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A Novel Model to Calculate Global Tilted Irradiation (GTI) from Solar Variables Using Netcdf and Rstudio

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Abstract— Currently the world power consumption is around 10TW per year and it is projected to be about 30TW by 2050. So our big challenge is to produce additional 20TW of non-CO2 energy to reduce GHG emission in the atmosphere by mid-century. The simplest and easiest way to reduce CO2 emission is the use of alternative clean energy sources. Among all the renewable energy sources, solar energy is one of the most abundant and the cleanest energy source. It can contribute a total amount of 10TW and the rest amount will be managed by hydrogen for transportation and fossil fuels for residential and industrial heating. This paper represents the European scenario of solar PV potential. A model is developed to calculate the global tilted irradiation and applied for several location of France. The result is compared with available realistic values in quest of verification.

Index Terms—solar PV, renewable energy, sustainable energy, alternative energy, energy management, energy generation, mathmetical model, NetCDF, R

1 Introduction

At present, the energy demand is fulfilled normally by fosil fuels. Globally, the combustion of fossil fuel has a bad impact on the environment. Fossil fuel combustion is the main reason for acid rain, ozone layerdepletion and global climate change. It is known as global worming and it seems a critical problem that theenvironment may face within next fifty years. One of the most important factors of global energy productionsystem is GHG emission from the power plants around the world and it is considered the main culprit forclimate change.

To overcome this situation, we need clean, safe and sustainable energy sources that can satisfy the energydemand for the upcoming future. It also needs to increase the use of alternative energy sources to traditionalfossil fuel. Both nuclear and renewable energy are believed to be able to provide partly solution for climatechange.

From the sustainable and safety point of view, Renewable Energy Sources will be the most effectivesolution as it contributes to the reduction of high dependence on imported energy and provides significantbenefit with regards to GHG emission. Several types of RES technologies such as solar power, biomassand wind energy have known worldwide. Solar energy can play a vital role for green energy production. Scientists are working on solar PV technologies to increase the efficiency with a reduced cost. Although

PV installations have low energy density with high production cost and in most countries a favourable legalframework exists, such as feed in tariffs.

The large-scale integration of solar power generation system presents significant challenges to the systemoperator due to the unpredictable and variable weather. Reserves quantisation depends on many variablessuch as the penetration of renewable, the system stability, the interconnections, and the forecasting accuracy of load and generation and the control requirements imposed bythe system operator.

The impact of fluctuations on the network involves forecast errors inthe short term and it needs the research on predicting time series of PV production, short-term forecastand forecasting errors of these models.

2 Background

2.1 Definition of Photovoltaics

Photovoltaic is a technology/method to create electrical power by converting solar radiation into direct current using semiconductors as they are illuminated by photons. As long as there is solar radiation of light shining on solar cell/panel, it will produce electrical power.List of pros and cons of solar PV including technical and non technical issues are given below.

Advantages of solar PV-

- PV fuel source is widely accessible and infinite
- No GHG emission, not harmful for climate change and free from water pollution.
- No fuel cost, needs only maintenance cost
- Theoretically long lasting
- Operated on ambient temperature; No high temperature corrosion.
- High reliability for modules; Manufacturers give long term guarantees, between20 to 30 years
- Predictable annual output; helpful for forecasting and reserve determination
- Different size of modules
- Can be integrated with buildings

Disadvantages of solar PV-

- High installation cost
- Climate or weather dependent
- Unpredictable time series output (daily or hourly)
- Lack of efficient energy storage which is economically viable

As this work represent the solar system, physical model of solar cell including the semiconductor material, band gap theory is not discussed here. Only a schematic of solar cell is shown in Fig. 1. Electrons are pumped by photon from val-

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ance band to conduction band. There, they are extracted by a contact selective to the conduction band (an n-doped sem-

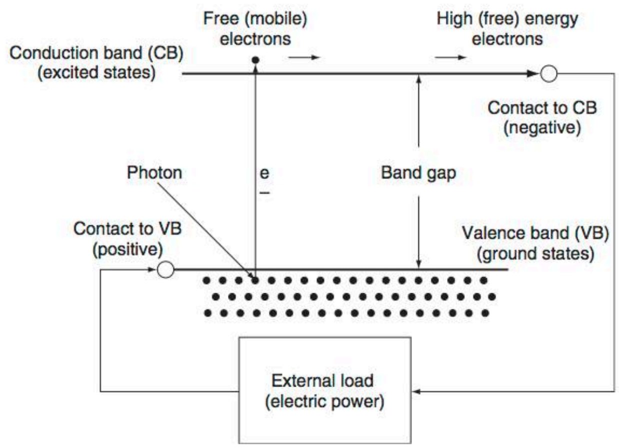

Fig.1.Schematic of a solar cell

-conductor) at a higher (free) energy and delivered to the outside world via wires where they do some useful work, then are returned to the valance band at a lower (free) energy by a contact selective to the valance band (a p-type semiconductor).

2.2 Factors: Tilt, Orientation, Tracking, Shading

It is thought that the tilt angle is really important for calculating solar PV output. It is so but not that much as it is taken care of. The tilt angle to optimize yearly production for fixed non-tracking arrays is usually some few degrees below the local latitude. It is true that yearly output PV production weakly dependent on the tilted angle, hence the slope of the roof. In fact, nearly a reasonable tilted angle is good for capturing solar irradiation. For example, at mid-latitudes locations, the difference in annual averaged effective hours varies just by 10% as the tilt angle of the modules varies from horizontal (0^0) to latitude tilt.It's surprising but true.

Regarding the orientation, if we install solar panel in northern hemisphere, the optimum orientation for fixed panel should be due south. But again, it is not that sensitive to minor deviation. Normally a PV array whose orientation is due south will get all the sunlight in the morning and get less in the afternoon. So for an array installed at 40^0 N latitude with 40^0 tilt and oriented from 45^0 east or west of true south, the annual output will be only 6% less compared to the optimum true south orientation. For my model 180^0 solar azimuth with 0^0 surface azimuths is considered in order to calculate annual solar PV production.

Tracking system can also be implemented to get more irradiation. Solar trackers that track from E to W oriented in long N-S linear arrays are known as single axis trackers. Trackers which are installed on special mounts that track the sun both its daily E-W motion across the sky and its daily and seasonal variation in vertical height is called double axis tracker. Single axis tracker can collect the sunlight 15-20% more where as double axis tracker can collect 25-40% more sunlight compared with fixed non tracking solar PV modules. Those tracking system is employed in large scale ground mounted arrays and the cost is comparatively higher than the fixed mount arrays. For smartresere, no tracking system is considered.

Avoiding shadow is an important factor for solar PV module. The PV array must not have much shadowing on it atleast not during the peak production hours from 9am to 3pm (solar time). The thing is that the shadowing part produce negligible energy as PVs can operate with diffuse light. But there are other effects that are more dangerous. Even a slight shadow from a thin pole or from a tree leaf on a corner or edge of a module could dramatically reduce the output from the shadowed module and also from the entire array. The reason behind it is due to the series connection off all arrays. If the current flow in one cell get restricted, then it restrict the output of all other cells in that modules and that is why total output-power/energy will fall down [2]. To reduce this type of losses, bypass diodes in series connection are used. Shadowing may present a significant limit in cities or towns with lots of trees or high-rise buildings. Shading analysis should be done before installing PV arrays both for buildings and ground mounted PV system [3].

2.3 Efficiency of solar PV

Solar efficiency [4] represents the percentage of the solar energy shining on a photovoltaic device that is converted into electrical energy or electricity. Solar efficiency can be described in two ways.

Solar cell efficiency is the amount of light that dump on the individual solar cell and converts to electricity. Solar panel efficiency is also calculated in the same way. It refers to the amount of light that the entire not only a single cell but in the total module and then convert to electricity. Solar cells are placed next and top to each other and then they are covered by glass to make up a solar panel. Solar PV efficiency is also represented by its area. If a panel can produce 260W peak power and if the size of the module is $1.6m^2$, the panel is said to have 16.25% of efficiency. Normally, solar panel's efficiency is less than solar cell's efficiency. This is due to the spacing between cells and also for the glass covering which reflects away a portion of solar irradiation. So if the area is small, then panel with highest efficiency should be used for roof top PV installation. But for panels with higher efficiency will cost more.

If we consider the efficiency of solar module produced by different companies, according to the article [5], Yingli solar (monocrystalline) holds the highest efficiency (16.2%) record in the market. But according to SRoeCo Solar [6] website data, Sanyo Electric of Panasonic Group has the efficiency more than 17% in industrial level. Different manufacturers are using different technologies to produce different types of solar panels in commercial level.

2.4 PV Systems

In 2001, around 75% of PV was used off-grid but in 2009, it became totally opposite and with 75% of PVnow destined for on-grid applications [6]. Off grid applications such as roof top solar PV are still growingrapidly. Off grid system is economic without the subsidies. It cost a lot to integrate solar PV with grid inrural areas. This is true both for remote places and developing countries as the utility grid infrastructure isrelatively exiguous.

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Off grid and on grid photovoltaic system can use the same type of modules in same weather conditionand will deliver same amount of energy (AC) output to the consumers. Considering the cost scenerio, ongrid solar PV will be less expensive per kW to install and maintain because it will operate more efficientlythan that of off grid PV system. But if there is no grid, it will then become very expensive to extend gridservice into a remote place. In that case, off grid PV system is the better. There are several types of PVsystems which are described as follows.

Small Off-Grid DC System: DC energy is produced by the PV module and then it issupplied to DC load. For space based system, water pumping, small solar home system and some otherapplications whose load requirement is less than 1KW in size, small off-grid DC system is used.

Small Off-Grid AC System: This is the PV system which is connected with AC appliancesbut not with the grid. Loads in this system are run from AC power. Though solar PV module'soutput is DC power, a DC to AC converter is used before connecting with AC appliances. Normally, battery is placed to store energy in order to make power balance between PV sources and the load requirements (i.e. using light, fan at night).

Grid Connected PV System: In this kind of system, PV energy is produced and thenconverted to AC electricity and after that either used on-site or delivered to the utility grid. From DCoutput, it needs to be converted to AC by an inverter. Like the other fossil fuel based power plant, synchronization of voltage and frequency must be done before connecting with the grid. Excess PVenergy is passed into the grid and and then it is distributed to all connected loads with the grid [7].

Micro Grid: Off grid PV system is well established for supplying electricity of single homeor small loads. When several remote houses form a community, to supply electricity generated byPV system to those houses, micro grid concept comes for that. With a centralized PV plant, it canbe done and it will be economic compared with single housing PV system. Micro grid has a capacityupto 100kW. For micro grid, unique metering technology and responsibility of managing it properly, paying bills jointly, need to be organized and developed nicely [8].

Smart Grid: It is a new concept. It is a bit complex to explain what the exact meaning of smart grid is. In general, smart grid [9] is a new approach to the integration of power generation, transmission systems, distribution networks, and consumption. It should have been adaptive, predictive, interactive, integrative and also optimized. Using the latest technology and informations, improvementof efficiency and proper management of load flow are the main goals of smart grid. Beside this renewableenergy integration such as solar PV and wind is also a part of it as reduction ov CO2is the key maindemand for the climate. Improvement of the quality, security, reliability and affordability of powersupply are also the key factors in smart grid. Bi directional flow of electricity is the main constrainfor distribution networks as it need to supply electricity in both utility grid to the consumers whohave grid connected solar PV. They need to send excess electricity of their solar PV system when theirdemand is less than generation. On the other hand, when the demand is more, they need to drainenergy from the utility grid. Now it is one of the keyconcern for solar PV integration with the grid.

3 Photovoltaic Energy Production

NetCDF, a network common data access method to store regular information and data, ground observation data, weather data with high-altitude and other meteorological data has been used in this work. NetCDF files have two advantages which are flexibility and quick dispatch [10]. Flexibility means netCDFfile uses a number of variables and many users can use it by following their own use agreement. For example, ArcGIS and Panoply have the accessibility to read netCDF files. Quick dispatch means netCDF file is based on ASCII format and has a high data compression ratio. So for visualization purpose, it executes faster than matlab.

In this paper a netCDF file (.nc) is created using different solar irradiance variables (Top of atmosphere- TOA, Global horizontal irradiation- GHI, Diffuse horizontal irradiation- DHI, Gamma, Alpha) in different latitude-longitude at hourly time steps (based on SoDa Data, 2008). This file is created using MATLAB coding to get the solar tilted irradiance (Global irradiation on tilt surface [GTI]- Gt , Beam tiltedirrediation- Bt , Reflected tildirradiation- Rt) to calculate solar photovoltaic energy output from those variables. Then a netCDF viewer, PANOPLY (a software from NASA), is used for visualizing the plots of weather variables on lat-long platform to see its density changes when time shifts. It is good software where we can define the dimensions, variable and attributes for better observation.

NetCDF file is a blessing for extracting the data. Data from a netCDF file can be extracted in two ways.

- Data extraction for all latitude-longitude points for raster plot on map (selected hours).
- Time series data extraction (for all hours) at a fixed latitude-longitude point.

Fig.2. Hourly changes of azimuth angle on different latitude-longitude

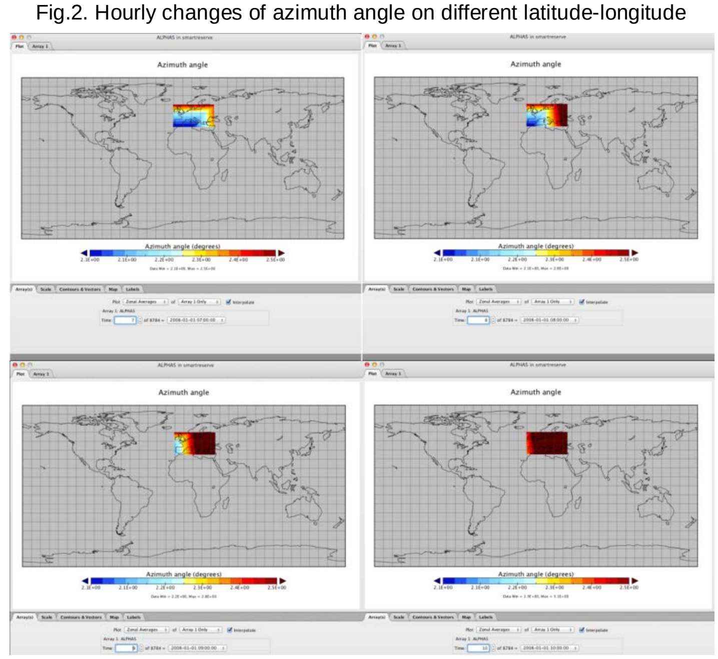

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Fig. 2 represents the changes of azimuth angle (α) on different latitude and longitude with timechanges. Using ncdf package in R, netCDF file can be executed. As the netCDF file contains a 3D array (56×103×8784), there are a total of 8784 hours represented by each column and it starts from V1 till V8784 as indicated in table 1 and a total number of 5768 latitude-longitude points which is shown by each rows. Using the netCDF file and R code, the value for GTI is executed from different parameter. In table 1 red box shows the value of GTI for each and every latitude-longitude point at a particular hour (V9= 9th hour of year 2008). Blue box represents the time series GTI values for each and every hour at a fixed latitude-longitude point. Thanks to netCDF package for making the execution easier.

Using RstudiosimulationTwo types of data extraction can be done from this netCDF file shown in table 1. Horizontal data extertion (blue marked row) represent the hourly change of global horizontal irradiation at a fixed latitude longitude point where as vertical data exterstion (red marked column) represents the change of global horizontal irradiation at different latitude longitude point at a fixed time.

4 Global Horizontal Irradiation (GHI)

Solar radiation is ultraviolet and infrared energy in the wavelength range approximately from 300 to 3000 nanometers (10^{-9} m). It has three components. The global horizontal irradiance (GHI) falling onto the Earth's surface consists of the diffuse horizontal irradiance (DHI) from the sky and the direct normal irradiance (DNI) from the sun.

$$GHI = DHI + DNI \sin\theta \quad (1)$$

Where θ is the solar zenith angle (vertically above the location is 0^0, horizontal is 90^0).

TABLE 1
DATA EXTRACTION FROM NETCDF FILE USING RSTUDIO

Longitude	Latitude	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12
-1.55	54.60	0	0	0	0	0	0	0.000000	0.000000	172.86701	1931.0185	3558.920	4633.330
-1.55	54.15	0	0	0	0	0	0	0.000000	0.000000	108.61408	1424.2065	2107.133	3276.659
-1.55	53.70	0	0	0	0	0	0	0.000000	0.000000	0.00000	2157.4845	4235.032	7146.425
-1.55	53.25	0	0	0	0	0	0	0.000000	0.000000	3067.76336	2319.8858	4691.450	6609.972
-1.55	52.80	0	0	0	0	0	0	0.000000	0.000000	1653.33807	2027.0228	3723.672	3823.643
-1.55	52.35	0	0	0	0	0	0	0.000000	0.000000	1563.44373	2540.9518	5095.364	12272.421
-1.55	51.90	0	0	0	0	0	0	0.000000	0.000000	1062.87952	2337.0759	4180.052	7799.640
-1.55	51.45	0	0	0	0	0	0	0.000000	0.000000	852.98097	1802.9032	2941.796	4554.323
-1.55	51.00	0	0	0	0	0	0	0.000000	0.000000	628.44813	1566.5305	2712.171	5793.965
-1.55	50.55	0	0	0	0	0	0	0.000000	0.000000	1714.00497	5944.2209	10142.453	9921.363
-1.55	50.10	0	0	0	0	0	0	0.000000	0.000000	2658.34951	11695.5631	0.000	0.000
-1.55	49.65	0	0	0	0	0	0	0.000000	0.000000	2889.47665	12227.6888	0.000	0.000
-1.55	49.20	0	0	0	0	0	0	0.000000	0.000000	2298.40400	8511.6896	0.000	0.000
-1.55	48.75	0	0	0	0	0	0	0.000000	4.929015	3238.13753	12535.0520	0.000	0.000
-1.55	48.30	0	0	0	0	0	0	0.000000	0.000000	828.52122	1698.8412	4332.936	9636.817
-1.55	47.85	0	0	0	0	0	0	0.000000	0.000000	1261.32719	2940.8368	10608.849	0.000
-1.55	47.40	0	0	0	0	0	0	0.000000	0.000000	1862.40632	5740.5852	0.000	0.000
-1.55	46.95	0	0	0	0	0	0	0.000000	59.148185	4129.42690	13283.2318	0.000	0.000
-1.55	46.50	0	0	0	0	0	0	0.000000	79.039983	5228.56835	0.0000	0.000	0.000
-1.55	46.05	0	0	0	0	0	0	0.000000	103.685060	6224.55328	0.0000	0.000	0.000
-1.55	45.60	0	0	0	0	0	0	0.000000	29.574093	2272.94058	7874.6950	0.000	0.000
-1.55	45.15	0	0	0	0	0	0	0.000000	54.394906	2604.87683	6571.2933	10289.020	13888.402
-1.55	44.70	0	0	0	0	0	0	0.000000	39.607859	2108.04712	4839.8284	9856.199	0.000
-1.55	44.25	0	0	0	0	0	0	0.000000	182.725043	6806.57965	0.0000	0.000	0.000
-1.55	43.80	0	0	0	0	0	0	0.000000	207.370120	7067.16602	0.0000	0.000	0.000
-1.55	43.35	0	0	0	0	0	0	0.000000	236.944212	7604.44218	0.0000	0.000	0.000
-1.55	42.90	0	0	0	0	0	0	0.000000	261.765026	8541.84669	0.0000	0.000	0.000
-1.55	42.45	0	0	0	0	0	0	0.000000	276.552072	7501.68066	0.0000	0.000	0.000
-1.55	42.00	0	0	0	0	0	0	0.000000	192.583074	3559.27360	11239.2047	0.000	0.000
-1.55	41.55	0	0	0	0	0	0	0.000000	340.805008	9593.01023	0.0000	0.000	0.000
-1.55	41.10	0	0	0	0	0	0	0.000000	390.095163	11737.28579	0.0000	0.000	0.000
-1.10	54.60	0	0	0	0	0	0	0.000000	0.000000	232.19093	2243.0690	4641.338	6194.201

4.1 Global Horizontal Irradiation in Europe

Fig.3 represents the mean annual global horizontal irradiation in Europe for 2008 which is executed according to the netCDF file using Rstudio platform. It if found that our simulated annual global horizontal irradiation is similar to the Solargis raster plot shown in Fig.4

From both plots, it is obvious that yearly horizontal irradiation found different at different locations and the maximum is counted more than 1,900kWh/m². So it can be said that the radiation in Europe less compared with Africa and Middle East. But still, Spain, Portugal, Italy and southern France have good irradiation value than the northern part of Europe.

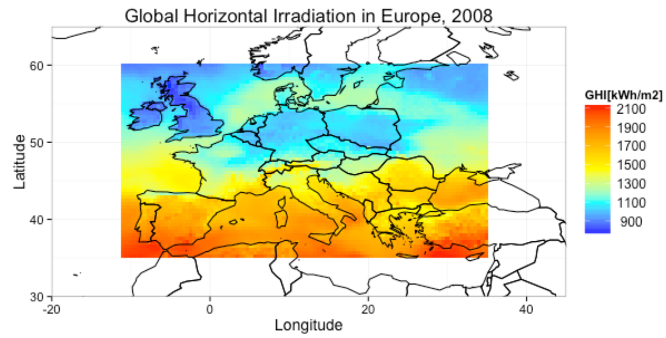

Fig.3 Annual global horizontal irradiation (kWh/m²)

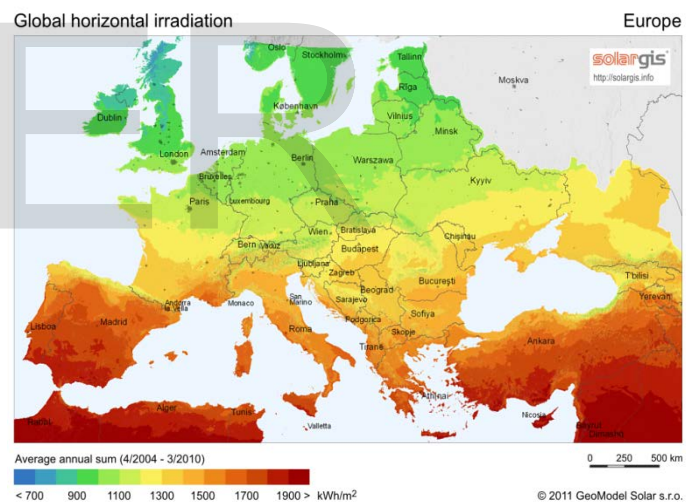

Fig.4 Yearly global horizontal irradiation (kWh/m²), Solargis

4.2 Global Horizontal Irradiation in France

Global horizontal irradiation is the most important parameter for evaluation of solar energy potential of a particular region and the most basic value for PV simulations. Global solar irradiance is a measure of the rate of total incoming solar energy (both direct and diffuse) on a horizontal plane at the Earth's surface. The most accurate measurements are obtained by summing the diffuse and horizontal component of the direct irradiance.

The differences in solar horizontal irradiation in France are essentially due to the climatic conditions influencing the number of sunshine hours. While the southern area is most favourable, especially the Coted'Azure, an installation of photovoltaic solar panels is not only profitable in the South but also yield the highest output. The variation in the periods of sunshine

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between the South and the North of France will only determine what kind of sensor surfaces will be set up. As proof, Germany, where the climatic conditions are even less favourable than those in the North of France, is the European leader in the solar energy.

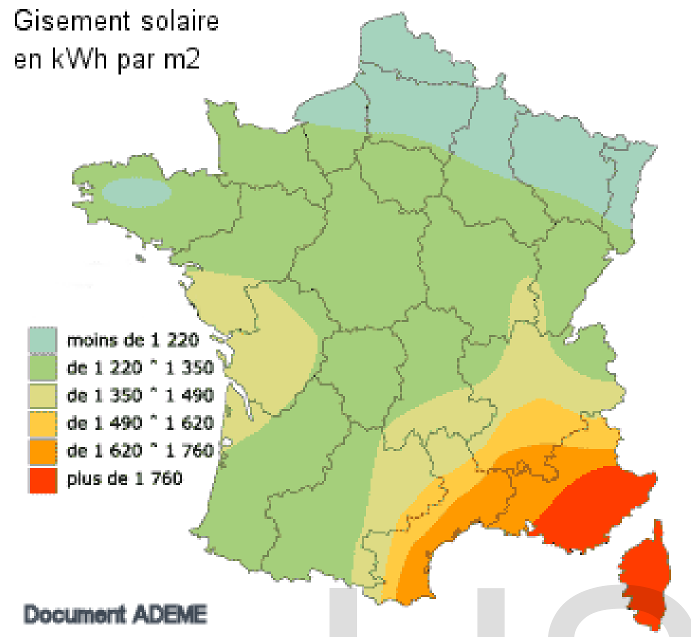

Fig. 5 Yearly global horizontal irradiation (kWh/m²) in France by ADEME

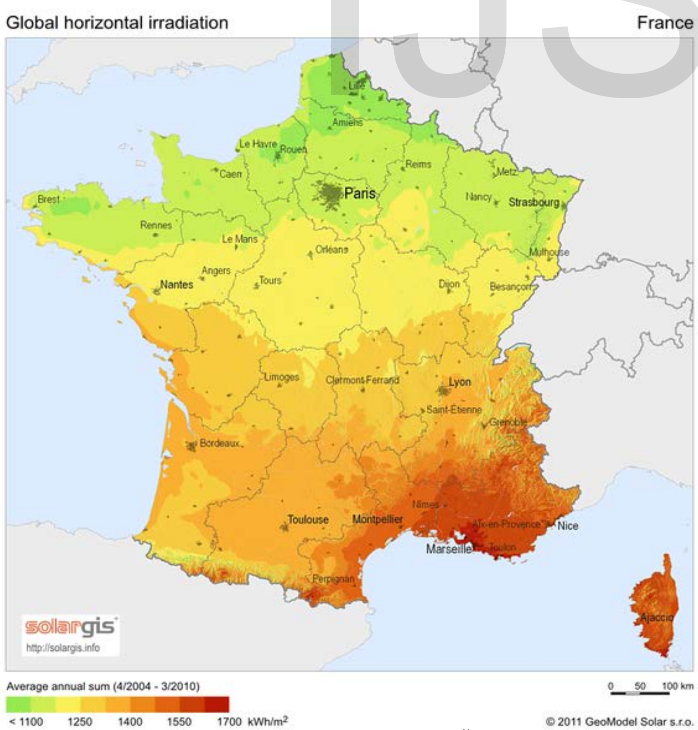

Fig. 6 Yearly global horizontal irradiation (kWh/m²) in France by Solargis

In Fig. 5, a map has been published by the "Agence de l'Environnement et de la Maitrise de l'Énergie" (ADEME), France. The measuring unit is kWh/m². From another source (Solargis) as showed in Fig. 6, it is obvious that the period of sunshine is more favourable in the southern part of France than in the north of France. We can also say more preciously that the Cote D'Azur province is blessed with solar irradiation throughout the whole year.

Similarly, in Fig. 7, a raster plot is performed based on data provided from SoDa and found the global horizontal irradiation for France is similar as Solargis and ADEME data source.

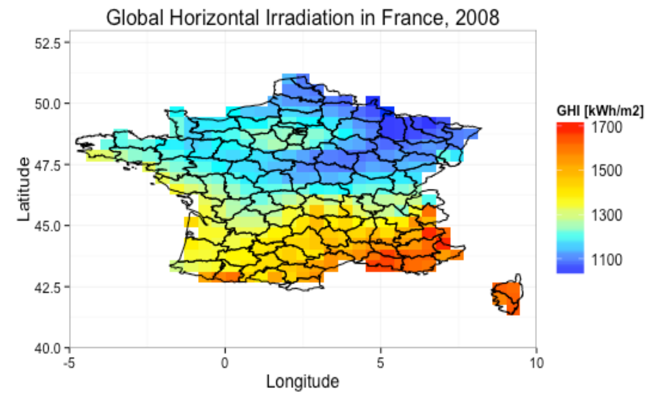

Fig.7(a) Global horizontal irradiance in France (ggplot)

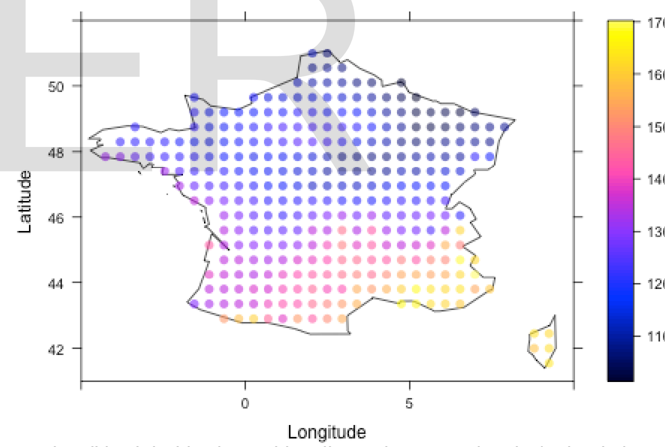

Fig.7(b) Global horizontal irradiance in France(spplot/pointplot)

To find the global horizontal irradiation at different lat-lon points, a spatial point plot (spplot) is performed. For France, a total of 319 latitude-longitude points are extracted from netCDF file. Using "map where" library, names of the location are also extracted for different lat-lon points.

In table 2, 15 points is shown according to the maximum solar horizontal irradiation. Most of the points are situated in the region of Cote D'Azur.

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TABLE 2

TOP 15 LON-LAT POINTS FOR MAXIMUM GHI (kWh/m^2) IN FRANCE.

S/N	Longitude	Latitude	Location	GHI
1	7.00	44.25	Alpes-Maritimes	1702.370
2	6.55	44.70	Hautes-Alpes	1687.278
3	5.20	43.80	Vaucluse	1671.521
4	4.75	43.35	Bouches-du-Rhone	1670.612
5	5.20	43.35	Bouches-du-Rhone	1666.352
6	9.25	41.55	Corse du Sud	1645.550
7	5.65	43.80	Alpes-de-Haute-Provence	1638.414
8	8.80	42.45	Haute-Corse	1637.543
9	6.55	43.80	Alpes-de-Haute-Provence	1635.645
10	9.25	42.00	Haute-Corse	1632.667
11	5.65	43.35	Bouches-du-Rhone	1631.948
12	6.10	43.80	Alpes-de-Haute-Provence	1624.259
13	7.00	44.70	Hautes-Alpes	1622.954
14	6.55	44.25	Alpes-de-Haute-Provence	1621.261
15	9.25	42.45	Haute-Corse	1621.089

Though Italy, Portugal and Spain have more possibilities to generate more power using solar PV, still if we just consider southern part of France, it has also a great potential too.

5 GLOBAL TILT IRRADIATION (GTI)

PV panels have a wide field of view and must be positioned to receive the maximum amount of solar radiation throughout the year. For cost-benefit reasons, panels are often installed at a fixed angle, instead of following the sun's movement in the sky. In this case, solar panel should be installed at the ideal angle to measure the irradiance on tilted surface.

PV modules are installed on different mounting systems, such as fixed tilted construction, single axis tracking, double axis tracking and their variations. For each particular mounting system, tilted irradiation is calculated individually. Fixed tilt construction without any tracking has been considered in this work.

5.1 Equation to calculate GTI

The global solar irradiation on a tilt surface(Gt) [11], can be divided into three parts: (i)Beam tilt irradiance, Bt , (ii) Diffused tilt irradiance, Dt , (iii) Reflective tilt irradiance, Rt .

$$G_t = B_t + R_t + D_t \quad (2)$$

Beam tilt irradiation (B_t) is the radiation that is neither reflected nor scattered but reaches the surface directly in the line from the solar panel. The equation for calculating B_t is

$$B_t = B_N \cos\theta_i = (B_h/\cos\theta_z)\cos\theta_i \quad (3)$$

Where B_N is the direct beam irradiation and B_h is the beam horizontal irradiation. θ_i and θ_z are inclined angle of the beam radiation on tilt surface and zenith angle respectively. r_b is the ratio of θ_i and θ_z whose maximum value is 0. The value of θ_i can be calculated using the following equation-

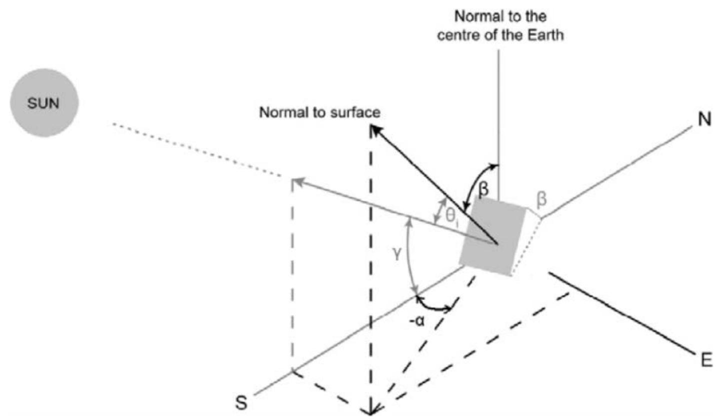

Fig.8 Effects of solar radiation incident and normal lines

$$\begin{aligned}\cos\theta_i = {} & \sin\delta\sin\emptyset\cos\beta - \sin\delta\cos\emptyset\sin\beta\cos\alpha \\ & + \cos\delta\cos\emptyset\cos\beta\cos\omega \\ & + \cos\delta\sin\emptyset\sin\beta\cos\alpha\cos\omega \\ & + \cos\delta\sin\beta\sin\alpha\sin\omega\end{aligned}$$

Where δ, Ø, ω, β and α represent the solar declination angle, the latitude of the location, hour angle, tilt angle and azimuth angle respectively.

When the surface is not purlely horizontal, a bit tiled towards the equator facing the north hemisphere, the value of θi can describe by following equation:

$$\cos\theta_i = \cos\delta\cos(\emptyset - \beta)\cos\omega + \sin\delta\sin(\emptyset - \beta) \quad (4)$$

On the other hand, if the surface is horizontal (β=0) then the equation for θi is equal to θz. So, solar zenith angle (θz) can also be calculated by the same equation.

$$\cos\theta_i = \cos\delta\cos\emptyset\cos\omega + \sin\delta\sin\emptyset \quad (5)$$

To do the modelling of the reflected tilt irradiation (Rt), assume the reflected rays are diffused and also the coefficients of the reflected beam and diffuse radiation are identical. As the irradiation reflected from the ground is small, a simple isotropic model is enough to get the value [12].

$$R_t = \rho R_r G_h \quad (6)$$

Where, $\rho$is the albedo? The ground reflected diffuse irradiance depends on ground reflection of transposition factor (Rr) which can be denoted by the following equation-

$$R_r = (1 - \cos\beta)/2 \quad (7)$$

The diffuse tilt irradiation is calculated based on isotropic and anisotropic models. In the isotropic models, it is assumed that the intensity of diffuse sky radiation is uniform over the sky dome. But in the anisotropic models, it is different and it is assumed that the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disk) and isotropically distributed diffuse component from the rest of the sky dome. In this model, Hay's sky-clarity factor, an anisotropic model is used to calculate diffuse radiation on a tilted surface [13].

In Hay's model, diffuse radiation is composed of an isentropic component along with a cumsolar one. It doesn't consider horizontal brightening.

$$D_t = D_h R_d \quad (8)$$

Where D_h is the diffused horizontal irradiation and Rd is the ratio of diffuse radiation on a tilted surface to that of a horizontal [14].

$$R_d = F_{Hay} B_h + \left(1 - F_{Hay}\right)(1 + \cos\beta)/2 \quad (9)$$

An anisotropy index (F_{Hay}) is used in Hay's model which is

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known as Hay's sky-clarity factor. It is the ratio between direct solar radiation on a horizontal surface (Bh) and extraterrestrial solar radiation on a horizontal surface (Gext).

$$F_{Hay} = B_h / G_{ext} \quad (10)$$

If the value of Hay's sky-clarity factor (FHay) is 0, this model can be reduced to the Liu-Jordan model.

$$R_d = (1 + \cos\beta)/2 \quad (11)$$

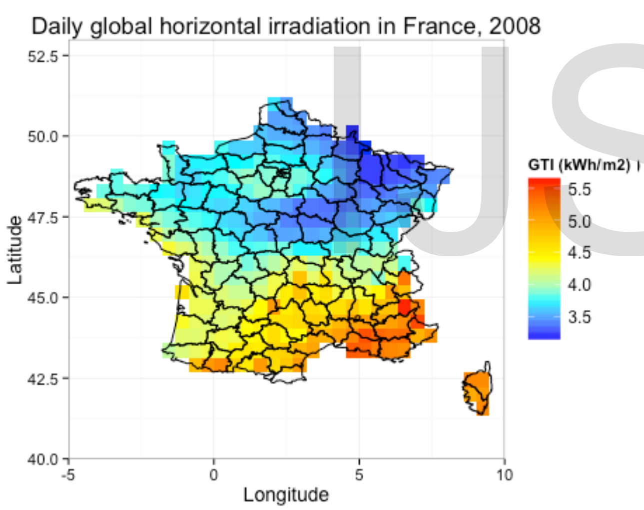
So, just in one equation, global tilt irradiation (Gt) is as follows

$$G_t = (B_h / \cos\theta_z)\cos\theta_i + \rho G_h (1 - \cos\beta)/2 + D_h\left[F_{Hay} B_h + (1 - F_{Hay})(1 + \cos\beta)/2\right] \quad (12)$$

5.2 Global tilted irradiation in Europe

The ideal installation of solar panels depends on the azimuth, the type of panel, latitude, climate, and so on. No matter the type of solar panels, it is best to get them as close to south-facing as possible. An ideal system would be positioned at 180^0, due south. The formula for optimum tilt angle is considered same as local latitude. But to get the maximum irradiation, inclination should be a few degrees less than the local latitude.

Fig.9 Raster plot of GTI (kWh/m^2/day) in France



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French latitudes lie in between 43^0 to 51^0 (approximately). For getting a optimized plot, 40^0 inclination (optimum) [15] with 180^0 azimuth and 0.2 albedo are considered in order to calculate GTI from SoDa data (i.e. beam horizontal irradiation, diffused horizontal irradiation, global horizontal irradiation, top of atmosphere, solar azimuth angle, solar elevation angle). Thanks to R. ncdf package which allow doing all simulation nicely and giving the desired output.

As 2008 was a leap year, it consists of 366 days (8784 hours) instead of 365 (8760 hours). Annual global irradiation on tilted surface is calculated based on those values and in order to make things easier, mean hourly and daily irradiance (kWh/m^2) on tilted surface is shown in table 3 which just only represent top twenty locations whose GTI have the maximum value. A raster plot is also shown in Fig. 9 which represent different french locations with different irradiation on tilted surface. It is found that HautesAlpes has the maximum mean daily irradiation of 5.64 kWh/m^2 whereas Ardennes has the minimum daily irradiance with 3.13 kWh/m^2

TABLE 3

DAILY MEAN GLOBAL IRRADIANCE ON TILTED SURFACE IN FRANCE

	Longitude	Latitude	French Location	Annual GTI (kWh/m2)	Hourly Mean GTI (kWh/m2)	Daily Mean GTI (kWh/m2)
1	6.55	44.70	Hautes-Alpes	2062.872	0.2348443	5.636262
2	7.00	44.25	Alpes-Maritimes	2007.390	0.2285280	5.484672
3	5.20	43.80	Vaucluse	1997.134	0.2273604	5.456650
4	4.75	43.35	Bouches-du-Rhone	1982.050	0.2256432	5.415437
5	5.20	43.35	Bouches-du-Rhone	1968.707	0.2241242	5.378981
6	5.65	43.80	Alpes-de-Haute-Provence	1959.841	0.2231149	5.354757
7	6.55	43.80	Alpes-de-Haute-Provence	1949.875	0.2219803	5.327527
8	6.10	43.80	Alpes-de-Haute-Provence	1941.707	0.2210504	5.305210
9	6.55	45.60	Savoie	1931.475	0.2198856	5.277253
10	5.65	43.35	Bouches-du-Rhone	1913.974	0.2178932	5.229438
. . .						
310	6.10	48.75	Meurthe-et-Moselle	1198.366	0.1364261	3.274225
311	4.75	49.65	Ardennes	1196.889	0.1362579	3.270190
312	6.10	49.20	Moselle	1188.731	0.1353291	3.247898
313	5.20	48.75	Meuse	1183.280	0.1347086	3.233006
314	5.65	48.75	Meuse	1182.036	0.1345670	3.229608
315	5.65	49.20	Meuse	1181.632	0.1345209	3.228502
316	5.20	49.20	Meuse	1180.983	0.1344470	3.226728
317	6.55	49.20	Moselle	1175.812	0.1338584	3.212602
318	4.75	50.10	Ardennes	1168.641	0.1330420	3.193009
319	5.20	49.65	Ardennes	1144.575	0.1303023	3.127255

6 CONCLUSION

This paper describes the development of a mathematicalmodel to calculate global tilted irradiation for Europe (especially for France). AnetCDF file with different solar irradiance parameters is developed to visualise the parameters changes along with the change of latitude and longitude in Panoply software. A simulation based coding is developed in Rstudio to calculate Global tilted irradiation. Raster plots are made to find out suitable locations with potential solar irradiance. In our next publication we will discuss on a mathematical model for calculating annual solar photovoltaic energy production using global tilted irradiation and some other coefficients. Thus we can locate suitable places for installing solar PV.

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