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Changing The Policy of Fixed Orientation of PV Modules from Maximum Radiation to Maximum Saved CO_2 Emissions of Thermal Power Plants

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Abstract

Generally, optimal fixed orientation of PV modules is supposed to be the one that receives maximum solar energy. To receive maximum energy, tilt angle is typically set on the latitude angle of the installation site and the module orients toward the south axis of earth. In other words, it is assumed that if the module orients toward the maximum point of solar energy absorption, maximum electrical energy is generated and maximum fossil fuel pollutants emitted from one sample thermal power plant to generate the equivalent electricity is saved. PV system orientation angle accuracy has the potential to avoid tonnes of GHG emissions without any investment, operation and maintenance costs. If the module is not placed in the proper orientation, the emitted pollutants of the sample plant would not be maximum. In this research, fuel type and efficiency of sample plants are considered as the prime factors in determining the optimal orientation. The paper aims to show that the proper orientation for maximizing saved CO_2 emissions of thermal power plants is not equal to the orientation of maximum radiation and the related tilt and azimuth angles are different.

Keywords: Pollutants; Tilt angle; Azimuth angle; GHG emissions

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1. Introduction

The angular position of PV modules is found to have an immense impact on its electrical performance (Mamun et al. [1]). PV modules intrinsically have low efficiency and if they are not set on the proper orientation, they will convert only a small portion of the received radiation into electrical energy. Module orientation means adjustment of tilt and azimuth angles. Tilt angle is the angle between the PV module and horizontal plane. Azimuth angle is the angle between the module's normal vector and due south direction. In the northern hemisphere, if the module is set towards south, the azimuth angle will be zero (Masters [2]).

Most researches in finding optimal orientation of PV modules focus on gaining maximum electrical energy. If a module receives maximum available radiation during a year, in fact, it will generate maximum electrical energy (Rowlands et al. [3]).

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In some applications, to gain more radiation, a tracker could be installed. A tracker is a specific device intended to move PV modules in a way that they continuously face the sun with the aim of getting maximum radiation (Banerjee [4]). Sun trackers keep the best orientation relative to the sun. Although using a sun-tracker is not essential, its use can boost the collected energy 10–100% in different time periods and geographical conditions. However, they have some negative points including complex structure, more mechanical instruments and high cost of the system. So, in many cases, solar plants without a tracker would be preferred (Mousazadeh et al. [5]).

In this research, fixed orientation means invariant tilt and azimuth angles for at least one year of the module's overall life period. According to Duffie and Beckman [6], the best orientation of a PV module is latitude tilt angle and zero azimuth angle in the northern hemisphere.

Elghamry et al. [7] shows that the PV at a roof has the highest energy generated followed by the PV at south direction under the tropical climatic conditions of Alexandria city, Egypt.

Soulayman [8] analyzed that changing the tilt angle 12 times in a year (i.e., using the monthly optimum tilt angle) maintains approximately the total amount of solar radiation near the maximum value that is found by changing the tilt angle daily to its optimum value. This achieves a yearly gain in solar radiation up to several times of the case of a horizontal surface depending on the latitude value.

There are researches that describe module orientation according to various objectives. Many countries have real-time market prices of electricity for large customers, time-dependent tariffs or tariffs that depend on peak demand. In Canada, the impact of such tariffs on the optimal orientation of non-tracking PV modules is discussed. Compared to conventional south facing modules tilted at an angle just under the latitude, it demonstrates that optimal orientation adds 4–19% to the revenue/cost savings, potentially affecting the economic viability of a PV installation (Haysom et al. [9]).

Mubarak et al [10] discussed that south-oriented collectors give the highest electrical power during the day in Hanover, whereas combinations of east and west orientations (E-W) result in the highest self-consumption rate (SC), and combinations of southeast and southwest (SE-SW) orientations result in the highest degree of autarky (AD), although they reduce the yearly PV Power by 5–6%.

In some sites of the USA, Hummon et al. [11] mentioned that orienting fixed modules slightly to the west of due south generally increases revenue in the simulated systems because of the time-varying value of electricity. However, this effect is small, typically providing an increase in value from 1% to 5%.

Module orientation has a relation with the internal rate of return of solar power plants. MacDougall et al. [12] optimized module orientation to achieve maximum IRR resulting in an IRR increase between 1.3% and 8.2%.

Analysed demand patterns significantly affect optimal PV orientation (Litjens et al. [13]). Therefore, it is recommended that optimal PV orientation should not only be based on maximising energy production, but also on expected demand patterns and market prices.

In many Middle East countries, the energy production sector is dominated by low priced fossil fuels that can present economic and environmental issues. Electricity sector will face a shortage in coming years as electricity demand is expected to grow. The geography and climate can help in prevailing various forms of renewable energy technologies. This will free up oil and gas for export and allow electricity to be produced more cost effectively (Kordvani et al. [14]).

A fossil-fuel power station burns fuels such as gasoil, natural gas and mazut to produce electricity. In many countries, such plants provide most of the consumed electrical energy. Fossil-fuel power stations have machinery to convert the heat energy of combustion into mechanical energy, which then operates an electrical generator. The flue gas from combustion of fossil fuels is discharged into the air. This gas contains CO_2 and water vapour, as well as other substances such as Nitrogen Oxides (NO), Sulphur Oxides (SO), etc (Khattak et al. [15]).

One of the main reasons for the importance of greenhouse gases (GHGs), especially CO_2 emissions, is climate change. Fossil-fuel power plants are among greatest industrial emission producers (Steen [16]). Emissions from power plants pose a potentially large risk to human health and the environment. Therefore, any attempt for reduction of emissions including renewable energy attempts and environmental attitudes will gain huge benefits in the long time. The primary greenhouse gases in earth's atmosphere are water vapour, Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Choler Fluor Carbon (CFC) and Ozone (O_3). Power plant emissions such as CO_2 could be reduced by harnessing renewable energies. Excess amount of CO_2 not only damages the environment, but also damages the ozone layer.

In the recent research (Ahmed et al. [17]) draws a relationship between accuracy of orientation angles impact on PV system's GHG mitigation potential. In this research, GHG emissions reductions potential includes Cars & light trucks not used, Barrels of crude oil not consumed, People reducing energy use by 20%, Acres of forest absorbing carbon, Hectares of forest absorbing Carbon, Tons of waste recycled, Annual GHG emissions reduction.

Farangi et al. [18] showed that from the environmental (CO_2 emissions) and electricity generation perspective, a comparison between two scales of a PV power plant demonstrates that CO_2 emissions and the annual electricity exported to the grid, have a linear relation with the scale of the power plant.

Ahmed et al. [19] proposed that a single end energy user in a populous country like Pakistan can play a minute but positive role in GHG emissions mitigation through the use of a PV system. It can indirectly reduce GHG emissions by reducing the load on fossil fuel-based power systems and has positive cash flow in less than five years.

According to Shiravi et al. [20], three parameters in CO_2 emission reduction which are important and depend on the location of the power plant are as follows: (1) fuel types of non-renewable power plant like: natural gas, gas oil, coal and so on, (2) fuel composition which is different in various countries, (3) GHI (Global Horizontal Insolation) of the location.

Photovoltaic power plants, as a renewable energy source, are considered as an effective means toward reducing CO_2 emissions into the atmosphere. Setting tilt and azimuth angles on receiving maximum solar energy is a proper principle to produce maximum electricity. But it may not be the best orientation to minimise GHG emissions of thermal power plants replaced by solar power generation. Regarding these issues, the orientations are not necessarily the same.

The objective of the present study is to present a relationship between accuracy of orientation angles impact on PV system's CO_2 emissions mitigation potential. It will be shown that orientation of modules to maximise generated electrical energy would not maximise saved CO_2 emissions obtained from replacement of thermal power plants to PV modules and to reach maximum point of saved CO_2 emissions of thermal power plants, tilt angle should be less than latitude.

In the next section, first the framework of study is presented. Then, a case study is introduced and solar energy received on the modules, generated electrical energy and the amount of saved CO_2 emissions are modelled. The objective functions are optimised by Genetic Algorithm in MATLAB software and the results will be analysed and discussed.

2. Materials and Methods

In most applications, optimal orientation of PV modules means setting tilt angle on latitude and orienting the modules toward the south axis of earth. These adjustments imply that maximum solar energy is obtained in this orientation. In the first stage of study, based on the clear sky model (Masters [2]), maximum received radiation on the modules is modelled.

In the second stage, using radiation on the previous stage, generated electrical energy is modelled.

In the third stage, the relation between PV module's orientation and CO_2 emissions of thermal power plants will be presented.

Iran has an extremely high level of energy consumption per head of population. This is due to high levels of subsidies on energy and fuel for consumers and businesses, which does not incentivize efficient energy use (Kordvani et al. [14]). In 2019, the most share of CO_2 emissions of Iran's energy consuming sectors (domestic, industrial, transportation, power plant, etc) was allocated to the power plant sector. Also, Among GHGs and other pollutants of the plant sector, CO_2 emissions had the first rank [21]. Government is trying to attract private sector investors with a guarantee to purchase any renewable power produced in a long-term contract with higher prices in comparison to fossil fuel power. Although fuel-based power is more accessible and cheaper, the reason behind government policies and legal mechanisms to support the renewable energy sector is mainly environmental issues [14].

As mentioned before, if the modules orient toward the maximum point of solar energy absorption, in fact, maximum electrical energy is generated and it is assumed that it saves maximum emissions from thermal power plants but this assumption has some drawbacks. This concept is somehow true as far as ignoring different generation portfolios within a year and also ignoring the variation of fuel type consumed in the power plants in 365 days of a year. But in reality, both gaseous and liquid fuels are consumed in power plants and the generation portfolio varies during the year. Liquid fuels are an excellent energy source. They are easy to handle, store, burn and have nearly constant heating values. Some of the commonly used liquid fuels for power plants are gas oil and mazut. Gaseous fuels can be broadly divided into natural gas and manufactured gas. Natural gas is used in power plants and is carried through pipes to distances which are hundreds of kilometres far from the source. The cost of such transmission is often high. Natural gas possesses all the advantages of liquid fuels except for ease of storage. The major limitation of using natural gas as fuel is that the power plant must be located near a natural gas field otherwise the cost of transportation will be high. In Iran, natural gas is the main fuel of thermal power plants. But, on cold days of the year, shortage of natural gas enforces thermal plants to use liquid fuels like gasoil, as well.

Solar power generated from PV modules can replace generation from thermal power plants and decrease their produced energy. In this research, to show the effect of fuel emissions, thermal power plants are considered and other types of plants such as hydro or nuclear plants are ignored. In a country like Iran, a large number of thermal power plants participate in each hour to satisfy the load. So, there are a lot of choices for replacement of solar power generation in each hour. It is supposed that solar power covers part of the marginal power plant's generation in each hour. Marginal thermal power plants are the last plants with the highest rate of power generation cost and naturally the least efficiency among participants. So, marginal plants have the highest rate of pollutants (gr/kWh) among the participants in each hour. Hence, in this research, marginal plants are assumed as the best option for substitutions with solar power plants.

As stated before, the efficiency of a marginal thermal power plant, type of fuel and consequently amount of CO_2 produced by the combustion of fuels differ in 8760 hours. Third stage of the paper finds the best orientation of PV modules in a way that part of the mentioned marginal plant's generation is replaced by solar power generation so that maximum annual saved CO_2 emissions of thermal power plants are gained. It will be shown that the orientation of gaining maximum saved CO_2 emissions would not gain maximum solar energy. In the next sections, the three mentioned stages are modelled and the results will be presented and discussed.

The case study is a 7 MW solar field located in Tehran with 35.68 and 51.4 latitude and longitude coordinates. In the first stage, the received radiation on the module surface is modelled. In the second stage, electrical energy generated from solar energy is made and in the last stage, the amount of saved CO_2 emissions of marginal thermal plants replaced by solar power generation is modelled.

3.1. Radiation colliding PV module

In this paper, a clear sky model is used to evaluate total radiation striking the sloped surface. Clear sky model is an experimental method estimating radiation on a sloped surface (Duffie and Beckman [6]). In this model, the sky is assumed to be clear and with no clouds. The total radiation that a module receives; is divided into 3 parts: beam radiation (IBC), diffuse radiation (IDC) and reflected radiation (IRC). Beam radiation directly passes the atmosphere and strikes the sloped surface. Diffuse radiation is scattered by air molecules, water vapour and particles and a collection of it strikes the sloped surface. Reflected radiation is made by radiation reflection of different surfaces on the module. So, in order to model the radiation, a collection of beams, diffuse and reflected radiations are needed. Each part of radiation (Masters [2]) is calculated in as follows:

$$IBC = IB \times cos\,(\theta) \tag{1}$$

where IB is the beam insolation at earth's surface and is calculated as follows:

$$IB = Ae^{-km} \tag{2}$$

$$A = 1160\ +\ 75 \times sin\left(\frac{360 \times (n-275)}{365}\right) \tag{3}$$

$$K = 0.174 + 0.035 \times sin\left(\frac{360 \times (n-100)}{365}\right) \tag{4}$$

A, K and n are apparent extra-terrestrial flux, optical depth and day number, respectively. m is the air mass ratio and is computed as follows:

$$m = \frac{1}{sin(B)} \tag{5}$$

in which B is the altitude angle and can be calculated by the following equation:

$$B = \ arcsin\,[cosL \times cos\delta \times cosH + sinL \quad \times sin\delta] \tag{6}$$

H and L are hour angle and latitude angle. δ is the declination angle and is computed according to the following equation:

$$\delta = 23.45 \times sin\ \left[360 \times \frac{n-81}{365}\right] \tag{7}$$

θ is the incidence angle and is computed as follows:

$$\theta = arccos\,[cos\beta \times cos(\varphi s - \varphi c)\ \times sin \in\ + sin\beta \times cos \in] \tag{8}$$

where φs, φc and $\in$ are solar azimuth angle, collector azimuth angle and tilt angle.

the reflected insolation on a collector (IRC) is defined as follows:

$$IRC = \rho \times IB \times \left(sin(B) + \left(0.095 + 0.04 \times sin\left(360 \times \frac{n-100}{365}\right)\right)\right) \times \left(\frac{1-cos(\in)}{2}\right) \quad (9)$$

where ρ is ground reflection factor and is assumed 0.2

the diffuse insolation on a collector (IDC) is defined as follows:

$$IDC = \left(0.095 + 0.04 \times sin\, sin\left(\frac{360 \times (n-100)}{365}\right)\right) \times IB \times \left(\frac{1 + cos\, cos\,(\in)}{2}\right) \quad (10)$$

The radiation received on a module is calculated as follows (Masters [2]):

$$IC = \sum_{i=1}^{365}\sum_{j=1}^{24}[IC_{ij}(\alpha,\beta)] = \sum_{i=1}^{365}\sum_{j=1}^{24}[IBC_{ij}(\alpha,\beta) + IRC_{ij}(\alpha,\beta) + IDC_{ij}(\alpha,\beta)] \quad (11)$$

Where, *IC*: total radiation striking the sloped surface in a year, $IC_{ij}(\alpha,\beta)$: radiation on the sloped surface in j*th* hour of i*th* day in a year, α: tilt angle, β: azimuth angle, $IBC_{ij}(\alpha,\beta)$: beam radiation striking the sloped surface in j*th* hour of i*th* day in a year, $IRC_{ij}(\alpha,\beta)$: reflected radiation striking the sloped surface in j*th* hour of i*th* day in a year, $IDC_{ij}(\alpha,\beta)$: diffuse radiation striking the sloped surface in j*th* hour of i*th* day in a year

In (11), total radiation (IC) (Masters [2]) is the main function and tilt angle (α) and azimuth angle (β) are the variables. Maximising total radiation (11) in MATLAB software using Genetic Algorithm optimization tool, optimal tilt and azimuth angles will be calculated.

3.2. Generated Electrical Energy of PV module

PV modules absorb solar energy to generate electrical energy. The general rule for evaluation of electrical energy generated from radiation striking the module is described as follows:

$$E_{out} = \sum_{i=1}^{365}\sum_{j=1}^{24}[IC_{ij}(\alpha,\beta) \times PR \times \eta_{module}] \quad (12)$$

Where, E_{out} is the total generated electrical energy of a PV module in a year and η_{module} is module efficiency which in this study is assumed 20.9% [22].

Performance Ratio (PR) is the index of evaluation of installation quality of photovoltaic systems. PR involves all the losses of photovoltaic systems such as cable loss, inverter loss and so on, independent from climate conditions and orientation [23]. Considering all the assumed losses presented in table 1, PR is assumed 0.85.

Table 1. Assumed solar system losses [23]

Photovoltaic System	Losses
Inverter	1.2 %
Temperature	3 %
Direct Current Cables	0.8 %
Alternative Current Cables	0.8 %
Shading	5 %
Weak Irradiation	0.8%
Soil & Snow	4 %

3.3. CO_2 Emissions of Marginal Thermal Power Plants Replaced by Solar Power Generation

Economic growth in Iran depends on electricity; therefore, the trend of electricity generation should keep going in the future to guarantee this growth. In view of this need, the country has to build many new power plants. If most of them are thermal types, CO_2 and other air pollutants will increase and cause harmful environmental effects. In this paper, optimal orientation of PV modules is investigated in order to get the maximum amount of saved CO_2 emissions. As mentioned in section 2, the prominent greenhouse gas which attracts the most attention is CO_2, having the highest concentration among greenhouse gases in the atmosphere. Types of common fuels used in Iran's thermal power plants are gasoil, mazut and natural gas. Power plants in Iran often use more than one type of fuel depending on its availability over the year. Most days of the year, natural gas is the main fuel of thermal power plants. But, in cold months, plants have to use liquid fuels like gasoil, as well [21]. Table 2 shows different types of fuel assumed to be used by power plants in each month. As can be noticed, gasoil is assumed as the main fuel of marginal power plants during 3 cold months and in the other months, natural gas is the main fuel.

Table 2. Main fuel type of marginal thermal power plants in a year [21]

Month	Fuel Type
Jan	Gasoil
Feb	Gasoil
Mar	Natural Gas
Apr	Natural Gas
May	Natural Gas
June	Natural Gas
July	Natural Gas
Aug	Natural Gas
Sep	Natural Gas
Oct	Natural Gas
Nov	Natural Gas
Dec	Gasoil

In recent years, concerted efforts have been made to stop using mazut as feedstock in power plants of Iran. Power stations are gradually replacing polluting fuels with natural gas as a cleaner energy resource (Solaymani [24]). In this research, mazut is ignored because of its trivial usage in winter in comparison to natural gas and gasoil.

Natural gas is a cleaner fuel in comparison to other fossil fuels. When used in power plants, natural gas emits lower amounts of CO_2 than other conventional fuels, resulting in negligible emissions compared to other fuels. But because of its high consumption, 78.7% of CO_2 emissions was allocated to natural gas in the year 2019 [21]. As mentioned before, among energy generated sectors and energy consumed sectors in Iran, the power plant sector has the highest rank in CO_2 emission production. Also, among greenhouse gases and other pollutants of the plant sector, CO_2 emissions have the first rank [21]. So, minimization of CO_2 emissions of thermal power plants is a universal goal which in this research, is fulfilled by proper orientation of solar power plants. If PV modules are set in a proper orientation, it is the best mode to save emitted CO_2 from thermal plants.

The amount of released CO_2 is exclusive for each fossil fuel. In other words, one unit of different fuels releases different amounts of CO_2 [25]. CO_2 emissions per Million BTU (British Thermal Unit) according to fuel type is presented in Table 3.

Table 3. CO_2 Emission Coefficients by fuel type [25]

Fossil Fuel	Kilogram per Million Btu
Natural gas	53.07
Gasoline	71.30

As mentioned before, in each hour among committed plants, marginal plants emit the most pollutants and because of this feature, in this essay, the worst condition is considered. solar power generation is considered to replace the generation of marginal plants in 8760 hours of a year. The required data (8760 hours and efficiency in each hour) of marginal thermal power plants in the year 2019 is obtained from Iran Grid Management Company (IGMC) which acts as the market and system operator of Iranian bulk power networks.

Objective function of saved CO_2 emissions replaced by generation of PV module is described as follows:

$$obj = \sum_{i=1}^{365}\sum_{j=1}^{24}[IC_{ij}(\alpha,\beta) \times PR \times \eta_{module} \times \frac{0.0034}{S_{ij}} \times kg(co_2)_i] \quad (13)$$

S_{ij}, efficiency of marginal thermal power plant in j*th* hour of i*th* day.
This item includes 8760 efficiencies which are extracted from IGMC by formal correspondence.

$kg(co_2)_i$kilogram of CO_2 emitted from one MBTU (Million British Thermal Unit) released energy of natural gas or gas oil which is described in table 3. This item is determined based on each hour, marginal plant uses natural gas or gasoline. The type of fuel of each marginal plant can be determined based on table (2).

Equation (13) is a developed form of equation (12) in which generated electricity is converted from kWh to MBTU by 0.0034 coefficient. One kWh of energy equals 0.0034 MBTU.

In the next section, objective functions of equations (11), (12) and (13) are optimised by the Genetic Algorithm tool in MATLAB. tilt angle (α) and azimuth angle (β) are the variables. The results will be presented and discussed.

3. Results & Discussion

In this section, tilt and azimuth angles are going to be optimised by MATLAB software. The case study is a 7 MW solar field located in Tehran with 35.68 and 51.4 latitude and longitude coordinates. The presented functions (equation 11,13) are non-linear. so, Genetic Algorithms are used for their optimization. The results of case study are presented in table 4.

Table 4. Case Study Results

Scenario	Tilt angle	Azimuth angle	PV Field's annual radiation (GWh/year)	PV Field's annual saved CO_2 emissions (ton /year)
1.Tilt angle: latitude Azimuth angle: zero	35.68 °	0°	80.97	10010.14
2.Maximum Radiation	33.86 °	0°	81	10021.88
3.Maximum Saved CO_2 Emissions	32.37 °	-3.72 °	80.92	10029.93

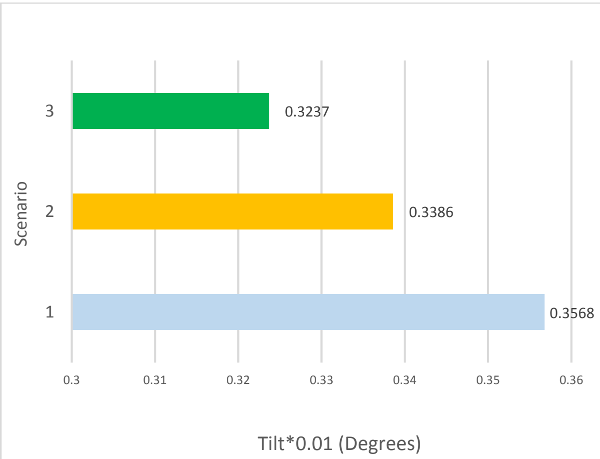

Figure 1. tilt angles in each scenario

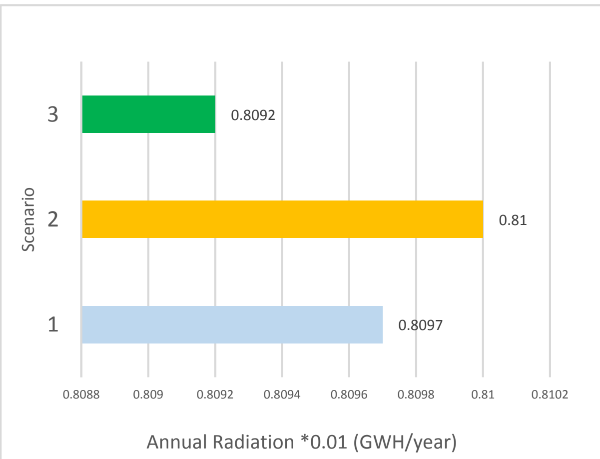

Figure 2. Yearly Radiation in each scenario

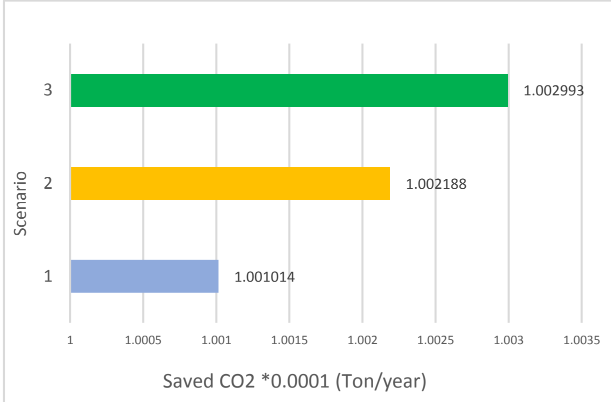

Figure3. Yearly saved CO_2 emissions in each scenario

4.1. Tilt Angle on Latitude Scenario

Considering the common scenario of orientation that is adjusting tilt angle on latitude (35.68°) and azimuth angle on zero, which is a common method in installation stage of non-tracker solar fields, the average annual radiation (equation 11) and saved CO_2 emissions (equation 13) of the 7 MW solar field are presented in table 4. As can be seen, the solar field receives 80.97 GWh solar energy in a year. If the modules convert this amount of solar energy into electrical energy, it can prevent 10010.14 tons of CO_2 emissions from releasing in a year.

4.2. Maximum Radiation Scenario

In most solar fields, gaining maximum radiation is the main criterion in orientation adjustment. In this scenario, optimising equation (11), annual radiation is maximised and its azimuth and tilt angles are calculated (tilt: 33.86, azimuth: 0). By optimising equation (11) in which annual radiation is the objective function and tilt and azimuth angles are the variables, it is shown that the previous scenario would not earn maximum solar energy. As can be noticed, there is an increase of 30 MWh in comparison to the previous scenario. In other words, annual radiation will be 30 MWh more, if tilt angle decreases 1.82 degrees from the latitude (35.68°). So, if the purpose of modules' orientation is to gain maximum solar energy, it is recommended to adjust the modules in the orientation of maximum radiation which is less than latitude. Also, saved CO_2 emission of marginal thermal power plants is 10021.88 tons in a year. Figure 4 shows the variations of tilt angle versus solar radiation.

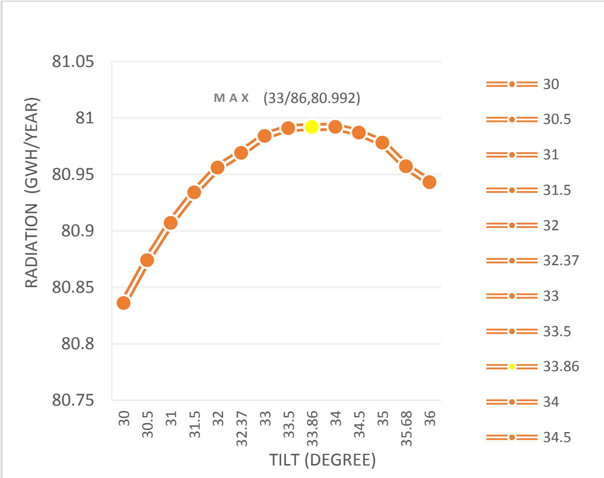

Figure 4. Yearly Radiation at different tilt angles and its maximum point

4.3. Maximum Saved CO_2 Emissions Scenario

In the third scenario by optimising equation (13), maximum annual saved CO_2 emissions as the objective function and tilt and azimuth angles as variables are obtained. In order to get maximum saved CO_2 emissions, tilt angle would decrease in comparison to the other cases and the azimuth angle would be 3.72 degrees towards west of south. In this orientation, 8.05 tons more CO_2 is saved in a year in comparison to the maximum radiation scenario. It can prevent 10029.93 tons of CO_2 from releasing. In this case, if the modules were set on receiving maximum solar energy, saved CO_2 emissions would be 8.05 tons less. Figure 5 shows the variations of tilt angle versus saved CO_2 emissions.

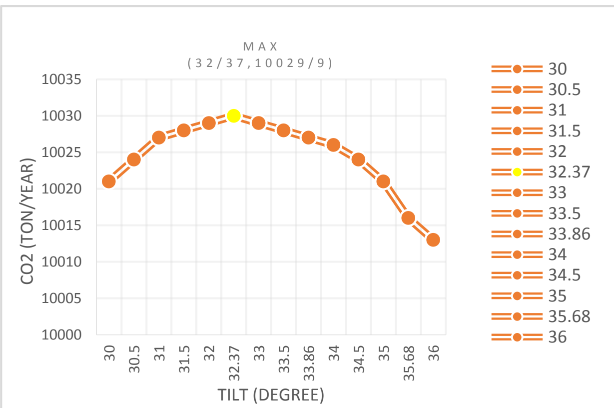

Figure 5. Yearly saved CO_2 emissions at different tilt angles and its maximum point

According to table 4, tilt angle is set at 32.37 degrees and the azimuth angle slightly deviates from the south axis to the west. In this scenario, 8.05 tons more CO_2 emissions can be saved in a year in comparison to the maximum radiation scenario. It means that, if the orientation of modules was set on receiving maximum saved CO_2 emissions, 8.05 tons more CO_2 would be prevented annually in addition to the amount of CO_2 emissions saved in the maximum radiation scenario. Moreover, annual radiation will decrease 80 MWh in comparison to the maximum radiation scenario, but it will be worth it. Because one of the main purposes of installing photovoltaic plants is to alleviate the impacts of pollutants emitted from fossil fuel-based power plants.

4. Conclusions

The aim of this research is to find optimal tilt and azimuth angles of PV modules. In some applications, a tracker is used to achieve this goal. But tracker increases solar system costs and their operational hardships and many designers prefer to set PV modules on-hand. Most designers choose maximum radiation as their benchmark in module orientation. The first scenario is setting tilt angle on latitude (35.68°) and adjust the modules toward south. The second scenario is setting tilt and azimuth angles in maximum annual radiation (tilt: 33.86, azimuth: 0). The second scenario indicates that the orientation of maximum radiation will increase the annual received solar energy by 30 MWh compared to the conventional method in which PV modules face the south with tilt angle equivalent to the location latitude. This is a cost-free change in the design stage and directly increases generated electrical energy and consequently the investor's revenue. There is a common view that orientation of maximum radiation means saving maximum emissions of thermal power plants. This opinion is somehow true. But in fact, the type of fuel being used in thermal power plants differs in a year. Also, the generation of each committed plant can be replaced by solar power. In this research, marginal plants were chosen as replacement. This variation in fuel type and various marginal plants in 8760 hours make tilt and azimuth angles of maximum saved CO_2 emissions different from tilt and azimuth angles of maximum solar radiation. According to the results, the tilt angle is 32.37 degrees and the azimuth angle slightly deviates from the south axis to the west. Solar field's generation can help to postpone investment of new power plants that are in most cases fossil fuel based. In the third scenario, 8.05 tons more saving of CO_2 emissions happens yearly in comparison to the maximum radiation scenario. This number may not be considered significant, but if the capacity of total installed PV modules in the world is supposedly 167800 MW in a year (Attia et al. [26]), the difference between maximum saved CO_2 emissions scenario and maximum radiation scenario would be 192970 tons. It means that if the orientation of all modules were changed from maximum radiation scenario to the maximum saved CO_2 emissions scenario, 192970 tons more CO_2 emissions would be saved. This amount of saved CO_2 corresponds to installation of a 167.8 GW solar field in which 192970 tons of CO_2 would be saved. So, setting the orientation from maximum radiation to maximum saved CO_2 is considered as a slight change, but it is equal to saving 192970 tons CO_2 which is considerable.

Here, it should be noted that the used clear sky model (Masters [2]) is based on an ideal climate in which clouds and shading are ignored. Also, efficiency data of marginal thermal power plants is extracted for just one year. In future research in order to have a long-term perspective, the efficiency of marginal plants will be predicted and all the climatic losses will be considered.

Nomenclature

GHG	Green House Gas
IC	Total radiation (Wh/m^2)
IB	Beam insolation at earth's surface (Wh/m^2)
IBC	Beam radiation (Wh/m^2)
IDC	Diffused Radiation (Wh/m^2)
IRC	Reflected Radiation (Wh/m^2)
E_{out}	Total electrical energy of a PV module in a year (Wh/y)
η_{module}	Module efficiency (%)
PR	Performance Ratio (%)
S_{ij}	Efficiency of marginal thermal power plant in jth hour of ith day (%)
$MBTU$	Million British Thermal Unit
α	tilt angle
β	azimuth angle
θ	Incident Angle
K	optical depth
N	day number
A	extra-terrestrial flux
φs	solar azimuth angle
φc	collector azimuth angle
ρ	ground reflection factor
m	air mass ratio
H	hour angle
L	latitude angle
δ	Declination angle
$kg(co_2)_i$	Kilogram of CO_2 emitted from one MBTU released energy of natural gas or gasoil
B	Altitude angle
$\in$	Collector tilt angle

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