Tilt sensitivity for a scalable one-hectare photovoltaic power plant composed of parallel racks in Muscat

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Tilt sensitivity for a scalable one-hectare photovoltaic power plant composed of parallel racks in Muscat

Osama A. Marzouk*

Abstract: Using the desktop tool (Energy3D) for modelling sustainable buildings and solar power generation, this work predicts the performance of a scalable photovoltaic (PV) power plant composed of south-facing parallel racks in Muscat (the capital of the Sultanate of Oman, latitude 23.6 degrees North). The pilot PV power plant has 3,535 PV panels of peak capacity 300 Wp, leading to a total theoretical peak capacity of 1,060.5 kWp. It covers a land area of 10,000 square meters (1 hectare). The work focuses on the sensitivity of the output electricity to the tilt of the PV panels. The analysis shows that a fixed year-round optimum tilt angle offers 6.6% less annual yield than the single-axis-horizontal tracking system (continuously varying tilt). Adopting a dual-tilt system (tilt of 8.6 degrees during April–September and 38.6 degrees during October–March) reduces this gap to 2.5%. The PV power plant can provide an annual yield of 1.794 GWh under a dual-tilt setting, and 1.92 GWh with single-axis-horizontal solar tracking. Some results are provided on a per-square-meter basis, for easy estimation of land needs. The accuracy of estimating electric annual yield was tested by benchmarking with the Global Solar Atlas (GSA) online tool by the World Bank, for the case of fixed optimum tilt.

Subjects: Renewable Energy; Technology; Design

Keywords: photovoltaic; PV; Energy3D; tilt; solar tracking

1. Introduction

According to the International Energy Agency (IEA) IEA (International Energy Agency, 2021b), the total energy supply (TES), excluding any electricity and heat trade, for the Sultanate of Oman during 1990–2018 was composed of natural gas (major component) and oil (minor component). For example, in 2018, TES of the Sultanate of Oman was 25,554 ktoe (kilotonnes of oil equivalent). Natural gas contributed 87.7% to this amount, while oil contributed the remaining 12.3%. Solar energy has not been a dominant part of the energy mix for the Sultanate of Oman.

PUBLIC INTEREST STATEMENT

This work is concerned with the use of photovoltaic panels (also called PV panels) for producing clean electricity from the sunlight. It considers a design of a hypothetical small electricity generation station that can be installed over a land area of 10,000 square meters (1 hectare; 107,639 square feet; or 2.471 acres) in Muscat, the capital of the Sultanate of Oman, located in the Arabian Gulf region. This work explores the ability to produce clean electricity under seven different scenarios of how the orientation of the solar panels is selected. The work shows that in the particular location of Muscat, the simple scenario of installing the panels at a fixed slope angle (also called tilt) during its entire lifetime results in a good performance that is not far from the scenario of using a solar tracker (which is more complicated). The expected month-to-month variation in the generated electricity is also demonstrated.
In a recent report by World Bank’s ESMAP (Energy Sector Management Assistance Program, 2020), the Sultanate of Oman came in the 6th position among top countries in terms of practical photovoltaic (PV) power potential, with a score of 5.168. This indicator is the specific photovoltaic power output of a PV system with PV panels mounted at an optimum tilt, expressed in kWh/kWp/day (average daily kilowatt-hour of produced electricity from a standard system having a rated theoretical peak capacity of 1 kWp, when operated for a whole year). The rankings included 209 countries or regions.

The IEA’s (Net Zero by 2050) roadmap for the global energy sector is the first global detailed study of how to transform to a net-zero energy system by 2050 (IEA (International Energy Agency), 2021a). In that pathway, the energy sector should rely heavily on renewable energy as compared to fossil fuels. It is aimed to have two-thirds of total energy supply in 2050 coming from solar energy, wind energy, biofuels, geothermal resources, and hydropower. Solar energy is expected to be the largest source, contributing 20% of the total energy supply in 2050, globally. The PV capacity is expected to increase 20 times between 2021 and 2050.

Investment in solar PV energy can benefit from the existence of predictive studies showing the possible gains and required infrastructure. This helps buyers make an informed decision about the scale at which they should consider when utilizing PV energy as compared to the main electric grid, either to reduce grid dependence (which means savings in electricity bills) or to eliminate it completely (thus, offering an attractive advantage for projects in very remote areas not served by the grid).

This work provides technical estimation of the electric AC (alternating current) yield as power from a small power plant, which serves as a prototype that can be scaled up or down as per the specific need of the user. The prototype has a foundation (land) area of 1 hectare (10,000 m²), with the shape of a square having 100-m length. It is based on an illustrative design provided with the solar modelling software program Energy3D (Xie et al., 2018), which is a computer-aided design (CAD) program for three-dimensional designing of green buildings as well as solar power stations. The program development received funding from the National Science Foundation (NSF) of the United States and from the American automotive company General Motors. The Energy3D version used here is 8.7.4 (2021). It has a number of stored cities in its database. For the Sultanate of Oman, only Muscat (the capital) is listed. Thus, the results in this work are relevant to Muscat in general, without reference to a specific location within it. The sensitivity of the electric yield to the tilt angle of the PV panels (angle of the PV panels above the horizontal) is examined. The annual and daily performance for the whole pilot plant and for virtual division with an area of 1 m² of its foundation land is presented. The work can benefit local individuals or organizations in sizing their PV system based on their known or expected demand. It also can benefit general readers outside Muscat and even outside the Sultanate of Oman by exposing them to an example where a PV system is assessed through a modelling tool that is available freely to the public.

2. Related studies and highlights
With regard to the tilt optimization in the Sultanate of Oman, previous studies (Kazem, Khatib, Alwaeli et al., 2013; Kazem, Khatib, Sopian et al., 2013) utilized the commercial computational modelling software program (MATLAB) with hourly meteorological data and performed numerical optimization of the PV module tilt angle for Sohar, which is a coastal area in Oman, and includes one of the major cities in the Sultanate of Oman (also called Sohar Brinkhoff). Sohar is located about 200 km to the northwest of Muscat, with coordinates of approximately 24.4° N (latitude) and 56.7° E (longitude). In these studies, it was suggested to adjust the tilt angle of a PV array twice a year, with a higher value of 49° being used during a 6-month period (21 September to 21 March), while a lower value of 0° (thus, the PV panels are fully horizontal) is used during the rest of the year.

The presented work here considers a different location in the Sultanate of Oman (Muscat, the capital). It examines six tilt configurations (in addition to the zero-tilt condition) for PV panels with different levels of adjustment complexity, such as adjusting the tilt every month and adjusting it every 6 months (which is referred to here as a dual-tilt configuration). The values proposed here for
Table 1. Some features of the analyzed PV plant

| Feature                        | Value | Unit |
|--------------------------------|-------|------|
| Peak capacity                  | 1,060.5 | kWp  |
| Land (foundation) area         | 10,000 | m²   |
| Number of PV panels            | 3,535 | -    |
| Number of PV panels per rack   | 505   | -    |
| Number of PV panels along the rack length | 101 | - |
| Number of PV panels along the rack width | 5 | - |

the dual-tilt configuration are different from those proposed in the mentioned earlier studies for Sohar, and the modelling tool used here is also different.

This work suggests different configurations of the tilt angle for an array of seven PV racks (which are rows of connected PV panels that are not allowed to rotate in the horizontal plane around a vertical axis, but its tilt can be adjusted and can rotate around a horizontal axis), and leaves the reader (as a designer of a PV system to be installed in Muscat) to select the one that is most suitable to their situation as a compromise between the simplicity of installation combined with operation on one side, and the expected electricity generation on the other side.

The highlights (or major findings) of this work include:

- Energy3D as a desktop modelling tool can be used to predict the performance of a photovoltaic system in different cities in the world with different configurations.
- Energy3D prediction of photovoltaic electric output for a sample problem was not very different from those obtained from another independent modelling tool.
- In Muscat, 1 square meter of land for installed photovoltaic system can generate about 190 kilowatt-hours of electricity over 1 year.
- In Muscat, applying a simple optimized fixed tilt of 23.6° (the latitude) to the photovoltaic panels gives a performance that is 12.4% less than using horizontal-axis tracking.
- In Muscat, a dual-tilt configuration can improve the performance of a photovoltaic system compared to the fixed-tilt configuration, by 4.4%.

3. PV plant characteristics
The small photovoltaic power plant designs presented here pertain to Muscat, with a generic location latitude of 23.6°. The Energy3D database records a latitude value of 23° for Muscat, but it is apparent that Energy3D uses whole numbers (integer values) for the latitude in its database of cities. In our analysis, a more-precise value of 23.6° is used when setting the PV panel tilt (Geodatos, 2021).

The PV plant is composed of seven racks (rows) of PV panels, raised on poles above the ground, with a pole height of 4 m. Each rack extends over 100 m in length (505 PV panels with portrait layout, connected side by side), and has a width of 8.3 m (5 stacked PV panels, connected top to bottom). This means that the rack extends through the entire length (100 m) of the square foundation of the power plant (from the east edge to the west edge). The rack spacing is about 15.2 m, which was selected such that the shading effect remains small, even during winter afternoons (where the shade length is relatively long). The number of racks (which is seven) is optimum for this spacing and land size, so that the land utilization is maximized.

The racks can be tilted, and the tilt can be one of the following:
Figure 1. Layout of PV racks above the ground foundation, with zero tilt, as provided by the Energy3D program.

Figure 2. Layout of the racks at 50° tilt in the Energy3D program, on December 21, at 3:10 pm (solar time). No rack shading exists at this instant of time.
Fixed throughout the year (fixed tilt)  
- Changing regularly every certain period (seasonal profile)  
- Attempting to follow the sun continuously, by rotating around a horizontal axis (single-axis-horizontal tracking)

Table 1 summarizes key features of the PV power plant.

Figure 1 shows the distribution of the racks on the square foundation. The PV panels in the figure are horizontal (corresponding to the case of no tilt). The racks are oriented toward the south, which is an optimum orientation for locations in the Northern Hemisphere (which is the case of the Sultanate of Oman) to allow receiving more solar radiation over the day (Donev et al., 2018). 

Figure 2 shows the racks at 50° tilt (which is the maximum value applied in this work) on December 21, at 3 hours and 10 minutes after the solar noon, with illustration of the shade. Partial shading of the PV panels starts to occur after this time.

The PV panels are of the model JKM300M-60 by the China-based manufacturer JinkoSolar. These panels are monocrystalline, with 60 cells per panel, and a theoretical peak power output of 300 Wp at Standard Test Conditions (STC) of 1,000 W/m² irradiance, AM 1.5 air mass coefficient, and 25°C cell temperature (JinkoSolar, 2021). The PV panel dimensions in Energy3D are 1.65 m (length) and 0.99 m (width), which are close to those in the data sheet of the panel (1.665 m and 0.992 m,  

Table 2. Comparison of predicted annual electric output from Energy3D and from GSA, for a 1,060.5 kWp PV pilot power plant in Muscat, with a fixed PV tilt of 23.6°  

| Tile case | Annual PV output (MWh) | % (Energy3D—GSA)/GSA |
|-----------|-------------------------|-----------------------|
| Energy3D  | 1,682.418               | -6.7%                 |
| GSA       | 1,922.543               |                       |

Figure 3. Modelled sun location (August 21, solar noon) in the Energy3D program.
The temperature coefficient for maximum power in Energy3D for this PV panel is −0.39%/°C, which was found to be not far from the one in the data sheet of the panel (~0.36%/°C). A default inverter efficiency of 95%, suggested by the program, is used. According to the data sheet, the mass of each panel is 19.0 kg.

Figure 3 shows the simulated loci of the sun above PV plant (a simulated heliodon). The particular sun location in the figure corresponds to August 21, at solar noon (when the sun is at its highest elevation in the sky).

4. Validation

As a benchmarking step that helps in judging the accuracy of outputs from Energy3D, a comparison with another data source was made for the expected annual electric energy. In this validation, the GSA (Global Solar Atlas) cloud-based modelling tool by the World Bank (GSA (Global Solar Atlas), 2021) was used to estimate the annual output electric energy for the same theoretical peak capacity of 1,060.5 kWp of the small PV power plant analyzed in Energy3D, under a fixed tilt of 23.6°. In GSA, the coordinates used were 23.6° (latitude) and 58.4° (longitude), and the PV system type was ground-mounted large scale. The comparison between the two results (from Energy3D and from GSA) is shown in Table 2. The difference is within 7%. This is considered as an indication of consistency. The small mismatch may be interpreted by possible difference in minor settings, such as the inverter loss.

5. Tilt profiles

The tilt of a PV panel is one of the factors that affect the electric output from it. Solar tracking helps increase the output from the PV panel (Seme et al., 2020), but it also introduces complication due to adding a tracking mechanism. A simpler approach is to use a year-average fixed optimum tilt, as the latitude of the geographic location of the PV panel (Honsberg & Bowden, 2019a). A third pathway is to use a piecewise-constant function for the tilt angle, which is adjusted two or more times during the year to allow temporal variation.

Seven configurations of the panel tilt (including the zero-tilt case) were applied to the PV power plant, using the relevant Energy3D functionality that allows fixed, seasonal, and continuously-changing tilts. These implemented configurations are
- No tilt (the panels are horizontal)
- Year-round optimum tilt of 23.6° (the latitude)
- Dual tilt, for simplified linear solar declination
- Dual tilt, for realistic sinusoidal solar declination
- Quarterly-adjusted tilt
- Monthly-adjusted tilt
- Continuously-changing tilt (single-horizontal-axis tracking)

The dual-tilt, quarterly-tilt, and monthly-tilt cases are summarized in Table 3. The monthly tilt values are taken from NASA (National Aeronautics and Space Administration) Surface meteorology and Solar Energy (SSE) dataset, at 23.5° latitude and 58.5° longitude (closest dataset point to latitude 23.6° and longitude 58.4° representing Muscat in the present work). It is mentioned here that on 13 June 2018 a new web portal of NASA (The POWER Project) replaced the former data archive web of SSE (ASDC (Atmospheric Science Data Center), 2021, The POWER Project (NASA Prediction Of Worldwide Energy Resources), 2021).

Figure 4. Approximation of the solar declination as a piecewise-linear function, and the equivalent 2-value piecewise-constant function.
The quarterly-tilt profile is derived from the monthly profile by applying the tilt of the months of March, June, September, and December to the month before and the month after each of these 4 specific months, as a quarter-long value. These 4 months are the two solstice months and the two equinox months (roughly the middle of the four seasons: spring, summer, fall/autumn, and winter, respectively).

The linear version of the dual-tilt profile approximates the solar declination (which is the angle between the equatorial plane and the sun rays, being positive if the sun is north of the equator, but negative if the sun is south of the equator (Reda & Andreas, 2008)) to vary as a piecewise-linear function with time during the year, as shown in Figure 4. It repeatedly changes from its positive peak value of 23.5° to its negative peak of −23.5° and then to the positive peak value again (Nguyen & Lauwaert, 2020; Shivalingaswamy & Kagali, 2017), following a linear change with time.

The high tilt value ($\theta_2$) and the low tilt value ($\theta_1$) under this tilt configuration (dual tilt with a simplified piecewise-linear change in the solar declination) are computed from

$$\beta_{1,2}(\text{linear declination}) = \varphi \pm (0.5)\Delta$$  \hspace{1cm} (1)

where ($\varphi$) is the latitude (which is 23.6° when representing Muscat in the present study), the factor (0.5) is the average of a general normalized linear function ($y = x$) that starts at $y = 0.0$ and ends at $y = 1.0$, and ($\Delta$) is the amplitude of the solar declination (which is 23.5°), and means the maximum possible amplitude of the angle between the sun rays and the equatorial plane of the earth.
Equation (1) gives tilt angles (rounded to nearest tenth) of 35.4° and 11.9°, as shown in Table 3 and as explained in the next equations. The values of 35.4° and 11.9° are the ones used in the computational modelling and entered in the Energy3D program for this tilt configuration.

\[
\beta_1 (\text{linear declination}) = 23.6° + (0.5) (23.5°) = 35.35° \approx 35.4°
\]

\[
\beta_2 (\text{linear declination}) = 23.6° - (0.5) (23.5°) = 11.85° \approx 11.9°
\]

The second term in Equation (1) is numerically ±11.75°, and it is illustrated by the dotted piece-wise constant profile in Figure 4. This piece-wise constant profile has an absolute area under the curve equivalent to the one obtained for the piece-linear constant declination profile in the same figure. This link between the two profiles justifies the appearance of the factor (0.5) in Equation (1).

A better representation of the variation in solar declination over time is done using a sine function (Al-Rawahi et al., 2011), as shown in Figure 5.

In this case (dual tilt with a realistic sinusoidal change in the solar declination), the tilt angles are computed from

\[
\beta_{12} (\text{sinusoidal declination}) = \varphi \pm \left(\frac{2}{\pi}\right) \Delta
\]

where the factor \((2/\pi) = 0.6366\) is the average of a general sine function \(y = \sin(x)\) in its positive half (Guichard et al). Equation (3) gives tilt angles (rounded to nearest tenth) of 38.6° and 8.6°, as shown in Figure 6 and Figure 7.

Figure 6. Tilted racks at a high tilt angle of 38.6°, as shown in the Energy3D program.

Figure 7. Tilted racks at a low tilt angle of 8.6°, as shown in the Energy3D program.
in Table 3 and as explained in the next equations. The values of 38.6° and 8.6° are the ones used in the computational modelling and entered in the Energy3D program for this tilt configuration.

\[
\beta_1(\text{sinusoidal declination}) = 23.6° + (0.6366) \times (23.5°) = 35.5601° \approx 38.6° \tag{4a}
\]

\[
\beta_2(\text{sinusoidal declination}) = 23.6° - (0.6366) \times (23.5°) = 8.6399° \approx 8.6° \tag{4b}
\]

The second term in Equation (3) is numerically ±14.9601°, and it is illustrated by the dotted piece-wise constant profile in Figure 5. This piece-wise constant profile has an absolute area under the curve equivalent to the one obtained for the sinusoidal declination profile in the same figure. This link between the two profiles justifies the appearance of the factor \(2/\pi\) in Equation (3).

Figure 6 shows the tilted racks at the high tilt of 38.6°, while Figure 7 shows the tilted racks at the low tilt of 8.6° for the dual-tilt, sine-based profile.

The user-defined tilt profiles are given in Figure 8. It excludes the single-axis tracking case, where the tilt is continuously calculated by the Energy3D program itself.

Before moving to the next section, it may be useful to add a visual representation of how the solar zenith angle (the angle between the sun rays and the vertical) changes during the year for the latitude of 23.6° (representing Muscat) at the instant of solar noon. This variation in the solar
zenith angle is shown in Figure 9. This angle depends on two parameters: the solar declination and the latitude, according to the following equation (Mousavi Maleki et al., 2017):

\[ SZA_n = \sin^{-1}[\sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)] \]  

where \( SZA_n \) is the solar zenith angle at solar noon and \( \delta \) is the solar declination (which varies during the year).

Another equation to calculate the solar zenith angle at solar noon is provided below (Honsberg & Bowden, 2019b).

\[ SZA_n = \max(\delta - \varphi, \varphi - \delta) \]  

The above equation means that the solar zenith angle at solar noon is the magnitude of the difference between the latitude and the solar declination. Equation (6) gives identical values for the solar zenith angle at solar noon \( SZA_n \) to those obtained from Equation (5).
Because the latitude is fixed here ($\phi = 23.6^\circ$), the solar zenith angle at solar noon ($\text{SZA}_{n}$) becomes a function of the solar declination ($\delta$) only. Figure 9 demonstrates the variation of the solar-noon solar zenith angle over the year, for both the sinusoidal (realistic) declination function and the linear (simplified) declination function. For sun rays to fall as perpendicularly as possible on the PV panels, the tilt of the PV panel should be equal to the solar zenith angle (SZA) at all times during the day, not just during the solar noon (Hailu & Fung, 2019). Regardless of the exact shape of the declination variation during the year, the solar zenith angle at solar noon ($\text{SZA}_{n}$) at the latitude of interest ($23.6^\circ$) varies from a minimum of $0.1^\circ$ (at the summer solstice, occurring annually on June 20 or 21 (Britannica, 2021)) to a maximum of $47.1^\circ$ (at the winter solstice, occurring annually on December 21 or 22). Outside the solar noon time, the solar zenith angle is larger than its solar-noon value ($\text{SZA} \geq \text{SZA}_{n}$), becoming close to $90^\circ$ near the sunrise and the sunset times, when the sun

| Tile case              | Annual PV output (MWh) | %Decrease below the maximum | Average kWh/year/ m$^2$(land) |
|-----------------------|------------------------|-----------------------------|-------------------------------|
| No tilt               | 1,682.418              | -12.4%                      | 168.2                         |
| Fixed tilt, 23.6°     | 1,793.909              | -6.6%                       | 179.4                         |
| Biannual tilt, linear| 1,862.624              | -3.0%                       | 186.3                         |
| Biannual tilt, sinusoidal| 1,872.028            | -2.5%                       | 187.2                         |
| Quarterly tilt        | 1,874.554              | -2.4%                       | 187.5                         |
| Monthly tilt          | 1,894.819              | -1.3%                       | 189.5                         |
| Horizontal-single-axis tracking | 1,920.272          | 0.0%                        | 192.0                         |

Figure 10. Daily and monthly electric output from the entire PV power plant (left axis) or for each square meter of its foundation land (right axis).
is near the horizon, being in a very low position in the sky. However, given that the solar irradiation is highest around the solar noon for a clear sky (Yang & Koike, 2005), the solar-noon value of the solar zenith angle should be given priority when considering the tilt angle of PV panels.

6. Results
Based on annual analysis, the variation of the predicted electric output energy with the tilt setting is illustrated in Table 4. The percentage drop in output compared to the single-axis tracking (SAT) in the table is computed as:

\[
\% \text{ Decrease} = 100\% \times \frac{\text{(output)} - \text{(SAT)}}{\text{SAT}}
\]

where (output) in Equation (7) refers to the predicted annual electric output under a specific tilt condition, and (SAT) refers to the annual electric output under the single-axis tracking (that is 1,920.272 MWh).

As expected, the single-axis tracking version of the PV power plant gives the highest electric yield. However, the difference between this best case and the simpler fixed-tilt case (optimized as a year-round value of 23.6°, which is the latitude) is only 6.6% of the single-axis-tracking value. If a change of the tilt every 6 months is enabled, this performance gap drops to 2.5% for the dual-tilt case based on sinusoidal solar declination.

Figure 10 gives monthly details about the predicted performance of the PV power plant as a whole under the seven tilt conditions. The figure shows the daily output (in kWh/day) for each month. It also converts this value into a land utilization index, by dividing the daily output from the
PV power plant by its land area of 10,000 m², resulting in an estimate of how much electric energy can be produced from each square meter every day (which varies from one month to another). Such land utilization index allows making a quick estimate of the land area needed based on the energy demand. For the solar tracking case, the month of highest output electric generation is May, while the month of lowest output electric generation is February.

The per-day output electric energy for each square meter is expressed as a per-month output in Figure 11, for the fixed tilt case, one of the two dual-tile cases (the more accurate case with the sine function implemented for solar declination), and the single-axis tracking case (the best case). The per-month value is obtained from the per-day value by multiplying the per-day value by the number of days in each month. February is considered to have 28 days (not 29 days), which is consistent with Energy3D (Xie & Nourian, 2021). Visual inspection suggests that the performance gap with the tracking case is primarily located in the three months of May, June, and July.

The estimated land usage in this work does not explicitly allocate a specific portion for photovoltaic system components other than the photovoltaic racks, such as inverters. It is assumed that these can be located within the spaces between the racks, and no additional area is needed. The system presented does not involve batteries or hydrogen energy storage (Yang & Koike, 2005) to store surplus generated electricity for later use. It can be viewed as operating while connected to the electric grid to reduce the consumption of the metered electricity from the grid, or to feed electricity to the grid during the daylight periods if applicable.

Each PV panel (JinkoSolar JKM300M-60) in the analysed photovoltaic system costs about 156 United States dollars (Renugen Limited, 2021), which is approximately equivalent to 60 Omani rials (XE, 2021). With a total of 3,535 identical PV panels of that type, the total cost of the PV panels alone (not considering a discounted price for a bulk order) is 551,460 United States dollars (212,100 Omani rials). The cost of the inverters and other electrical and structural auxiliary components (such as the cables, circuits breakers, and mounting structures for the PV racks). With the assumption that the cost of the PV panels roughly represents 50% of the cost for the whole PV system (NREL (United States National Renewable Energy Laboratory), 2021), the total system cost can be about 1.1 million United States dollars (420,000 Omani rials).

7. Conclusions and possible extensions
A generic localized photovoltaic power plant in Muscat was modelled using the computer-aided design software program Energy3D. The plant is based on 3,535 solar panels with 300 Wp peak power each, giving a total peak capacity of about 1 MWp. The solar panels are ground-mounted using poles, and arranged in parallel racks. The racks face the south, which is a preferred orientation for better performance. The effect of solar panel tilt was investigated. It was found that a fixed year-round optimized tilt angle (equal to the latitude) does not have a big drop compared to a continuously-varying tilt about a horizontal axis. Normalized output data (per day, per month, per square meter, or per hectare) allow a designer to quickly make an initial judgment about solar panel requirements given a specific electric demand. The analysis does not include economic aspects or energy storage. In case no electricity storage is applied, the plant can be either tied to a municipal grid or serving daytime loads only.

This work may be extended further by attempting to identify the impact of the spacing among the photovoltaic racks on their electric output. The present model may be then used as a reference case, and derived systems with different spacing distances can be analysed to reach a relation between the spacing distance and the electric output. Such relation should reveal a decline in the electric output as the spacing distance decrease below a certain limit. The user may tolerate some performance drop to save land area (making the rack layout more compact) in light of such relation. The work may also be performed at locations other than Muscat, in other countries different from the Sultanate of Oman.
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About the author
The author has conducted research in the area of solar energy, as a non-polluting source of electricity that is free, safe, environment-friendly, and sustainable. This work used a free software program for modeling solar systems, which is called Energy3D. This work can expose the reader to this tool, which may be used in other projects and is not limited to the case analyzed in the present study.

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