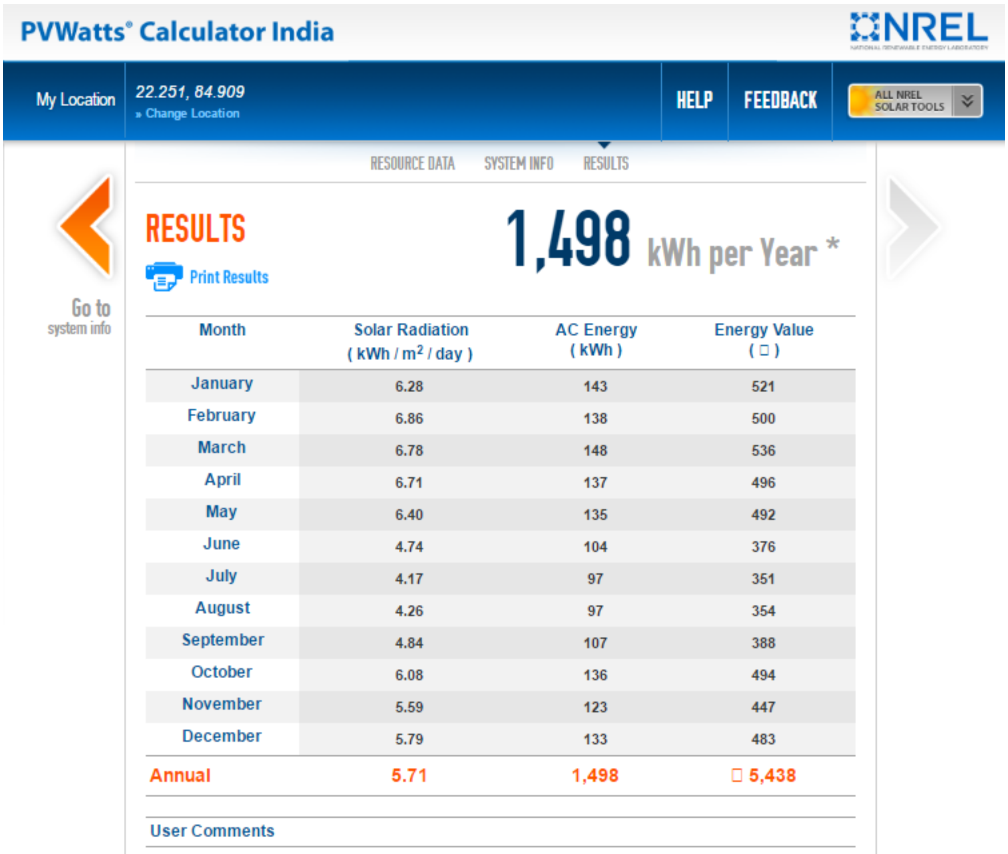
Fixed system: inclination=25°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	4.61	143	6.31	196
Feb	4.92	138	6.89	193
Mar	5.01	155	7.18	222
Apr	4.75	143	6.93	208
May	4.43	137	6.45	200
Jun	3.38	102	4.81	144
Jul	2.99	92.7	4.17	129
Aug	3.07	95.2	4.30	133
Sep	3.44	103	4.82	145
Oct	4.27	132	5.99	186
Nov	4.61	138	6.40	192
Dec	4.54	141	6.18	192
Yearly average	**4.16**	**127**	**5.86**	**178**
Total for year		**1520**		**2140**

E_d: Average daily electricity production from the given system (kWh)
E_m: Average monthly electricity production from the given system (kWh)
H_d: Average daily sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)
H_m: Average sum of global irradiation per square meter received by the modules of the given system (kWh/m^2)

Appendix-IV

Estimation of PV Energy Production at NIT Rourkela Using PVwatts





Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (□)
January	6.28	143	521
February	6.86	138	500
March	6.78	148	536
April	6.71	137	496
May	6.40	135	492
June	4.74	104	376
July	4.17	97	351
August	4.26	97	354
September	4.84	107	388
October	6.08	136	494
November	5.59	123	447
December	5.79	133	483
Annual	5.71	1,498	□ 5,438

Appendix-V

Estimation of PV Energy Production at NIT Rourkela Using In-house build Software

Month	Hg	Yr	Kt	Yt	Kg	Ya	Yf	Eac	Tv	PR
Jan	6.32	6.32	0.86	5.44	0.89	4.84	4.6	142.46	149.96	0.73
Feb	6.91	6.91	0.85	5.87	0.88	5.17	4.91	137.49	144.72	0.71
Mar	7.21	7.21	0.84	6.06	0.86	5.21	4.95	153.39	161.46	0.69
Apr	6.92	6.92	0.85	5.88	0.84	4.94	4.69	140.82	148.23	0.68
May	6.46	6.46	0.86	5.56	0.83	4.61	4.38	135.8	142.95	0.68
Jun	4.82	4.82	0.89	4.29	0.82	3.52	3.34	100.25	105.53	0.69
Jul	4.19	4.19	0.91	3.81	0.82	3.13	2.97	92.08	96.92	0.71
Aug	4.33	4.33	0.9	3.9	0.82	3.2	3.04	94.11	99.06	0.7
Sep	4.9	4.9	0.89	4.36	0.83	3.62	3.44	103.16	108.59	0.7
Oct	6.01	6.01	0.87	5.23	0.86	4.5	4.27	132.43	139.4	0.71
Nov	6.41	6.41	0.86	5.51	0.87	4.8	4.56	136.68	143.88	0.71
Dec	6.18	6.18	0.86	5.31	0.89	4.73	4.49	139.3	146.64	0.73

Appendix-VI

Matlab Program to plot Various Graphs

a) *Inverter Efficiency vs PLR*

```
clc;
clear all;
a=-0.385;
b=-1.125;
c= 97.12;
invo=@(PLR) ((a*(PLR^b))+c);
fplot(invo,[0.005,1]);
```

b) *Performance Ratio Factor*

```
clc;
clear all;
p1=[10^-8 3*(10^-7) -1.14*(10^-4); -3*(10^-7) 0 1*(10^-4); -2*(10^-5) -
4*(10^-4) 1];
p2=[10^-8 3*(10^-7) -1.14*(10^-4); -3*(10^-7) 0 1*(10^-4); -2*(10^-5) -
4*(10^-4) 1];
p3=[10^-8 3*(10^-7) -1.14*(10^-4); -3*(10^-7) 0 1*(10^-4); -2*(10^-5) -
4*(10^-4) 1];
    for a=0:45:180
        for j=1:1:3
            P1(j,1)= p1(j,1)*(a^2)+p1(j,2)*a+p1(j,3);
            P2(j,1)= p1(j,1)*(a^2)+p1(j,2)*a+p1(j,3);
            P3(j,1)= p1(j,1)*(a^2)+p1(j,2)*a+p1(j,3);
        end
        for fs=0.5:0.5:0.6
            for i=1:1:3
                P(i,1)=P1(i,1)*(fs^2)+P2(i,1)*fs+P3(i,1);
            end
            PR=@(B) P(1,1)*((B-25)^2)+P(2,1)*(B-25)+P(3,1);
            fplot(PR,[0,90]);
        hold on;
        end
    end
```

c) *Irradiance factor*

```
clc;
clear all;
g=[10^-8 3*(10^-7) -1.14*(10^-4); -3*(10^-7) 0 1*(10^-4); -2*(10^-5) -
4*(10^-4) 1];
    for a=0:45:180
        G(1,1)= g(1,1)*(a^2)+g(1,2)*a+g(1,3);
        G(2,1)= g(2,1)*(a^2)+g(2,2)*a+g(2,3);
        G(3,1)= g(3,1)*(a^2)+g(3,2)*a+g(3,3);
        gf=@(B) G(1,1)*((B-25)^2)+G(2,1)*(B-25)+G(3,1);
        fplot(gf,[0,90]);
        hold on;
    end
```

Dissemination

Journal Articles

1. "Development of Rasterized Map using PVGIS for Assessment of Solar PV Energy Potential of Odisha", IJRER, Vol. 6, No. 1, 2016.

2. "Validation of a Predictive Models to Estimate Annual PV Production: A case for Odisha", International Journal of Smart Grid and Clean Energy, Accepted.

3. "Development of the Simplified Predictive Model for the Estimation of Annual PV Energy Production: A Case Study for Odisha," IJETP, Under Review.

4. "Modelling microalgal biofuel production and carbon dioxide sequestration potential in fixed and track able photo bioreactor in Odisha: state of India," Sustainable development, Submitted.

5. "Review of the current state policy framework of India," IJSD, to be submitted on June 2016.

Conference Presentations

1. "Validation of a Predictive Models to Estimate Annual PV Production: A case for Odisha," IGCET 2016, Accepted.
2. "Design of an in-house PV potential mapping software," ICRAIE 2016, to be submitted on 25th July
3. "A Study on the PV potential analysis for grid connected PV system in NIT Rourkela," PIICON 2016, Submitted.

Vitae

RAKESH KUMAR TARAI

Qtr. No.7, Block-3, Telecom colony, Doorsanchar Bhawan,
Link Road, Cuttack-753012, Odisha.
Mobile No.: 9438177898
E-Mail*: rakeshktarai@gmail.com*

OBJECTIVE

To gain various knowledge related to my field and enhance skills to produce best result for my career.

EDUCATION

Course	***Institution***	***Board/ University***	***Year Of Completion***	***Aggregate Score(%)***
M .Tech (Industrial electronics)	*NIT,Rourkela*	NIT	*2016*	*8.43(CGPA)*
B.Tech (Applied Electronics and Instrumentation)	*Silicon Institute of Technology Bhubaneswar, Odisha.*	Biju Pattnaik University of Technology (BPUT)	*2014*	*7.92(CGPA)*
+2 science	*Ravenshaw Junior College, cuttack, Odisha.*	Council of Higher Secondary Education (CHSE)	*2010*	*74.17*
10th Board	*Secondary Board High School, cuttack, Odisha.*	*Board of secondary Education Odisha*	*2008*	*88.75*

TECHNICAL SKILLS

C , C++(fundamentals) , Cadence , MATLAB(Simulink), Q-GIS, PVGIS, Xilinx, MS Word, Powerpoint, Excel and Labview

PUBLICATIONS

1. "Development of Rasterized Map using PVGIS for Assessment of Solar PV Energy Potential of Odisha," IJRER, Vol. 6, No. 1, 2016.
2. "Validation of a Predictive Models to Estimate Annual PV Production: A case for Odisha," International Journal of Smart Grid and Clean Energy, Accepted.

TRAINING/PROJECT UNDERTAKEN

Institute / Organisation	Title	Duration
Silicon Institute of Technology	Design of parasitic aware Operational Amplifier for optimal performance	1 year
NIT Rourkela	Evaluation and analysis of PV Potential of Odisha	1 year
IIRS, ISRO, Department of Space Govt. of India	Remote Sensing, Geographical Information System & Global Navigation Satellite System	3.5 months

PERSONAL INFORMATION

Mother's Name : Kanchan Bala Mishra
Father's Name : Ramesh Chandra Tarai
Date of Birth : 8th April 1993.
Nationality : Indian.
Gender : Male.
Passport No. : L3602803
Languages : English, Odiya, Hindi.
Address : *Qtr. No.7, Block-3, Telecom colony, Doorsanchar Bhawan, Link Road, Cuttack-753012,*

DECLARATION:

I, hereby declare that all the above furnished information is true to the best of my knowledge and if found wrong, I am liable for legal procedures.

PLACE: Rourkela

Rakesh kumar Tarai

SIGNATURE

Index