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Renewable Energy - RENE

MSc Thesis

Characterization of PV technology over roofs and their constraints for a geographical analysis

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Abstract

This work is focussed on the characterization of PV technology over roofs and their constraints for a geographical analysis. The objectives of the work are to calculate the available roof surface area of the city Miraflores de la Sierra and to calculate the power and energy that can be produced by using solar pv technologies using available roof surface area of the city.

To find out the available area of Miraflores, at first the arcGIS is used to get the flat roof surface area. From the flat roof surface area, inclined roof surface area is calculated. Different type of constrains also considered to get the available roof surface area. After getting the available roof surface area, power and energy is calculated using different type of solar pv technologies.

All the area of the roof top is calculated of the city of miraflores. all the 1883 houses are considered in this project including all the main urban area and remaining urban area. At first the roofs are considered as flat roof and later inclined roof surface area is calculated using formula. The available roof surface area for solar pv installation is 28212.35 m^2.

In the city of miraflores, all the houses are inclined. So, to calculate the energy and power potential, it is very important to know the global radiation on tilted surface of the area. But, lack of the weather data of the city, the weather data of Madrid is considered and calculated. Annual global radiation on 20 degree tilted surface result is 4.64 kWh/m^2day

With a efficiency of 22.9% solar pv technologies(Si mono crystalline), annual energy output is 8177992kWh and the potential power output is 934 kW. Using a lower efficiency of 8.20% solar pv technologies Si(thin film polycrystalline), annual energy output is 2599050kWh and the potential power output is 297 kW.

Acknowledgements

I thank the Almighty GOD for giving me power, courage, patience and dedication to do the MSc thesis and to be a part of the project.

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1. Glossary

pv: Photovoltaics

DC: Direct current

c-Si: Crystalline silicon

AC: Alternating current

PR: Performance ratio

δ: Declination angle

d_n: Day number in a year

β: Tilted slope angle

GIS: Geographical information systems

2D: Two dimensional

a-Si: Amorphous silicon

a-SiGe: Amorphous silicon/ germanium/ hydrogen alloy

3D: Three dimensional

2. Introduction

Continuous power supply is essential for the advancement of a country. As the price of fossil fuel is increasing, renewable energy is a good alternative to this situation. Not only it is a good solution, it is also environment friendly technology. Now a day, all the countries are looking forward to expand this technology to produce the power. European Union sets a target to produce 20% energy of the total energy consumption by the renewable energy by the year 2020[1].

Solar PV is one of the major parts of renewable energy technologies. The amount of solar radiation incident on the ground is enough to meet the energy demand of the world. On average, the amount of solar radiation incident on earth surface, it can produce 1700 kW energy every year [22]. The average energy received in Europe is 1,200 kWh/m^2 per year.

Roof top pv technologies is very much popular now a days. In the grid connected pv system, owners can supply extra energy to the grid and earns money. When there is no solar energy available, they can also take electricity from the main grid. At standalone roof top system, owners can store energy in battery. When there is no solar energy available, they can use stored energy from battery.

Roof top pv system also a big factor to those place which are not connected to the main grid system. Using the solar energy, peoples can meet their energy demand.

The objective of this thesis is to find out the area of the roof top of the city Miraflores de la Sierra near Madrid, Spain. Different type of constraints and shading will be also considered to find the available roof surface area of the region. Using the available roof surface area, the amount of energy and power produced using different type of Solar PV technology will be also calculated.

Objective

To develop a model based on geographic information technologies and state of the art photovoltaics technology, to evaluate the potential use of roofs and urban spaces with solar photovoltaic in the city of Miraflores de la Sierra in Madrid, Spain.

Specific objective

1. To calculate the available roof surface area of the city Miraflores de la Sierra.
2. To calculate the power and energy that can be produced by using solar pv technologies using available roof surface area of the city.

3. Literature review

3.1. Photovoltaic concepts

Photovoltaic technology is the process of generating Direct current (DC) power from semi-conductors when they are illuminated by photons [2]. This process is made of several cells which convert sunlight into electricity [3]. Solar cells are made of semi conducting materials.

These semiconducting materials contain weakly bonded electrons which occupy a band of energy called valence band. When energy exceeds the band gap energy, the bonds get broken and the electrons get free to go in a new energy band named conduction band. The band gap separates the free electrons in conduction band from valence band. To free the electrons, energy is needed which is provided by photons which are particles of light.

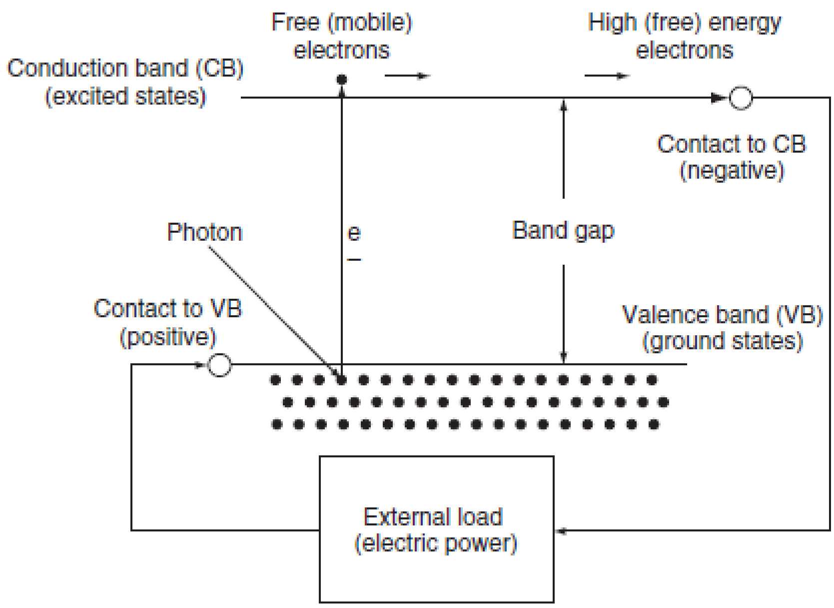

Fig. 3.1. Schematic of a solar cell

Fig 4.1 shows the basic working priciple of a solar cell.The solar cell works as a pn junction. By using doping, conduction band and valence band are produced where one becomes the n-side (lots of negative charge) and other becomes the p-side (lots of positive charge). when the sunlight of sufficient energy is incident on the solar cell, the atoms absorb the solar photons, breaking the bonds of valence electrons and send the electrons to the higher energy in conduction band. The electrons send to the outer load via wires. After some work, electrons are back at a lower energy level to the valence band.

3.2. Different types of solar pv technologies

There are several types of pv technologies. They can be defines as first, second and third generation. Basic crystalline silicon (c-Si) is considered as first generation and thin film technologies included in second generation technologies. Concentrator photovoltaics, organics and some other technology are included in the third generation technologies [4]. Fig 4.2 shows an interesting view of dominating the pv market by different type of technologies for a decade [5].

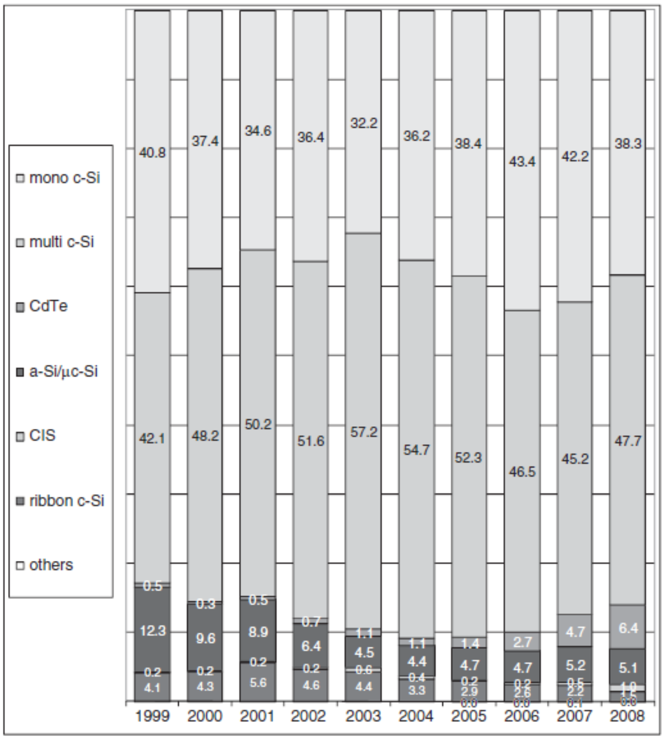

Fig. 3.2. Evaluation between different technologies

3.3. Crystalline silicon technology

Mono crystalline silicon technology

Mono crystalline silicon was first produced by using the Czochralski (Cz) technique almost 50 years ago [6]. Mono-Si cell efficiency is about 16-17% [7]. It comes directly from the microelectronics industry. It is known for better efficiency but it is still expensive comparing to multi crystalline (poly crystalline).

Fig. 3.3. Mono crystalline solar cell

Multi crystalline silicon technology

Multi crystalline silicon technology is known for its cost effectiveness though its efficiency is lower than mono crystalline silicon cell, about 13-15%. Multi crystalline solar cells are rectangular or square which gives a better opportunity to utilize the module area than mono crystalline silicon cells.

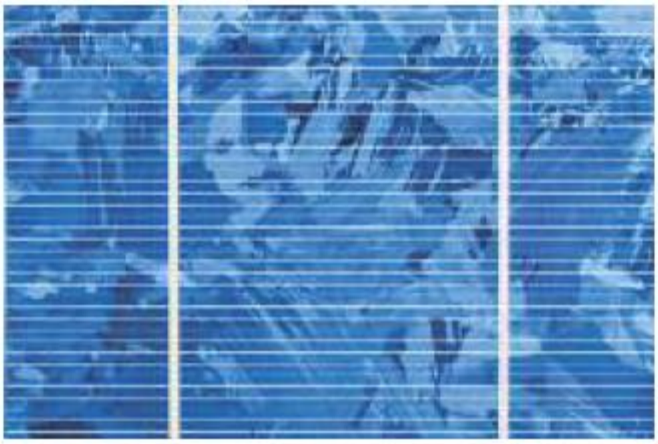

Fig. 3.4. Multi crystalline solar cell

There is another technology called Ribbons. Its efficiency is not good as multi crystalline.

3.4. Thin film technology

The thin film solar cells use materials which can absorb sunlight of different wavelength and this is why the cells are very thin [8]. The main objective to produce this kind of cell is to be cost effective. One of the causes for the high cost of Si cells are demand of purification and crystallinity of the material is high. In thin film, electrons need to travel short distance in the cell to cell contacts which give it advantages over Si cell. Si cells are produced from wafers, processed and assembled to make a module where as thin film solar cell technology produces lots of cells and formed as a module [8].

Fig. 3.5. Thin film module

3.5. Roof top pv system

3.5.1. Different types of roofs

To implement the solar panel, it is very important to know about the condition of the roof. There is mainly two type of roofs which include; flat and inclined.

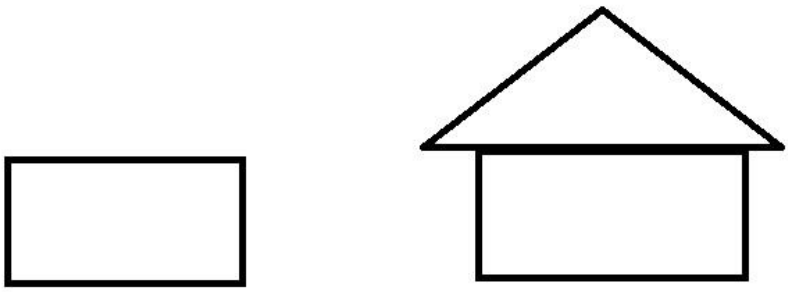

Fig. 3.5. Different types of roof

3.5.2. Different type of pv system

There are two types of pv system, grid connected and stand-alone(off grid) system[9].

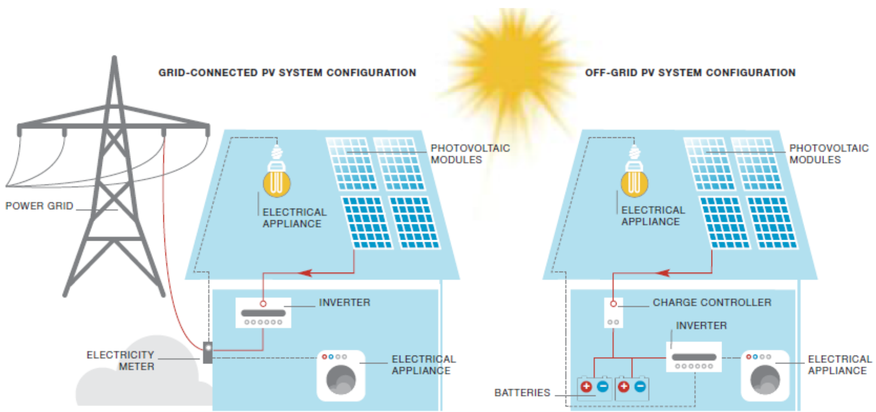

Fig. 3.6. Different types of pv system

When the pv system is connected with the local or main grid, it is considered as grid connected pv system. The owner of pv system can send power to the grid when there is some power remain after meeting the demand.

When pv system has no connection with grid, it can be considered as stand-alone system (off grid system). As it has no connection with grid, it contains a lot of batteries so that power can be stored to use later. As pv system produces DC current, inverter is also needed to convert the DC power into AC power.

3.6. Important factors

To calculate the inclined roof surface area, available total roof surface area, power and energy produced by the solar pv technology, some important factor plays a big role in the calculation.

3.6.1. Performance ratio

It is the ratio between the actual and theoretical energy outputs [12]. The performance ratio (PR) is expressed as percentage and it shows the relation between actual and theoretical output from solar pv. In real life, 100% PR cannot be achieved because of different kind of losses and other unavoidable reasons.

3.6.2. Orientation and inclination

The orientation and tilt of a system has a big impact how much avaialbe solar radiation the solar system can collect. Theoretically, the optimal orientation is true south and the optimal tilt is considered as equal to latitude. But,practically, it is preferable that the system to face the equator and the tilt should be 10-15degree less then the local latitude[20].

3.6.3. Sun position and declination angle

The declination of the sun is the angle between the equator and the line drawn from the centre of the earth to the centre of the sun [13].The declination angle δ changes due to the earth rotation on its own axis and also the rotation of the earth around the sun. the declination angle can be get by using [14] the formula of Cooper.

$$\delta = 23.45 \sin(360 \frac{284 + d_n}{365}) \qquad \text{(Ec. 3.1)}$$

Here, d_n is the number of the day of the year.

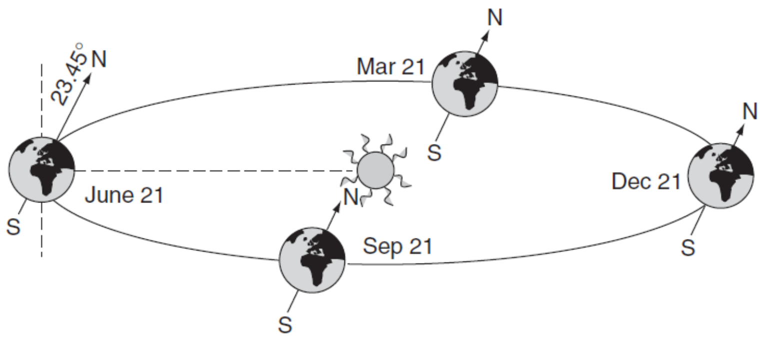

Fig. 3.7. The orbit of the Earth around the sun whole year

The declination angle becomes zero at spring equinox (march 21) and at autumn equinox (December 21), the line between the sun and the earth passes through the equator [15]. The declination angle reaches maximum 23.45 degree at June 21 (because of summer solstice in the northern hemisphere) and it reaches minimum -23.45 degree at December 21 (because of winter solstice in the northern hemisphere).

3.6.4. Elevation angle and zenith angle

Solar elevation angle is the angle between the horizontal and the line to the sun [14].The elevation angle is zero degree at sunrise and it becomes 90 degree when it comes to overhead [16]. Elevation angle changes through out the whole day and it depend on the latitude of a place and also on the day of year. It is also known as altitude angle.

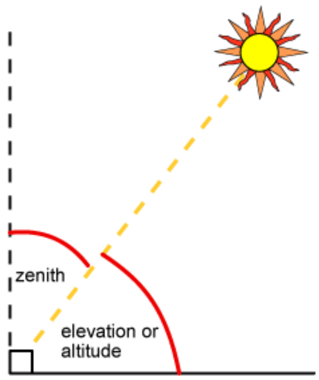

Fig. 3.8. Elevation angle and zenith angle

Zenith angle is measured from vertical axis. It is the angle between the vertical axis and the line to sun. Zenith angle=90°-elevation angle

3.6.5. Tilted slope, solar azimuth angle, surface azimuth angle

The tilted slope angle(β) is the angle between the surface and the horizontal surface[14].

Solar azimuth angle is the angular displacement from south of the incident beam radiation at the horizontal plane. In the figure 4.9,displacement east of south are negative and west of south are positive.

Surface azimuth angle is the angle between the projection of beam radiation to the horizontal plane of normal to the surface from the local meridian, considering zero to the south and east negative and west positive.

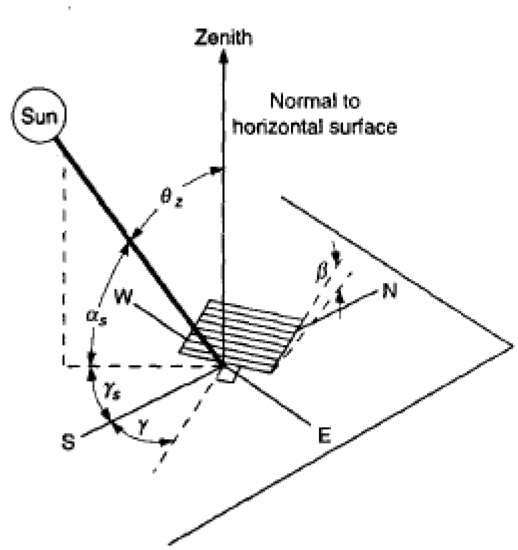

Fig. 3.9. Tilted slope, solar azimuth angle and surface azimuth angle

3.6.6. Solar and Time

Local solar time

The sun remain highest in the sky at twelve noon which known as local solar time (LST).

Local time

Local time (LT) changes from LST because of time zones and daylight saving.

Local Standard Time Meridian (LSTM)

The Local Standard Time Meridian (LSTM) is a reference meridian which is used for a particular time zone and is alike to the Prime Meridian, which is used for Greenwich Mean Time.

The (LSTM) is calculated using,

$$LSTM = 15°.\Delta T_{GMT} \quad \text{(Ec. 3.2)}$$

Where ΔT_{GMT} is the difference of the Local Time (LT) from Greenwich Mean Time (GMT).

Equation of Time (EoT)

The equation of time (EoT) is an equation which modify the eccentricity of the Earth's orbit and the Earth's axial tilt.

$$EoT = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B) \quad \text{(Ec. 3.3)}$$

Where as,

$$B = \frac{360}{365}(d - 81) \quad \text{(Ec. 3.4)}$$

In the equation 3.4, d is the number of the day of the year.

Time Correction Factor

The net Time Correction Factor responsible for the variation of the Local Solar Time (LST) within a given time zone due to the change of longitude within the time zone.

$$TC = 4(Longitude - LSTM) + EoT \quad \text{(Ec. 3.5)}$$

Local solar time can be found using,

$$LST = LT + \frac{TC}{60} \quad \text{(Ec. 3.6)}$$

Solar hour angle, ω

It is an expression of time, It is the angular measurement of the sun east or west of the local meridian due to the the rotation of the earth on its own axis at 15° per hour.

$$\omega = 15°(LST - 12) \quad \text{(Ec. 3.7)}$$

3.7. Solar radiation components

In the figure 4.10, it is clearly showing the different type of components of solar radiation hitting a terrestrial flat-plate pv surface. The total radiation falling on a surface is the summation of direct, diffuse and albedo radiation and it is known as global radiation.

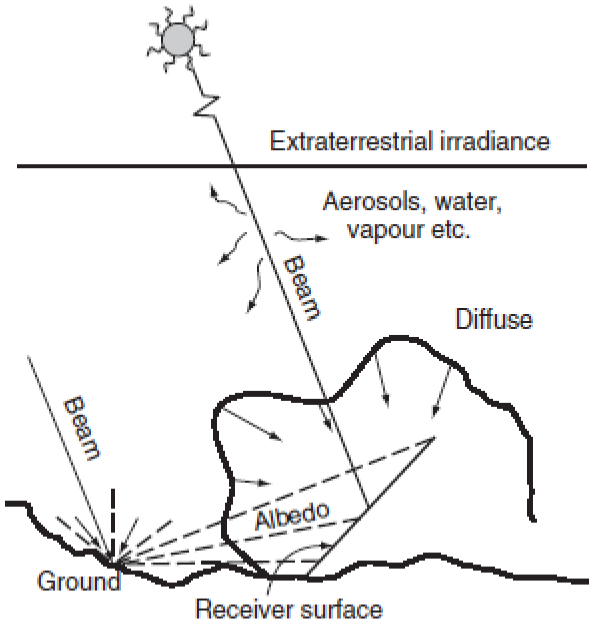

Fig. 3.10. Different components of solar radiation

3.7.1. Direct radiation

Direct radiation is the radiation which incident directly to the surface in a straight line from the sun. It incident on the surface without any scattering. It is also known as beam radiation.

3.7.2. Diffuse radiation

Some solar radiation hits the surfaces which are not directly coming from the sun. They are scattered from the sky and atmosphere and hit the surface later. This type of radiation is known as diffuse radiation.

3.7.3. Albedo radiation

Some solar radiation at first hits the ground and moved to the receiver surface. This type of radiation is called albedo radiation. It is also known as reflected radiation.

3.8. Shading in the use of pv technology over roofs

Different types of shading occurs frequently which are needed to be handle. The first one is caused by the trees, buildings or other obstacle nearer the solar pv panel, collector or other type of receiver [21]. The second type of shading is caused by different type of array solar panel which is used in series and parallel.

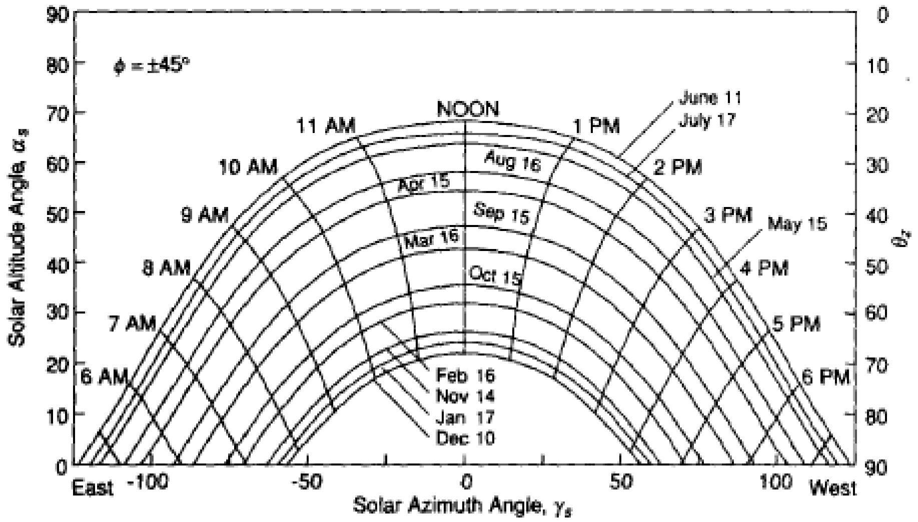

Fig. 3.11. sun position diagrams

In sun position diagrams, shaded objects can be included with solar azimuth angle and solar altitude angle and times of shading can be easily seen[26]. In figure 3.11,sun position diagram is plotted for 45°latitude(both negative and positive).

3.9. Introduction to GIS and ArcGis

Geographic information system (GIS) combines hardware, software, and data for analyzing all forms of geographically related information. It allows analyzing data in many ways that works in the form of maps, globes, reports, and charts[25]. ArcGIs is a GIS tool which can manage and analyze geographic data and map.

4. Methodology

To find out the available area of Miraflores, at first the arcGIS is used to get the roof surface area. After getting the available roof surface area, power and energy is calculated using different type of panel.

4.1. Determination of the roof surface area

4.1.1. Determination of the area of Miraflores

A map is taken from website[27], where the entire municipality of Madrid province is showed.

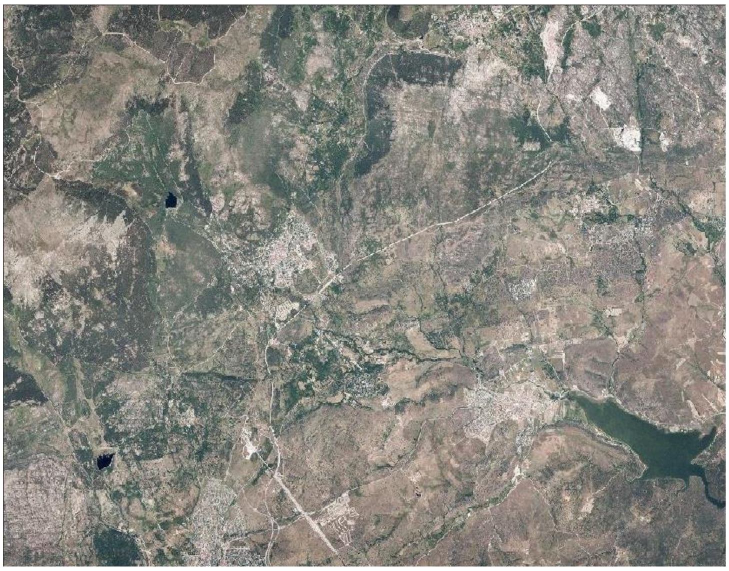

Fig. 4.1. Map used in ArcGIS

From the whole map, Miraflores de la Sierra is selected and take the limit of the city.

Fig. 4.2. Area of Miraflores

From another website[28], All of the Madrid urban area is taken and used the arcGIS. After selecting the boundary of Miraflores, it showed that there are 4 urban areas in the boundary of Miraflores, one is considered as main town of Miraflores de la Sierra where as others are Los Endrinales, Las Huelgas and los pinarejos. The remaining urban areas are considered as “remain urban area”.

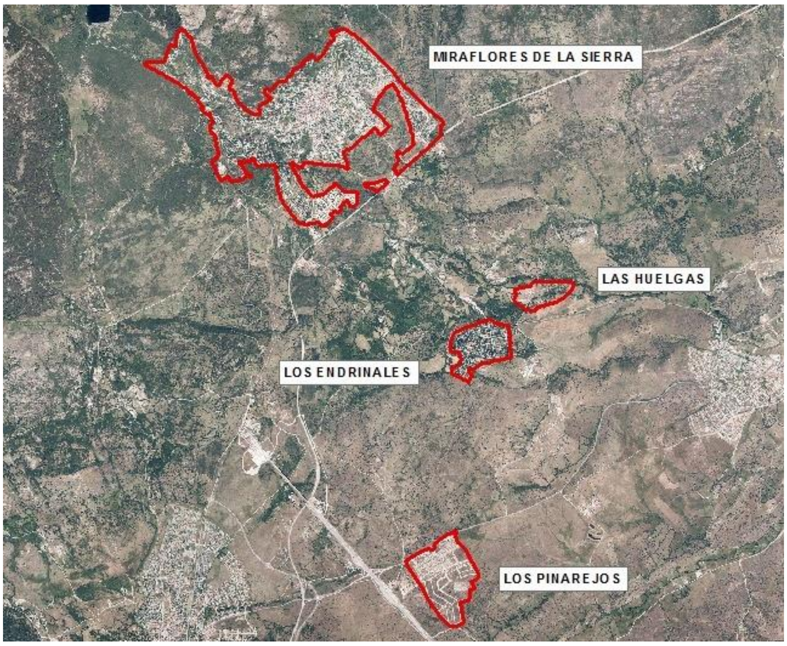

Fig. 4.3. Different urban areas of Miraflores

4.1.2. Determination of the building of Miraflores

The building map of Madrid is taken from www.ign.es and used in arcGIS. The limit of Miraflores and all the urban areas are already indicated. So, building within the limit of miraflores was only seletected.

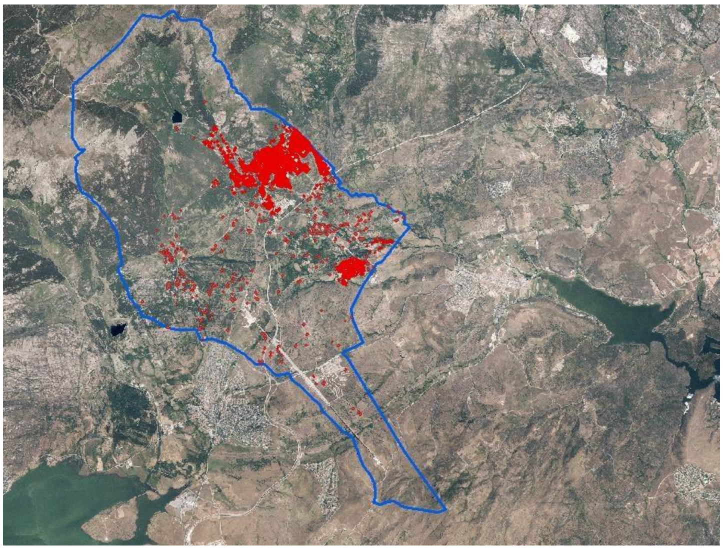

Fig. 4.4. Buildings in the limit of Miraflores

It was observed that there are buildings inside the selected urban areas as well as there is some building outside the urban areas but in the boundary of Miraflores. Those building are considered in the group of “remaining urban area”.

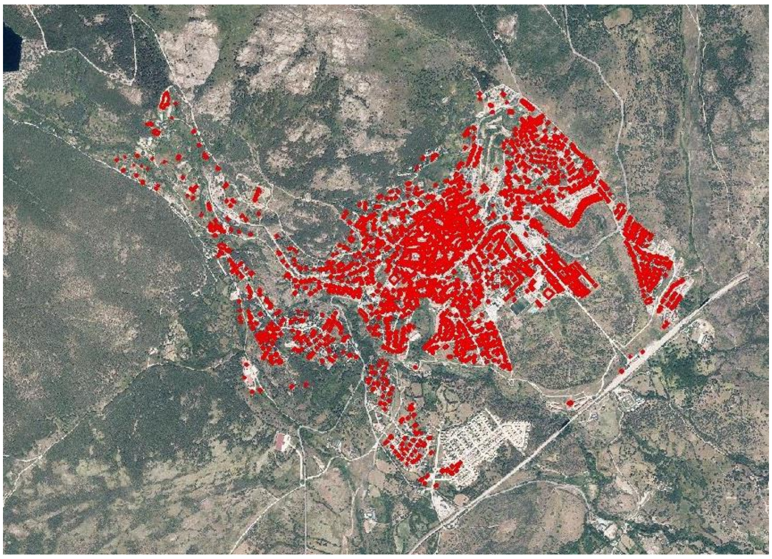

Fig. 4.5. Buildings of the town-miraflores de la Sierra

This is roof captured by arcGIS of the town of miraflores de la Sierra. The maximum density house of the miraflores is in this part of the city. 1239 house is remaining in this town.

Fig. 4.6. Buildings of urban area 1-los Endrinales

These are housing of Los endrinales which we consideres as urban area 1.

Fig. 4.7. Buildings in the urban area 2-Las Huelgas

Las huelgas is considered as urban area 2. There is only few house in this urban area.

Fig. 4.8. Buildings in the urban area 3-Los Pinarejos

These are the house in Los pinarejos which we considered as the urban area 3.

Besides the main town and 3 urban areas, there are lots of house here and there in the limit of miraflores de la Sierra. In this work,these are considered as “remaining urban area”.

By using ArcGIS, using 2D projection, every house area is calculated.

Fig. 4.9. Buildings in the Miraflores de la Sierra

Fig. 4.10. Buildings in the Miraflores de la Sierra

The building areas that are calculated from 2D projections and as they are inclined, the slope angle has to be considered to get the actual roof surface area [1].

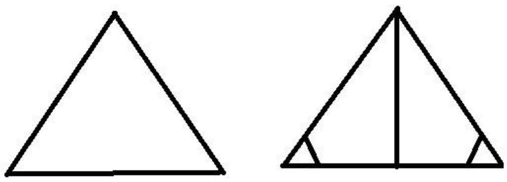

Fig. 4.11 calculating inclined roof surface

Almost all the houses of the miraflores are inclined. So it is very important to get the accurate area of the inclined roof. Using arcGIS, it considered all the roofs as flat roofs and calculated the roof area. To get the inclined surface area, inclination angle Ɵ was considered. Every house area was divided by cos(Ɵ) to get the inclined area. For a easier and better calculation, all the roofs were assumed as 20 degree slope angle from horizontal.

Roof inclined area,

$$S_{inclined} = S_{flat} / \cos\theta \quad \text{(Ec. 4.1)}$$

Using the arcGIS and applying this formula, total roof surface area of miraflores de la Sierra was achieved.

4.2. Determination of the available roof surface area of Miraflores de la Sierra

To find out the available roof surface area, different factors and constraints had impact on the total area. Different type of limitations had influence to find out the available roof surface area such as orientation, inclination, shading, some objects like chimney, aerials or window occupied some roof surface etc.

In this project, it is considered to put the pv solar panel in any one of the inclined surface of the roof. The panel was considered to put on that inclined surface which has the best orientation to get the maximum sunlight. We considered the roof surface available per building goes down to 50%, here a roof type coefficient C_{RT}=0.5 is introduced [1].

As some space of roof occupied by chimney, aerials or window, it was considered that 70% of the roof pitch is available to install the pv panel. This is why corrective feature coefficient C_F=0.7 is used.

It was also considered that 10% of the roof surface area will occupied by solar thermal systems. This is why solar thermal coefficient C_{ST}=0.9 is used[1].

The most important effect on roof surface was shading. The shading of the pv module series was also considered. To get rid of this unwanted shadow effect, a sufficient gap must be kept between all solar panel, so covering index coefficient C_{COV}= 0.45 is also introduced.

There was another type of shadow. Shadow was produced by other buildings and by the roof itself also. As, the find out procedure of roof surface area was 2D and there was no availability data regarding this, we assumed this shadowing coefficient C_{SH} as 0.43 according to Izquierdo et al. (2008)[10].

Considering all these limitations and coefficient, the available roof surface area of the miraflores will be,

$$S^{avail}_{roof} = C_{RT} * C_F * C_{ST} * C_{COV} * C_{SH} * S_{inclined} \qquad \text{(Ec. 4.2)}$$

Using this equation, the available roof surface area for PV installation was found out.

4.3. Determination of Solar radiation on the roof surface area

To find out the solar pv generation on the roof surface available area, it is very important to get the solar radiation on the inclined roof surface area of Miraflores. As the solar radiation data for the miraflores is not available, so in this project, nearest weather station data was used which was available. The solar radiation data is taken from the website[29] that contains the data for the research center CIEMAT, Madrid, Spain. The latitude of the place is 40.46 North and longitude is 3.73 West.

From the data of the website, solar beam, diffuse and total solar radiation on horizontal surface was collected. Solar elevation angle and solar azimuth angle was also achieved from the data. But, as almost all the houses of the miraflores are inclined, so we needed to use the global solar radiation on inclined surface.

The hourly total irradiation on a tilted surface(G_{TH}) is composed of direct (B_{Th}), sky-diffuse (D_{Th}) and ground reflected (R_{TH}) radiation[11].Using the iso-tropic model,

$$G_{Th} = B_{Th} + D_{Th} + R_{Th} \qquad \text{(Ec. 4.3)}$$

Ec. 5.3 can be written as,

$$B_{Th} = B_N \cos\theta_i = B_h \cos\theta_i / \cos z \qquad \text{(Ec. 4.4)}$$

B_N is direct beam and B_h is direct horizontal solar radiation.

$$\begin{aligned}\cos\theta_i &= \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega + \\ &\cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \qquad \text{(Ec. 4.5)}$$

From weather data, direct normal beam irradiation was found. So, for B_{Th}, the formula was used[23],

$$B_{Th} = B_N \cos\theta_i$$

Ec. 5.3 can be written,

$$G_{Th} = B_N \cos\theta_i + r_d D_h + G_h \rho[1-\cos(S)]/2 \qquad \text{(Ec. 4.6)}$$

Whereas,

B_{Th}- hourly direct solar radiation on a tilted surface

B_h- hourly direct solar radiation on a horizontal surface

B_N- hourly direct beam normal irradiation

D_{Th}-hourly diffuse solar radiation on a tilted surface

D_h- hourly diffuse solar radiation on a horizontal surface

R_{Th}-hourly reflected solar radiation on a tilted surface

G_h- hourly total solar radiation on a horizontal surface

G_{Th}- hourly total solar radiation on a tilted surface

r_b- beam ratio factor, the ratio of cos(Θ)/cos(Z)

r_d-ratio of the hourly diffuse solar radiation incident on a tilted surface to that on a horizontal surface

S-tilted plane slope angle

Z-solar zenith angle

α_s- solar azimuth angle

α_T- surface azimuth angle

δ- solar declination angle

Ø- latitude of the site

ρ- ground reflectivity

Θ_i -solar incidence angle on tilted surface

From the weather station data, B_N, D_h, G_h was achived. As solar elevation angle was also achieved, so solar zenith angle was also achieved because

zenith angle,Z=90-elevation angle (Ec. 4.7)

To find out r_d, there is lots of way to solve it. In this work, Liu and Jordan (1962), Koronakis (1986) and Badescu (2002) method was used[11] to solve. At the final calculation, only Liu and Jordan model was used.

For Liu and Jordan model,

$$r_d = [1 + \cos(S)] / 2 \quad \text{(Ec. 4.8)}$$

For Badescu model,

$$r_d = [3 + \cos(2S)]/4 \qquad \text{(Ec. 4.9)}$$

For Koronakis model,

$$r_d = 1/3[2 + \cos(S)] \qquad \text{(Ec. 4.10)}$$

The ground reflectivity was assumed as 0.2.

As the houses of miraflores have different tilted plane slope angle, In this work,20(deg.) tilted slope angle was assumed to do all the calculation. The houses also have different tilted plane azimuth angle, so tilted plane azimuth angle was assumed as 0(degree), 15(degree), 30(degree).It was assumed that 30%,30% and 40% of the total house of miraflores have surface azimuth angle as 0(degree), 15(degree), 30(degree).

4.4. Determination of the power and energy can be produced on the available roof surface area

After getting the available roof surface area and the tilted solar radiation on the inclined roof of miraflores, Its important to calculate the energy and power potential of the city using solar pv technologies.

Total annual energy output can be calculate as[17],

$$E=I_{tilt}*365*e*S^{avail}_{roof} \qquad \text{(Ec. 4.11)}$$

Where, I_{tilt} is the mean global insolation on tilted surface, calculated as annual average and e is the module efficiency and S^{avail}_{roof} is the available roof surface area for pv installation.

Now, considering different kind of losses (inverter losses, dc and ac cable losses, temperature loss etc),to get a more accurate result, total annual energy is multiplied by performance ratio(PR)[18]. Its range is between 0.5 and 0.9, we considered as 0.75.

To find out the power,

$$\text{Power}=\frac{Energy}{Time} \qquad \text{(Ec. 4.12)}$$

5. Results and discussions

In this section, all the results of the area, solar radiation on inclined surface, energy and power is put here. To get a better and quick result, Excel and Matlab is used.

5.1. Area of the miraflores de la Sierra

Urban area	**Area(m^2)**
Miraflores de la Sierra	309665
Las Huelgas	5885
Los Endrinales	24649
Los Pinarejos	25567
Remaining urban	69175
Total	434944

Table. 5.1. Roof surface area of different urban areas of Miraflores

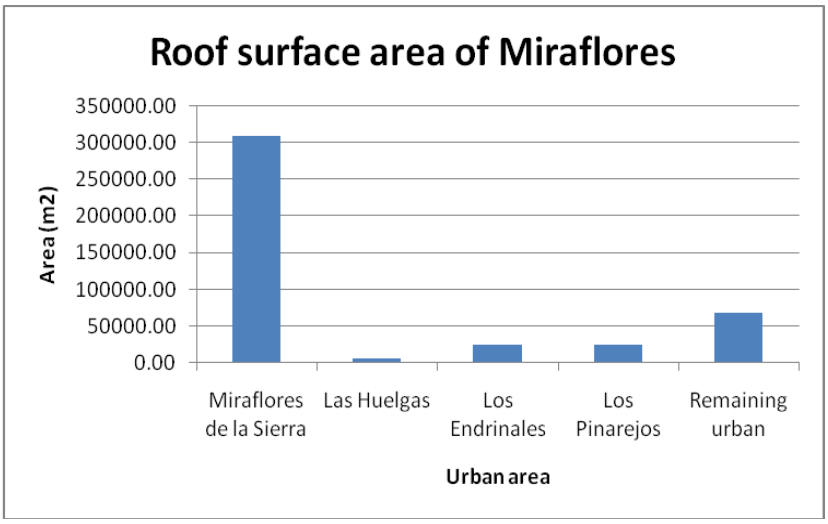

Figure. 5.1. Roof surface area of different urbana reas of Miraflores

All the roof surface area of Miraflores is calculated.There is almost 1883 houses in the región. These area is calculated in 2D projection. These are the area of flat surface calculated using ArcGIS..

Urban area	**Area(m^2)**
Miraflores de la Sierra	329539.1438
Las Huelgas	6263.266503
Los Endrinales	26231.61794
Los Pinarejos	27208.42482
Remaining urban	73615.53492
Total	462857.9879

Table. 5.2. Inclined Roof surface area of different urbana areas of Miraflores for solar pv installation

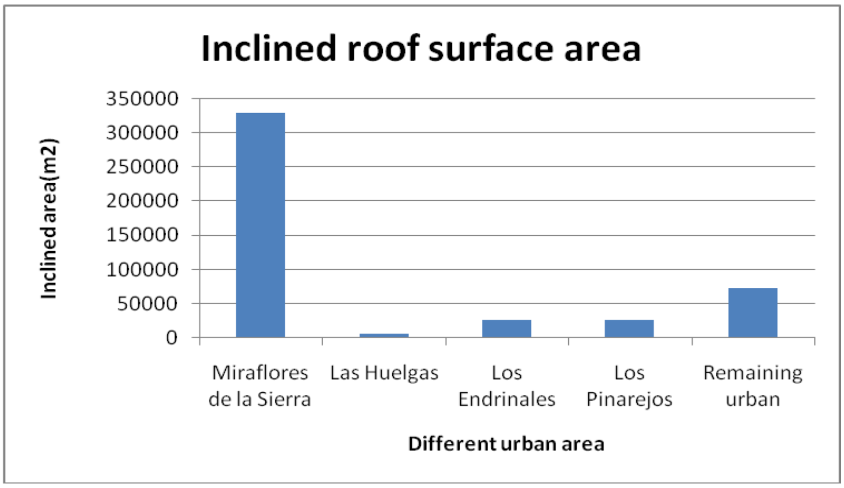

Figure. 5.2. Inclined Roof surface area of different urbana areas of Miraflores for solar pv installation

In table 5.2 and figure 5.2, all the inclined roof surface is calculated. The total inclined roof surface area of Miraflores is 462857.98m^2. the máximum roof surface area is for the town, 329539.14m^2.

5.2. Available area of miraflores de la Sierra

Urban area	Area(m^2)
Miraflores de la Sierra	20086
Las Huelgas	381
Los Endrinales	1598
Los Pinarejos	1658
Remaining urban	4487
Total	28212.35

Table. 5.3. Available Roof surface area of different urbana reas of Miraflores for solar pv installtion

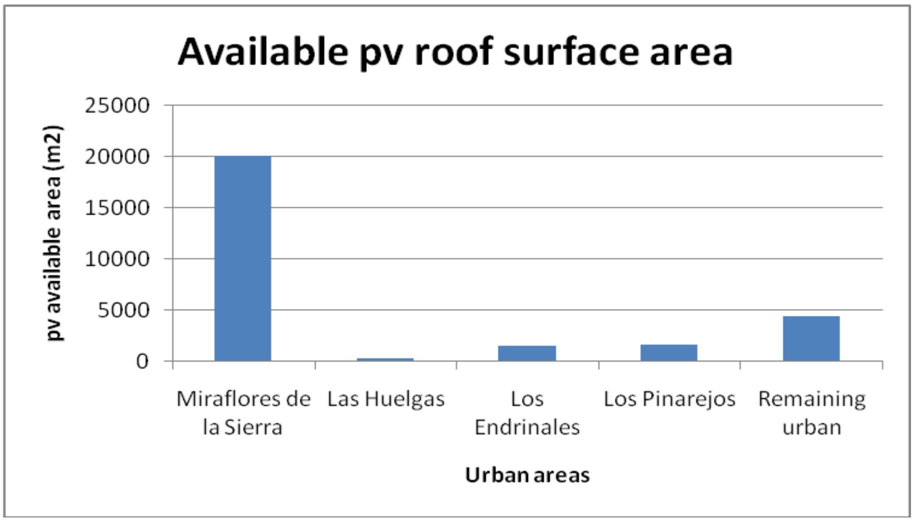

Figure. 5.3. Available Roof surface area of different urbana reas of Miraflores for solar pv installation

After getting the roof surface area of Miraflores,different type of coefficient considered to find out the available roof surface area of pv installation. The available roof surface area for solar pv installation area is 28212.35m^2 in the city of Miraflores.

5.3. Solar radiation on horizontal and inclined surface

The yearly solar radiation data is obtained from Ciemat,Madrid,Spain. The global horizontal radiation annually for everyday is 4.467 kwh/m^2.

Surface azimuth angle	LJ model	BA model	KR model
0	4.64	4.56	4.66
15	4.64	4.56	4.66
30	4.60	4.53	4.63

Table. 5.4. Global tilt radiation using diffrent model

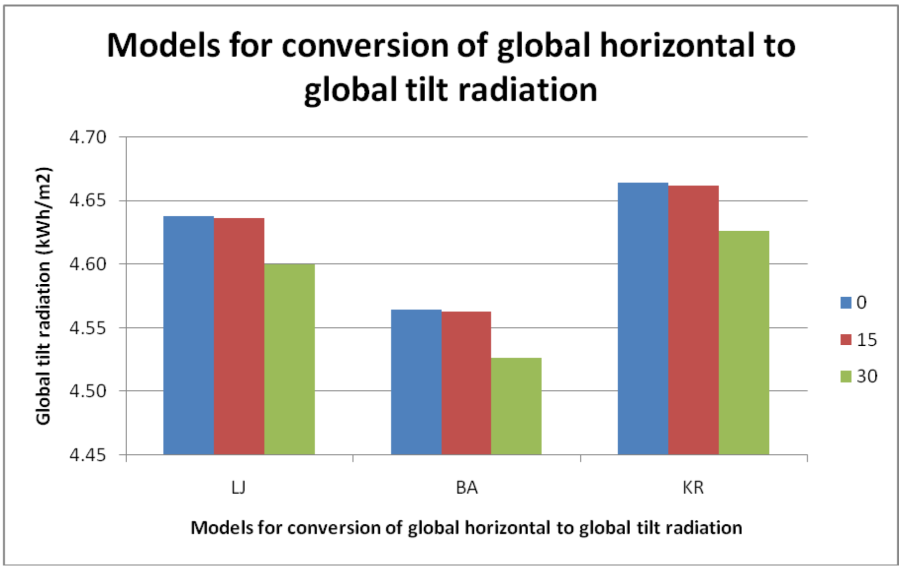

Figure 5.4. Global tilt radiation using different type of model

Using the avaialble data for Madrid, global tilt radiation was found out using different type of model. The slope of the inclined surface was considered as 20degree and surface azimuth angle varies as 0, 15 and 30 degrees. Solar tilt radiation calculated by Liu and Jordan model, Badescu model and Koronakis Model. Liu and Jordan model values were used to further calculation.

Month	Surface azimuth angle,0	Surface azimuth angle ,15	Surface azimuth angle ,30
Jan	2.76	2.66	2.54
Feb	2.91	2.91	2.90
Mar	3.36	3.36	3.36
Apr	5.44	5.44	5.44
May	6.40	6.41	6.42
Jun	6.94	7.07	7.14
Jul	6.86	6.98	7.03
Aug	7.12	7.18	7.16
Sep	5.12	5.11	5.03
Oct	4.04	3.96	3.85
Nov	2.48	2.41	2.32
Dec	2.49	2.40	2.28
Annually average	4.64	4.64	4.60

Table. 5.5. Global tilt radiation using LJ model for monthly average

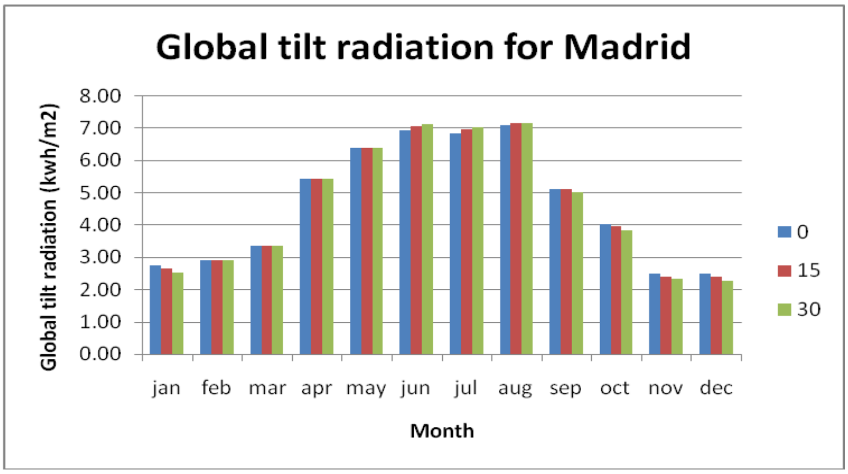

Figure 5.5. Global tilt radiation using Liu and Jordan of model for monthly average

All the 12 month average is showed in the table 6.4 and graph 6.4. the global solar tilt radiation for 0,15 and 30 degree is 4.64khw/m^2,4.64kwh/m^2 and 4.60 kwh/m^2.It is showing that when the house is fully south oriented, It was getting the máximum value of global tilt radiation. When the surface azimuth angle is getting higher, the global tilt radiation is getting lower.

5.4. Power and energy generation in miraflores de la Sierra

	efficiency	energy(kwh)	Enrgy using PR(kWh)
Si (crystalline)	22.90%	10903990	8177992
Si(multicrystalline)	15.50%	6550451	4912838
Si(thin film polycrystalline)	8.20%	3465400	2599050
a-Si/a-SiGe/a-SiGe	10.40%	4395141	3296356

Table. 5.6. Total anual energy output and total actual anual energy output considering PR

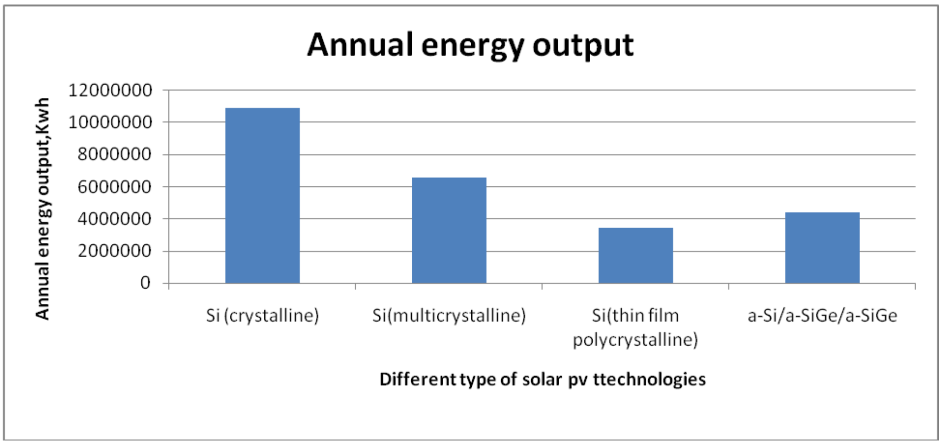

Figure. 5.6. Total anual energy output using different technologies

In the table 5.6 and figure 5.6, total annual energy output was showed using different type of solar pv technologies[19]. The maximum efficiency was containied by silicon crystalline type and minimum efficiency was contained silicon(thin-film polycrystalline) type. The maximum annual energy generation is 8177992kWh and the minimum is 2599050Wh.

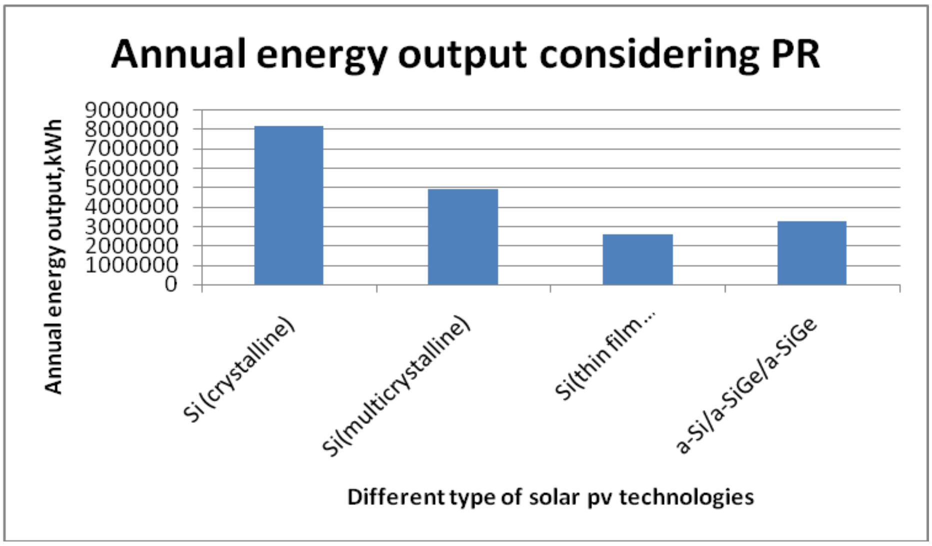

Figure. 5.7. Total actual anual energy output using different technologies considering PR

To get the actual anual energy output, PR was considered and found out actual anual energy output using different type of solar pv technologies[19]. The maximum annual energy generation is 10903990kWh and the minimum is 3465400kWh.

	efficiency	Enrgy using PR(kWh)	Power(kw)
Si (crystalline)	22.90%	8177992	934
Si(multi crystalline)	15.50%	4912838	561
Si(thin film polycrystalline)	8.20%	2599050	297
a-Si/a-SiGe/a-SiGe	10.40%	3296356	376

Table. 5.7. Potential power output using different type of solar pv technologies

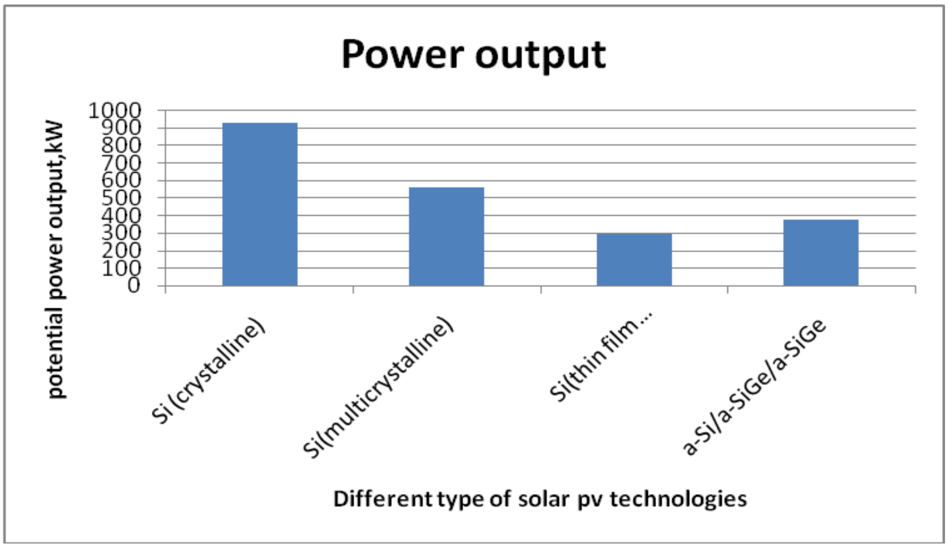

Figure. 5.8. Potential power output using different solar pv technologies

After finding out the actual energy annually, potential power also found out using different type of solar pv technologies. The máximum power output was found by Si(crystalline), 934 kW and the mínimum power output was found by Si(thin-film polycrystalline), 297 kW.

Conclusions

Using renewable energy now a days is a good option to meet the demand. To do it, it is very important to know about the related parameter. To utilize the roof surface area of miraflores and to use renewable energy, it's very important to get the clear view of the available roof surface area, solar radiation.

All the area of the roof top is calculated of the city of miraflores. all the 1883 houses are considered in this project including all the main urban area and remaining urban area. Because of 2D projection, at first the roofs are considered as flat roof and later inclined roof surface area is calculated using formula. The available roof surface area for solar pv installation is 28212.35 m^2.

In the city of miraflores, all the roofs are inclined. So, to calculate the energy and power potential, it is very important to know the global radiation on tilted surface of the area. But, lack of the weather data of the city, the weather data of Madrid is considered and calculated. Annual global radiation on 20 degree tilted surface result is 4.64 kWh/m^2day. All the data is calculated using the last 1year data from the research center. As all the houses are not south oriented, so calculation were done for 0,15,20 degree surface azimuth angle.

There is many constraints considered in the roof top area of miraflores. Lots of coefficient considered to get a better result for the available roof surface area for solar pv installation.

Calculating annual energy production using solar pv technologies, it was seen that higher efficiency solar pv technologies gives higher energy output annually. But, it can be suggested that before going to implement the solar pv technologies, the cost factor also should be considered, as there has to be a trade off between the efficiency and cost of solar pv technologies.

With a efficiency of 22.9% solar pv technologies(Si mono crystalline), annual energy output is 8177992 kWh and the potential power output is 934 kW. Using a lower efficiency of 8.20% solar pv technologies Si(thin film polycrystalline), annual energy output is 2599050 kWh and the potential power output is 297 kW

Future work

Doing this project, there was some constraints during the calculation. In the future work, some part can be improved.

The inclined area- as there were no 3D projection remained, to calculate the inclined area, some formula was used. It can suggested that getting the 3D projection of the city,can give a better result for the inclined area of the city miraflores.

Solar tilt radiation- there was no available radiation data of miraflores, so the data from the nearest weather station was used. Though all the calculated data was real data, it can be suggested that getting the real data for miraflores will make a major change of calculated energy and power potential of the city. The total inclined roof surface area is 462857m^2. In this work, only one year data was analyzed. It is strongly suggest that to take the real data of 10/12 years and analyze it because only one year data analyze cannot give a accurate result.

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