ORIGINAL RESEARCH ARTICLE

CASE STUDY ON POWER GENERATION FROM AGRIVOLTAIC SYSTEM IN INDIA

ABSTRACT

This study analyses and evaluates the performance of a 7.2 kWp SPV power plant that was installed in the field of the REE department of the College of Agriculture Engineering and Technology, JAU, Junagadh (21.5 N, 70.1 E). According to the International Energy Agency (IEA), the SPV power plant's performance was examined. For a full year, the power plant is properly observed. During the course of the experiment, the average system efficiency, capacity factor, and overall performance ratio were found to be 80.83%, 16.03%, and 12.07%, respectively. 10104.77 kWh in total were produced during the experimental period. The system's performance is compared to PV systems installed globally and determined to be comparable.

Key words

Agrivoltaic, Power plant, Final & Reference yield, Efficiency

1. INTRODUCTION

It is anticipated that the world's population, which is currently 7.7 billion, would increase to 8.5 billion in 2030 or 9.7 billion in 2050 as a result of recent population increases (Department of Economics 2019). As a result, the necessities of the global society are expanding (Amaducci S. et al. 2018). For instance, the demand for electricity at the energy level has recently been increasing significantly, and it is predicted that this growth will continue in 2021 and 2022 (increases of around 1200 TWh and 1000 TWh, respectively), following the reduction induced by COVID 19 in 2020 (almost 500 TWh less than the previous year) (IEA 2021). Institutions are supporting the switch to a sustainable energy model due to this fact and the harm that conventional, fossil-fuel based energy causes to the environment. In this paradigm, renewable energy sources are becoming more significant.

Due to its many benefits, which include universal availability, ease of installation, cheap maintenance and acquisition costs, increased efficiency, and durability, photovoltaic energy is crucial in this situation. A decrease in the LCOE (Levelized Cost of Energy) is another benefit of these characteristics (Kavlak G. et al.2018, Victoria M. et al. 2021). As a result, the amount of PV electricity installed globally has sharply increased. As a result, according to the IEA's 2021 forecast, new installations will reach 139 GW in 2020 and 117 GW and 119 GW in 2021 and 2022, respectively (IEA 2020). PV energy has its critics since historically speaking, the vast areas of land set aside for grid-connected PV facilities are no longer appropriate for agri-food production. The likelihood of satisfying the rising food demand brought on by population increase is negatively impacted by this reality (Nonhebel S. et al. 2005), especially in locations with limited land resources and dense populations (Weselek A. et al.2019).

Agrivoltaic system, the solution to this issue is to combine PV with agricultural output on the same piece of land. PV panels are set up in this manner so that farming is viable beneath them. Goetzberger and Zastrow first put forth this idea in 1982. (Goetzberger A. et al. 1982). However, it took three decades before it was deployed in test Agrivoltaic plants (Weselek A. et al.2019). Since then, a number of studies have assessed the behaviour of Agrivoltaic system from an agricultural and energy perspective (Agostini A. et al. 2021, Valle B. et al.2017, H. Dinesh et al. 2016, Dupraz C. et al. 2011, Irie N. et al. 2019). Regardless of the fact there's not many industrial or research facilities (Weselek A. et al.

2019). PV panels have an impact on crop productivity since they lower incident irradiance levels and partially shade the crop. (Leon A. et al. 2018, Majumdar D. et al. 2018, Marrou H. et al. 2013).

Objective

In this work, the 7.2 kW SPV power plant performance is carried out with the following goals in mind.

1) To assess the SPV power plant's energy generation performance in accordance with the International Energy Agency (IEA).

2. DESCRIPTION OF THE AGRIVOLTAIC SYSTEM

For this study, the experimental SPV Power Plant construction that was previously designed and established at the Department of Renewable Energy Engineering has been considered for assessment. The SPV power plant's overall rating was 7.2 kW, or 0.047 kW/m2, spread across an area of 153.88 m2. The SPV power plant was constructed so that the amount of shade that affects crops is minimised and that land utilisation is comparable to the traditional SPV power plant design, meaning that the quantity of energy produced per unit land area is unchanged. To ensure that the SPV panels get the majority of solar radiation, the tilt angle of the SPV panels is fixed at 21.5 N, which is equal to the latitude of the Junagadh region.

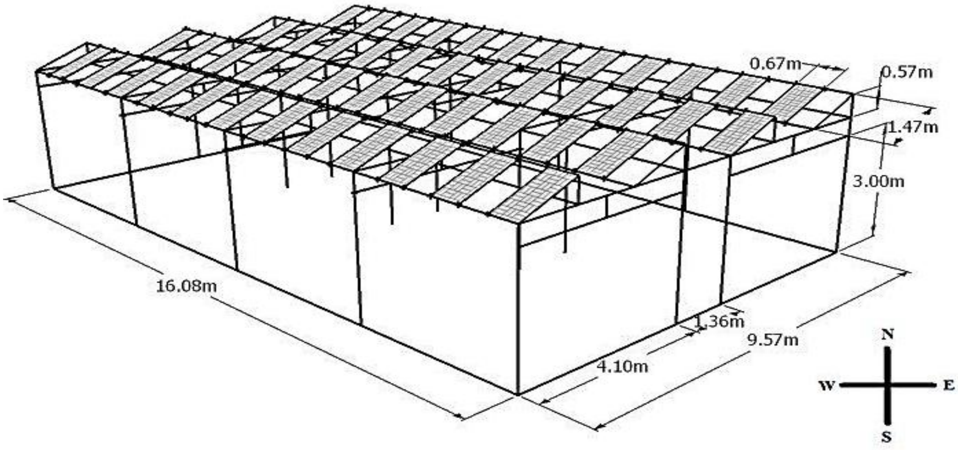

Fig. 1: Isometric view of SPV Power Plant

With 12 numbers of solar panels in each row, each with a 150 W output capacity, there were a total of 48 polycrystalline solar panels fixed in four rows in the shape of a chessboard and installed facing south. Open circuit voltage (VOC) and short circuit current (ISC) ratings for polycrystalline panels are 22.30 V and 8.82 A, respectively. Its operating cell temperature is 48 °C plus 2 °C. 1.34 metres separate the panels (from panel to panel). According to Fig. 1, the bottom end of the panels was 3.50 m above the ground. Panels are cleaned twice a month to increase yield. To convert DC electricity into AC power, an inverter with a fixed power rating of 7.5 kVA was used. Figure 2 depicts the SPV power plant's output path.

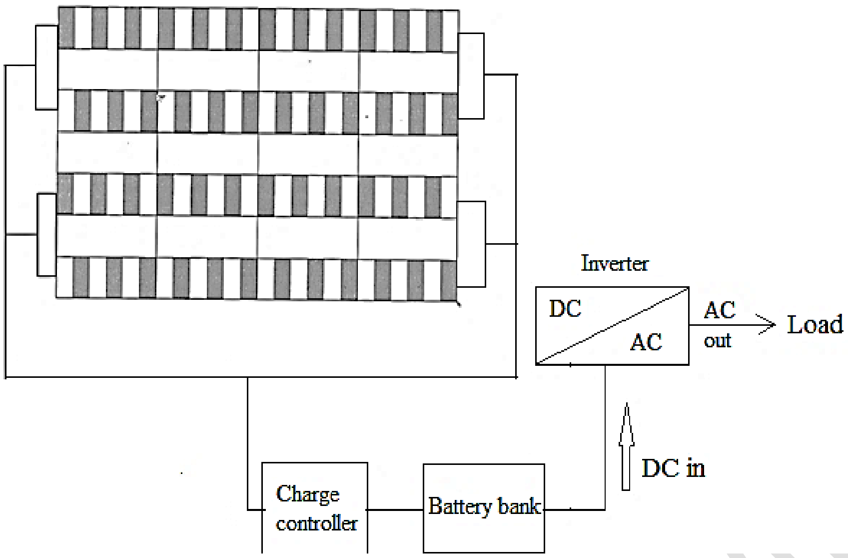

Fig. 2: Schematic diagram of SPV power plant output

3. METHODOLOGY

3.1 Performance Analysis of the Agrivoltaic system

The specifications of solar panels are listed in the table 1. For the performance analysis of the SPV power plant, the following six metrics for performance were taken into account as shown in table 2. These performance indicators essentially show how well the system performs overall in terms of energy output, solar resource utilisation, and overall system losses.

- Total energy generated by the PV system (E_{AC})
- Final yield (Y_F)
- Reference yield (Y_R)
- Performance ratio (PR)
- Capacity factor (CF)
- System efficiency (η_{sys})
- The specifications of solar panels are listed in the table 1.

Table 1. Specification of the solar photovoltaic module

PV module	Specifications
Type of material	Poly crystalline
Maximum power P_{max}(W)	150
Open circuited voltage V_{oc}(V)	22.3
Short circuited current I_{sc} (A)	8.82
Maximum power voltage V_{max} (V)	18.3
Maximum power current (I_{max}) (A)	8.2
No. of cells in a module	(4 × 9) 36 nos.
Module dimensions (mm)	146070 × 35

Table 2. Performance parameter of Agrivoltaic Power Plant

Total energy generated by the PV system (E_{AC})	$E_{(AC,d)} = \sum_{t=1}^{24} E_{(AC,t)}$, $E_{(AC,m)} = \sum_{d=1}^{n} E_{(AC,d)}$	$E_{(AC,t)}$= Total hourly AC energy output (kW h), $E_{(AC,d)}$= Total daily AC energy output (kW h), $E_{(AC,m)}$= Total monthly AC energy output (kW h).
Final yield (Y_F)	$Y_F = \frac{E_{AC}}{P_{PV,Rated}}$	Y_F = Final yield (kW h/kWp) E_{AC} = AC energy output (kWh), $P_{PV,Rated}$ = Rated output power (kWp).
Reference yield (Y_R)	$Y_R = \frac{H_t(kWh/m^2)}{G(kW/m^2)}$	Y_R = Reference yield (kW h/kWp), H_t= Total in-plane solar insolation (kW h/m^2), G = Reference irradiance (kW/m^2).
Performance ratio (PR)	PR (%) $= \frac{Y_F}{Y_R}$ x 100	Y_F = final yield (kW h/kWp), Y_R = Reference yield (kW h/kWp).

Capacity factor (CF)	$CF = \frac{E_{AC,a}}{P_{PV,a} \times 8760} x\ 100$	CF = Capacity factor (%) $E_{(AC,a)}$= Total annual AC energy output (kW h), $P_{PV,a}$= Total amount of energy generated (kW h)
System efficiency (η_{sys})	$\eta_{sys,m} = \frac{E_{AC,m}}{H_t \times A_m} \times 100$	$\eta_{sys,m}$= Monthly system efficiency (%), $E_{(AC,m)}$= Total monthly AC energy output (kW h), H_t= Total in-plane solar insolation (kW h/m^2), A_m = Total area (m^2).

4. RESULTS AND DISCUSSION

4.1 Monthly total energy generated from Agrivoltaic system

Solar modules transform the solar radiation they collect into usable power. The total amount of energy produced was expressed in kWh. Figure 3 displays the calculated monthly energy output for the experimental period. 10104.77 kWh in total were produced during the experimental period.

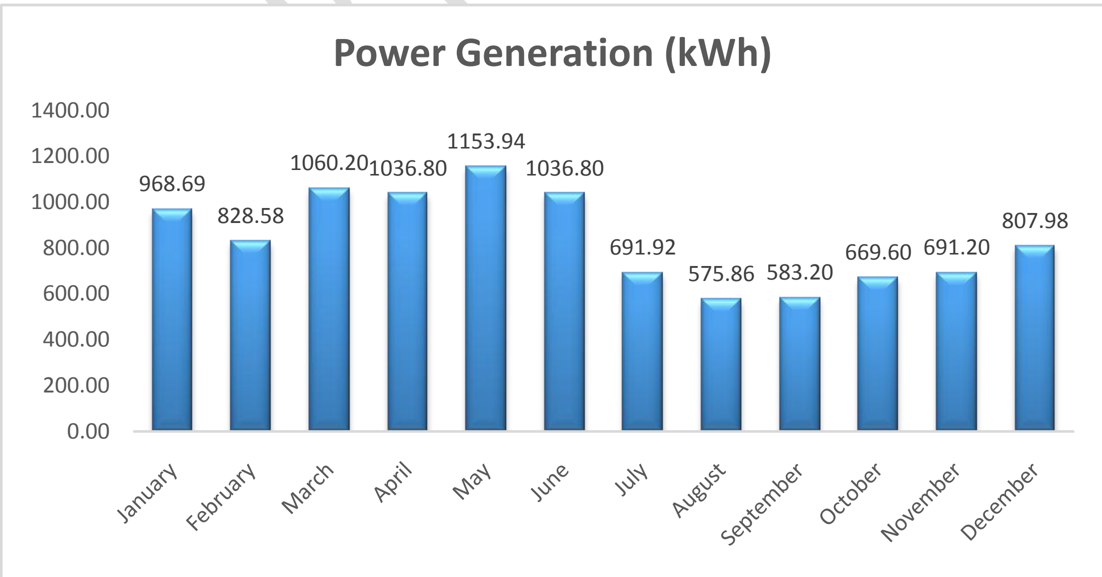

Fig. 3: Monthly energy generation for different months from SPV power plant

4.2 Final yield (Y_F) and Reference yield for different months of year

Final yield (YF) is calculated by dividing the total AC energy produced by the PV system over a specified time (a day, a month, or a year) by the installed PV system's rated output power. The number of hours per day that the solar radiation would have to be at reference irradiance levels in order to contribute the same incident energy as was seen is represented by the reference yield.The results for final yield were quite similar to those of Gautam et al. (2017), Bharathkumar and Byregowda (2014), and Kymakis et al. (2009).In Fig. 4, estimated values for both the final yield and the reference yield are shown as bars.

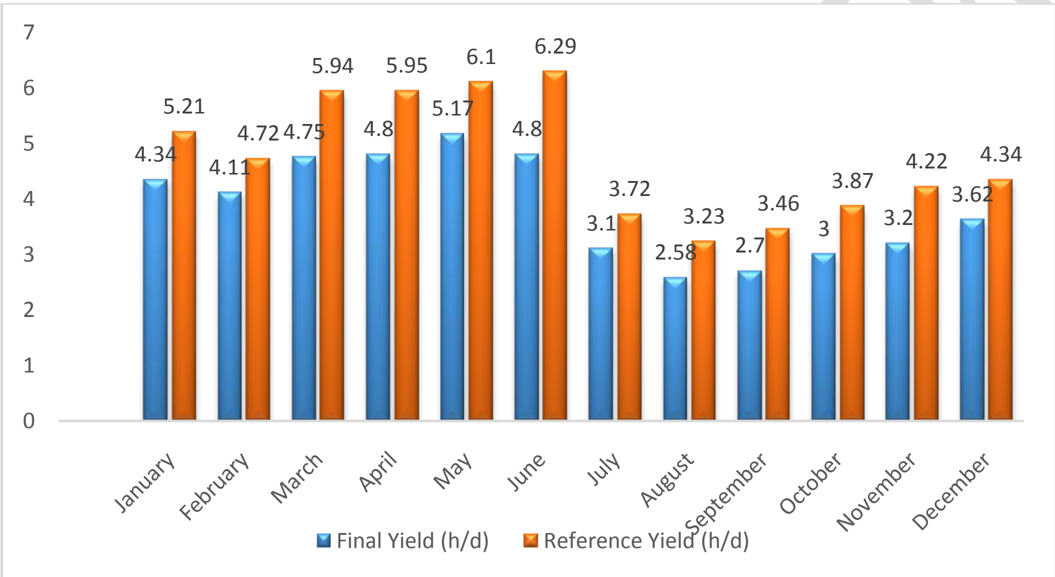

Fig. 4: Final yield and reference yield for different months

4.3 Performance ratio (PR) of Agrivoltaic system

It represents all system losses experienced during the conversion from DC rating to AC output. Depending on the area, solar irradiance, and weather, PR typically ranges from 0.6 to 0.9. The experimental duration performance ratio was determined in accordance with Table 2 and is depicted in Fig. 5. The performance ratio values found in this study and those from Kymakis et al. (2009), Sharma and Chandel (2013), and Bharathkumar and Byregowda (2014) were very similar.

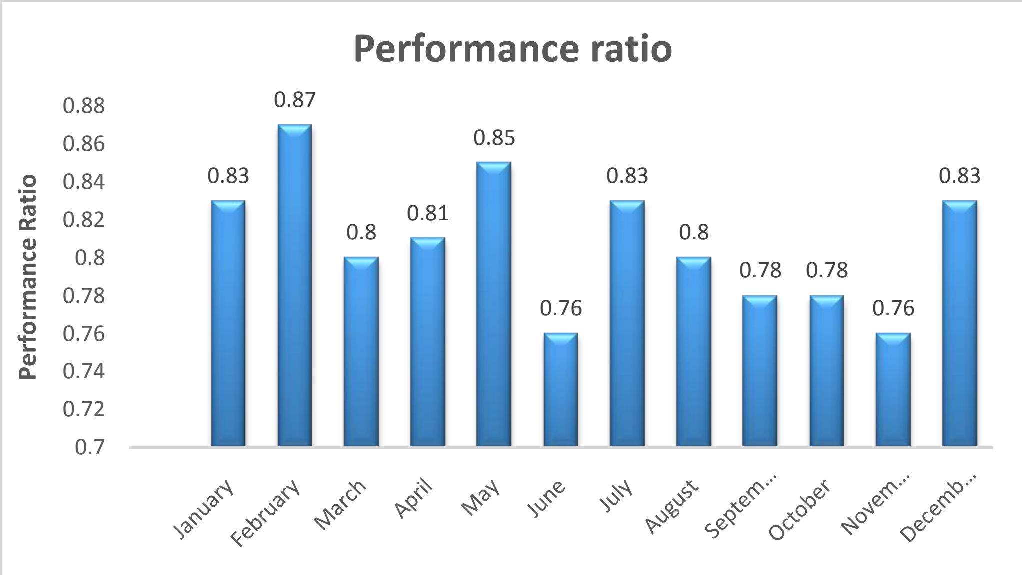

Fig. 5: Performance ratio for different months

4.4 Capacity factor (CF) of SPV power plant for different months

Only the experimental duration was taken into account for the capacity factor (CF) computation. Therefore, the number of days in each month is substituted for the capacity factor 365 in the formula. Table 3 lists the determined capacity factor values for each month.

Table 3: Capacity factor for different months of study period

Months	Capacity Factor (%)
January	18.08
February	17.11
March	19.81
April	20
May	21.53
June	20
July	12.92
August	10.76
September	11.25
October	12.49
November	13.33
December	15.07

4.5 System efficiency during experimental duration

Agrivoltaic construction has 48 panels in total, each measuring 1480 mm by 670 mm. A is therefore calculated as 47.60 m2 for 48 panels. In accordance with Table 2, the monthly system efficiency for the study period is calculated and displayed in Fig. 6. The system efficiency numbers found in this study and those from Sharma and Chandel (2013) agreed closely.

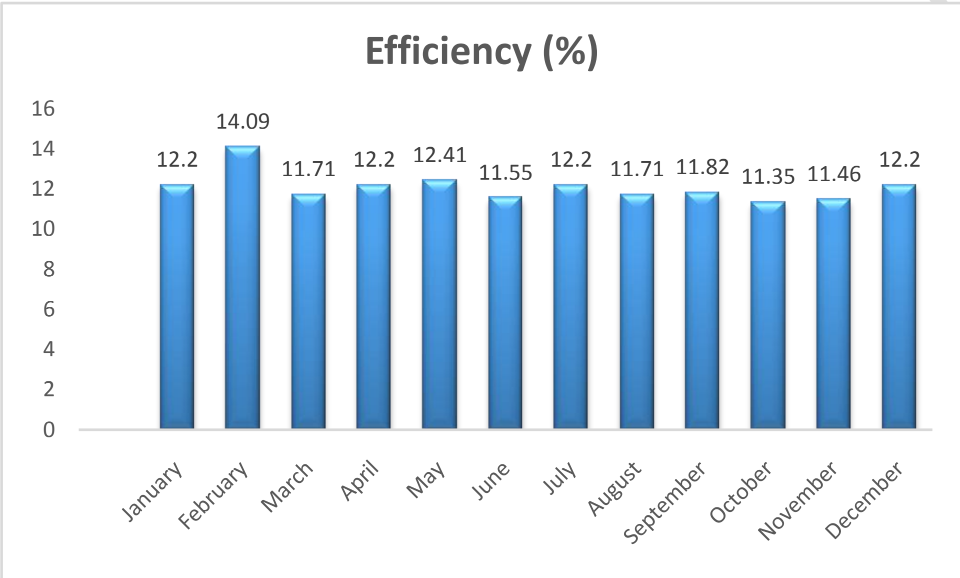

Fig. 6: System efficiency for different months

5. CONCLUSION

The Department of Renewable Energy Engineering at JAU, Junagadh, built and installed an experimental SPV Power Plant design with a 7.2 kW capacity that covered an area of 153.88 m^2.Total energy output during the experimental period was obtained as 10104.77 kWh and daily energy output was observed higher in May month. During monsoon season *i.e.* July, August, September and October energy generation is was found lower than other months. The overall performance ratio during the experimental period was observed as 80.83. The overall system efficiency during the experimental period was found as 12.07 %. This agrivoltaic technology is making a significant difference for future energy needs in India, where solar energy is available all year round.

REFERENCES

Agostini, A., Colauzzi, M., and Amaducci, S. (2021) Innovative Agrivoltaic systems to produce sustainable energy: an economic and environmental assessment, Appl.Energy 281.

Amaducci, S., Yin, X. and Colauzzi, M. (2018) Agrivoltaic systems to optimise land use for electric energy production, Appl. Energy 220:545-561, https://doi.org/10.1016/j.apenergy.2018.03.081.

Bharathkumar, M. and Byregowda, H. V. 2014. Performance Evaluation of 5MW Grid Connected Solar Photovoltaic Power Plant Established in Karnataka. *International Journal of Innovative Research in Science, Engineering and Technology*. **3**(6): 13862-13868.

Department of Economic and Social Affairs of United Nations, World population prospects (2019). https://population.un.org/wpp/2019. (Accessed 17 December 2021).

Dinesh, H. and Pearce, J.M. (2016) The potential of Agrivoltaic systems, Renew. Sustain. Energy Rev. 54:299-308, https://doi.org/10.1016/j.rser.2015.10.024.

Dupraz, C., Marrou, H., Talbot, G., Dufour, L., Nogier A. and Ferard Y. (2011)Combining solar photovoltaic panels and food crops for optimizing land use: towards new Agrivoltaic schemes, Renew. Energy 36: 2725-2732, https://doi.org/10.1016/j.renene.2011.03.005.

Dupraz, C., Marrou, H., Talbot, G., Wery, J., Roux, S., Liagre, F., Ferard Y. and Nogier A. (2011). To mix or not to mix: evidences for the unexpected high productivity of new complex Agrivoltaic and agroforestry systems. Renewable Energy, **36**(10): 1-3.

Gautam, B., Ali Khan, F. and Singh, A. 2017. Performance analysis of 5 MWp grid-connected solar PV power plant using IEC 61724. International Research Journal of Engineering and Technology. 4(7): 2801-2805.

Goetzberger, A. and Zastrow, A.,(1982) On the coexistence of solar-energy conversion and plant cultivation, Int. J. Sol. Energy 1:55-69, https://doi.org/10.1080/01425918208909875.

IEA photovoltaic power systems programme, snapshot of global PV markets (2021). https://iea-pvps.org/wp-content/uploads/2021/04/IEA_PVPS_Snapshot_ 2021-V3.pdf, 2021.

International Energy Agency -IEA, Electricity market report - July 2021.https://www.iea.org/reports/electricity-market-report-july-2021, 2021. (Accessed 17 December 2021).

International Energy Agency -IEA, Renewables 2020, Paris. https://www.iea.org/reports/renewables-2020, 2020.

Irie, N., Kawahara, N., Esteves, A.M. (2019) Sector-wide social impact scoping of Agrivoltaic systems: a case study in Japan, Renew. Energy 139:1463-1476, https://doi.org/10.1016/j.renene.2019.02.048.

Kavlak, G., McNerney, J. and Trancik, J.E. (2018).Evaluating the causes of cost reduction in photovoltaic modules, Energy Pol. 123:700-710, https://doi.org/10.1016/j.enpol.2018.08.015.

Kaymakis, E., Kalyakasis S. and Papazoglou T. (2009). Performance analysis of a grid connected Photovoltaic Park on the island of Crete. Energy Conversion and Management, 50 :(3) **DOI**: 10.1016/j.enconman.2008.12.009

Kirmani, Sheeraz, Majid, Jamil and Iram, Akhtar (2017). Effective low cost grid connected solar photovoltaic system to electrify the small scale industry/commercial building. International Journal of Renewable Energy Research, **7(2):** 797-806. DOI: https://doi.org/10.20508/ijrer.v7i2.5657.g7061

Leon, A. and Ishihara, K.N., (2018) Assessment of new functional units for Agrivoltaic systems, J. Environ. Manag. 226: 493-498, https://doi.org/10.1016/j.jenvman.2018.08.013.

Majumdar, D. and Pasqualetti, M.J.(2018) Dual use of agricultural land: introducing 'Agrivoltaics' in phoenix metropolitan statistical area, USA, Landsc. Urban Plann. 170: 150-168,https://doi.org/10.1016/j.landurbplan.2017.10.011.

Marrou, H., Dufour L. and Wery, J. (2013) How does a shelter of solar panels influence water flows in a soil-crop system? Eur. J. Agron. 50:38-51, https://doi.org/10.1016/j.eja.2013.05.004

Marrou, H., Guilioni, L., Dufour L., Dupraz C and Wery, J. (2013) Microclimate under Agrivoltaic systems: is crop growth rate affected in the partial shade of solar panels? Agric. For. Meteorol. 177:117-132, https://doi.org/10.1016/j.agrformet.2013.04.012.

Marrou, H., Wery, J., Dufour L. and Dupraz C. (2013). Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. European Journal of Agronomy, **44**: 54-66. https://doi.org/10.1016/j.eja.2012.08.003.

Nonhebel, S. (2005) Renewable energy and food supply: will there be enough land? Renew. Sustain. Energy Rev. 9: 191-201, https://doi.org/10.1016/j.rser.2004.02.003.

Pandya, N. N. and Chaudhary, I. D. 2017. Growth of Renewable/Solar Energy and Government Initiatives for Roof-Top System. International Journal For Technological Research In Engineering. **4**(10): 2141-2143.

Sharma, V. and Chandel, S. (2013) Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India. Energy, **55(C)**:476-485. DOI: 10.1016/j.energy.2013.03.075

Valle, B., Simonneau, T., Sourd, F., Pechier, P., Hamard, P., Frisson, T. , Ryckewaert, M. and Christophe, A.(2017) Increasing the total productivity of a land by combining mobile photovoltaic panels and food crops, Appl. Energy 206:1495-1507, https://doi.org/10.1016/j.apenergy.2017.09.113.

Victoria, M., Haegel, N., Peters, I.M., Sinton, R. Jeager-Waldau, A., Ca~nizo, C. del., Breyer, C., Stocks, M., Blakers, A., Kaizuka, I., Komoto, K. and Smets, A. (2021) Solar photovoltaics is ready to power a sustainable future, Joule 5:1041-1056,https://doi.org/10.1016/J.JOULE.2021.03.005.

Weselek, A., Ehmann, A., Zikeli, S., Lewandowski, I., Schindele, S. and Heogy, P.(2019) Agrophotovoltaic systems: applications, challenges, and opportunities. A review, Agron. Sustain. Dev. 39, https://doi.org/10.1007/S13593-019-0581-3/FIGURES/1.