International Journal of
Innovation and Industrial Revolution
IJIREV
EISSN: 2637-0972

Volume 8 Issue 25 (June 2026) PP.429-452

INTERNATIONAL JOURNAL OF
INNOVATION AND
INDUSTRIAL REVOLUTION
(IJIREV)
www.gaexcellence.com/ijirev

GLOBAL ACADEMIC EXCELLENCE

ASSESSING THE FEASIBILITY OF AGRIVOLTAICS SYSTEMS FOR SUSTAINABLE LAND USE: A SIMULATION-BASED EVALUATION OF ENERGY GENERATION AND AGRICULTURAL PRODUCTIVITY IN BEHEIRA GOVERNORATE, EGYPT

Mohammed Elsayed Samier Madboli Ibrahim [1]*, Mohd Rafi Adzman [2], Elsayed Madbouly[3]

[1]Faculty of Electrical Engineering and Technology, Universiti Malaysia Perlis, Arau 02600, Malaysia
✉ moh-madboli@hotmail.com https://orcid.org/0009-0008-2309-6531

[2]Faculty of Electrical Engineering and Technology, Universiti Malaysia Perlis, Arau 02600, Malaysia
✉ mohdrafi@unimap.edu.my https://orcid.org/0000-0002-0347-1698

[3]The Arab Open University, English Intensive Unit, Academic Coordinator, KSA
✉ saidibrahim43@hotmail.com https://orcid.org/0009-0005-7209-3968

*Corresponding Author

Article Info:

Article history:
Received date: 25.04.2026
Revised date: 17.05.2026
Accepted date: 28.06.2026
Published date: 30.06.2026

To cite this document:

Ibrahim, M. E. S. M., Adzman, M. R., & Madbouly, E. (2026). Assessing the Feasibility of Agrivoltaics Systems for Sustainable Land Use: A Simulation-Based Evaluation of Energy Generation and Agricultural Productivity in Beheira Governorate, Egypt. *International Journal of*

Abstract:

Egypt's agricultural development and solar energy exploitation are competing for the country's limited land and water resources, and this conflict is particularly prominent in high-yield agricultural regions such as the Nile Delta. While the agrivoltaics strategy, which enables dual use of land for both photovoltaic power generation and crop cultivation, has been proposed, there is a lack of assessment of its actual on-site performance at the provincial level in Egypt, and a clear research gap persists in Buhara Province, the nation's major wheat-producing region. This study set up two scenarios on a 1-hectare local plot: a standalone photovoltaic array scenario with 70% coverage, and an agrivoltaic scenario with 40% coverage, to verify the feasibility of this model for sustainable land use. PVsyst simulation was used to estimate energy generation and techno-economic performance, while wheat productivity was assessed using a shading-based yield reduction assumption derived from similar agrivoltaics and crop-shading studies. The 70% solar-only PV scenario recorded an annual PV array output of 2,626.9 MWh/year and exported 2,490.7 MWh/year to the grid, generating an estimated annual electricity revenue of USD 99,628. It achieved an LCOE of USD 0.042/kWh, a payback period of 11.7 years, an NPV of USD 684,422.64, and an ROI of 71.6%. The 40% agrivoltaics scenario recorded an annual PV array output of 1,502.5

Innovation and Industrial Revolution, 8(25), 429-452.

MWh/year and exported 1,404.8 MWh/year to the grid, generating USD 56,192/year from electricity sales. Under partial PV shading, wheat yield was estimated at 5.14 t/ha compared with 6.59 t/ha under open-field conditions, giving a combined annual return of USD 57,023.13–57,112.47. Although the solar-only scenario showed stronger direct financial performance, the agrivoltaics scenario achieved an LER of approximately 1.35, indicating 35% higher land-use efficiency than separate wheat cultivation and PV production. The results show that agrivoltaics can support food production, renewable energy generation, carbon-emission reduction, and more efficient land-use planning in Beheira Governorate.

DOI: 10.35631/IJIREV.825026

Keyword:
Agrivoltaics Systems, Agrivoltaics, Solar Energy, Shading, Agriculture

Introduction

Agriculture and energy production are two essential pillars for sustaining human societies, but they often face competing demands, particularly in regions with limited land and water resources(Ayadi et al., 2024). In countries like Egypt, where agricultural land is scarce and water resources are under increasing pressure, it is crucial to develop strategies that optimize the use of available land while also addressing the growing demand for renewable energy(Ansari et al., 2023). Agriculture in Egypt's Nile Delta is highly dependent on irrigation, which consumes a large amount of water resources. However, according to a 2025 study by Al-Fadhli et al., (Al-Fadhli et al., 2025a) the region is facing two core challenges triggered by climate change: water scarcity and inefficient water resources management. Identifying a sustainable solution that balances agricultural production and energy production is critical to Egypt's long-term development.

Agrivoltaic systems are regarded as a sustainable solution to mitigate conflicts in land resource utilization. These systems can improve land use efficiency, while reduce water evaporation and enhance water use efficiency (Amaducci et al., 2018)(Barron-Gafford et al., 2019). In regions with abundant sunlight such as Egypt, these systems can balance local agricultural demands and clean energy production. The 2025 study by Ahmad et al (Ahmad et al., 2025). pointed out that such systems are particularly suited for regions with limited land resources and can achieve the stable coexistence of energy and agricultural production.

Egypt's Beheira Governorate is an ideal site for research on the feasibility and effectiveness of agrivoltaics systems. The governorate's fertile land can support large-scale wheat cultivation, and a 2024 study by Makar et al. (Makar et al., 2024) also confirms that the region has extremely high potential for solar energy development. Agriculture in this governorate is one of the core pillars of Egypt's economy, but the sector faces the challenges of water scarcity and low land use efficiency, while a large share of its solar energy potential remains untapped. This research team will take Beheira Governorate as its study scope, assess the feasibility of integrating agricultural and solar power production, and explore how such systems can resolve the competing, critically important demands of local food and energy production.

Objectives and Research Gap

The main objective of this simulation-based study is to assess the feasibility of agrivoltaic systems in a 1 hectar area located in Beheira, Egypt. In order to be able to determine effectiveness of it, 2 scenarios were compared: a full PV scenario were 70% of the total land is covered in PV panels and a 40% coverage scenario were the panels only covers 40% of the land with the agricultural yield taken into account. Although agrivoltaics has been studied in different global contexts, most existing studies focus on general land-use efficiency, crop shading response, and food-energy-water benefits under different climate conditions (Amaducci et al., 2018)(Barron-Gafford et al., 2019). In Egypt, related studies have mainly discussed canal-top photovoltaic systems, agricultural grid-connected photovoltaic designs, solar irrigation, and wider policy planning for multifunctional land use(Alhejji et al., 2021)(Farghally et al., 2022)(Abouaiana & Battisti, 2022). However, limited work has directly evaluated an agrivoltaics system for wheat production in Beheira Governorate, despite its agricultural importance and high solar potential.

This study addresses the current research gaps in the field. It selects two land use strategies, pure photovoltaics and agrivoltaics, and establishes five core assessment dimensions for Beheira Governorate, Egypt (photovoltaic energy output, Land Equivalent Ratio (LER), Levelized Cost of Energy (LCOE), avoided CO_2 emissions and crop yield). The study breaks down and refines various quantifiable indicators to carry out a comparative assessment and aims to provide practical evidence to determine whether agrivoltaics can support local sustainable land management that balances both renewable energy development and food production.

Agrivoltaics Potential in Global Context

Photovoltaic (PV) agriculture is an integrated model that combines photovoltaic power generation systems with agricultural production. Capable of resolving the land-use competition conflict between energy production and food security, this model has gained steadily rising global attention in recent years. It is particularly well-suited for regions facing shortages of water and land and has already been deployed in parts of the Middle East (with conditions similar to those of Egypt's Beheira Province), Europe, and the United States. These deployments aim to maximize land use efficiency and provide sustainable solutions for both sectors.

The Middle East region generally faces widespread water scarcity and high solar radiation intensity. Agrivoltaic systems can both reduce evaporation of agricultural water and generate renewable energy; local empirical research from the United Arab Emirates (UAE) shows that this system can improve the water use efficiency of tomatoes and lettuce, and lower crop heat stress through the shading effect of solar panels(Al-Fadhli et al., 2025b). Similarly, in Saudi Arabia, agrivoltaics projects have demonstrated how the dual use of land can help mitigate the challenges of desertification while enhancing food production and energy supply(Zubair, 2024).

In Europe, countries such as Germany and France have become pioneers in agrivoltaics, particularly in areas with a mix of agriculture and high solar potential. In Germany, studies have shown that agrivoltaics systems can improve crop yields by protecting plants from excessive heat while also providing a viable source of renewable energy(Trommsdorff et al., 2021). The combination of solar panels and crops like strawberries and wheat has proven beneficial, with both agricultural and energy outputs increasing compared to traditional land-use practices(Ali Abaker Omer et al., 2025). In France, agrivoltaics systems have been utilized to support viticulture, with vines benefiting from partial shading, which enhances water efficiency during drought conditions(Damien Fumey et al., 2023).

In the United States, agrivoltaics research has focused on optimizing systems for a variety of crops and climates. In California, agrivoltaics systems have been successfully tested for crops such as lettuce and almonds, where they have helped improve water retention in the soil, especially during dry spells(Damien Fumey et al., 2023). Furthermore, studies in Arizona have shown the potential for agrivoltaics to combine solar energy production with the cultivation of desert-adapted crops like sorghum(Ruth Muir, 2025). These efforts have contributed to a growing body of evidence suggesting that agrivoltaics can offer a sustainable solution to address the challenges of food production and renewable energy generation in arid and semi-arid climates.

Agrivoltaics Potential in Egypt

Agrivoltaics is highly relevant to Egypt because of intense land and water stress alongside excellent solar resources. Most Egypt-specific work so far sits at the interface of solar irrigation, canal-top PV and agricultural PV fields, with only a few explicitly "agrivoltaics" design and policy papers, plus broader global reviews outlining what Egypt could adopt (Farghally et al., 2022)(Alhejji et al., 2021)(Mamun et al., 2022). Studies on PV-powered irrigation in Al Minya, Assiut and Lake Nasser show that solar pumping can dramatically cut both energy costs and water use for crops like wheat, maize, olives and mixed village agriculture (Adly et al., 2024)(Osama et al., 2023)(El Ghetany et al., 2021). Canal-top PV in Assiut demonstrates simultaneous evaporation reduction and power generation (Alhejji et al., 2021). Multiple targeted studies have systematically reviewed the application of agrivoltaics in Egypt: Farghally et al, (Farghally et al., 2022) documented a 400kWp ground-mounted project in Bashim and proposed that dedicated shading research tailored to local Egyptian crops must be carried out. Abouaiana et al, (Agostini et al., 2021) pointed out that this field remains at the stage of establishing its supporting legal framework, which aligns with Egypt's Vision 2030 global research on arid lands with the same climatic conditions corroborates that this model can improve the efficiency of land and water use.

Simulation parameters

Location

Beheira which is located at 30.7879° North latitude and 30.3346° East longitude. Situated on the southern edge of the Nile Delta in northern Egypt, the governorate borders the Mediterranean Sea to its north. The region's fertile soil and the waters of the Nile have nurtured its deep-rooted local agricultural heritage.(Mohamed, 2020). Beheira Province, Egypt, is one of the country's most important agricultural regions, playing a core role in the production of staple food crops including wheat. Covering an area of approximately 10,000 square kilometers, it has a population of over six million, and the majority of its residents make their living through agriculture(Elhini et al., 2024),

Beheira Governorate in Egypt has a hot desert climate. Summer temperatures in the region often exceed 35°C, while winter temperatures stay between 10°C and 20°C. Rainfall is extremely scarce, so all local agricultural production relies entirely on irrigation from the Nile River (Nashwan et al., 2019). Despite these climatic constraints, the governorate has a favorable geographical location and high solar radiation levels, making it highly suitable for the integrated development of solar energy projects within agricultural production systems.

PV System Parameters

This section discusses the core parameters of the PV system components and simulation.

PV Cells Specifications

The selected panel is the LR5-72 HPH 550M. It is a high-efficiency monocrystalline silicon photovoltaic (PV) module manufactured by Longi Solar (LONGI). It is well-suited for harsh climate agrivoltaic systems that require a balance of high efficiency and high reliability. All the Specifications Under standard test conditions (STC) are in Table (1).

Table 1: The Key Parameters of The LR5-72 HPH 550M

Parameter	Value and Unit
Nominal Power	550.1 Wp
Technology	Si-monocrystalline
Short-Circuit Current (Isc)	13.98 A
Maximum Power Point Current (Impp)	13.12 A
Open Circuit Voltage (Voc)	50.60 V
Maximum Power Point Voltage (Vmp)	41.95 V
Temperature Coefficient	-0.34%/°C
Efficiency	23.77 %
Unit cost	200 USD + tax

Source: (Longi solar (Longi solar, 2025))

The LR5-72 HPH 550M photovoltaic (PV) panel can deliver substantial energy output under optimal operating conditions. Equipped with a high conversion efficiency of 23.77% and a relatively low temperature coefficient, it meets the core demand for power generation under high temperatures in hot regions, making it a high-quality option for such application scenarios.

Inverter Parameters — Sungrow SG111 HV

The Sungrow (SG111HV) is chosen because it is a high-voltage three-phase grid-connected string inverter developed for large-scale photovoltaic power plants and is compatible with utility-scale and commercial photovoltaic systems. The specification of the inverter is provided in Table (2).

Table 2: The Key Parameters of The Sungrow SG111 HV

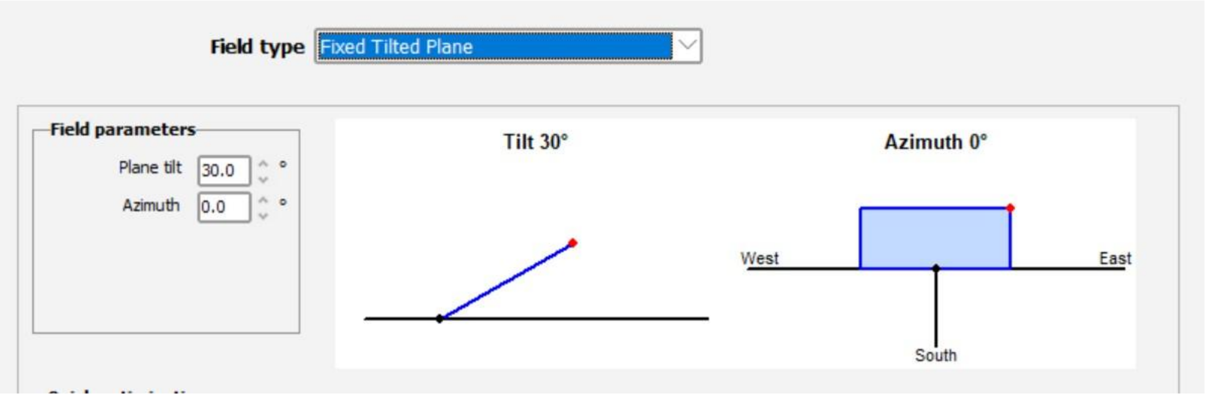
Parameter	Value and Unit
Model Name	Sungrow SG111 HV
Max. DC Input Voltage	1500 V
Nominal DC Voltage	1015 V
Min. DC Startup Voltage	835 V
MPP Voltage Range	780 – 1450 V
Max. DC Current	146 A
Max. AC Output Power	111 kVA (@ 50 °C)
Nominal AC Voltage	540 V
AC Voltage Range	432 – 648 V
Max. AC Output Current	121 A
Efficiency (Max / Euro)	98.9 % / 98.7 %
Power Factor (Nominal)	> 0.99
Operating Temperature Range	–25 °C to +60 °C
Unit cost	8000 USD

Source: (Sungrow SG111 HV(Sungrow, 2025))

These specifications show that the SG111 HV is built for high-power grid-tied solar PV systems, providing efficient DC-to-AC power conversion with robust protection and wide operating voltage range suitable for modern utility-scale installations.

General Simulation Parameters

After choosing both the PV cells and inverter, some other simulation parameters will remain constant for both scenarios such as the tilt angle and azimuth. A 30o tilt angle is maintained and azimuth angle is set at 0 In simulation for both scenarios as shown in figure (1)



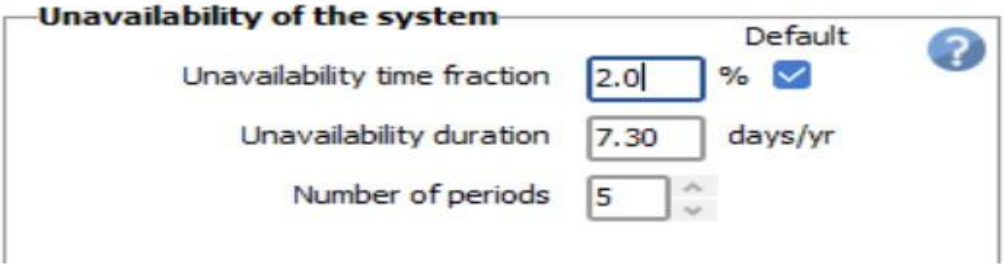
Field type: Fixed Tilted Plane

Field parameters
Plane tilt 30.0 °
Azimuth 0.0 °

Figure (1) Tilt and Azimuth Setting In Simulation

Source:(Pvsys Simulation)

An unavailability period was set in the simulation for 2% of the fraction to ensure that the system can undergo maintenance once in almost every 2 months for at least 24 hours window for each maintenance as shown in figure (2).



Unavailability of the system

Default

Unavailability time fraction 2.0 % ☑

Unavailability duration 7.30 days/yr

Number of periods 5

Figure (2) System Unavailability

Source:(Pvsys Simulation)

a yearly soiling loss factor was set to 3% in both simulations as shown in figure (3) it means that 3% of the solar panel's potential energy production is lost every year due to the accumulation of dirt and dust on the panels.

Yearly soiling loss factor

Default

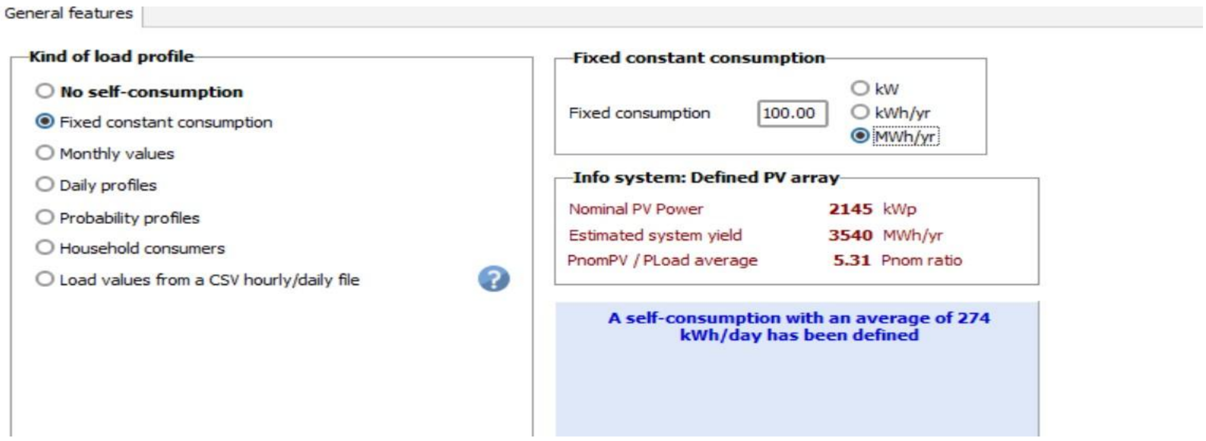
Yearly loss factor 3.0 % ☑

☐ Define monthly values

Figure (3) Yearly Soiling Loss Factor

Source:(Pvsys Simulation)

a fixed load consumption is assigned at 100 MWh/yr for both simulations that is used throughout the year for sustaining the system as shown in fig (4)



General features

Kind of load profile

○ **No self-consumption**
● Fixed constant consumption
○ Monthly values
○ Daily profiles
○ Probability profiles
○ Household consumers
○ Load values from a CSV hourly/daily file

Fixed constant consumption

Fixed consumption 100.00 ○ kW ○ kWh/yr ● MWh/yr

Info system: Defined PV array

Nominal PV Power	2145	kWp
Estimated system yield	3540	MWh/yr
PnomPV / PLoad average	5.31	Pnom ratio

A self-consumption with an average of 274 kWh/day has been defined

Figure (4) Load Consumption

Source:(Pvsys Simulation)

Scenario Definitions

To assess the feasibility and effectiveness of agrivoltaics systems in Beheira Governorate, this study compares two distinct land-use scenarios simulated on a 1-hectare area of land. These scenarios aim to evaluate the performance of the land under different configurations, focusing on solar energy generation, agricultural productivity, and overall sustainability.

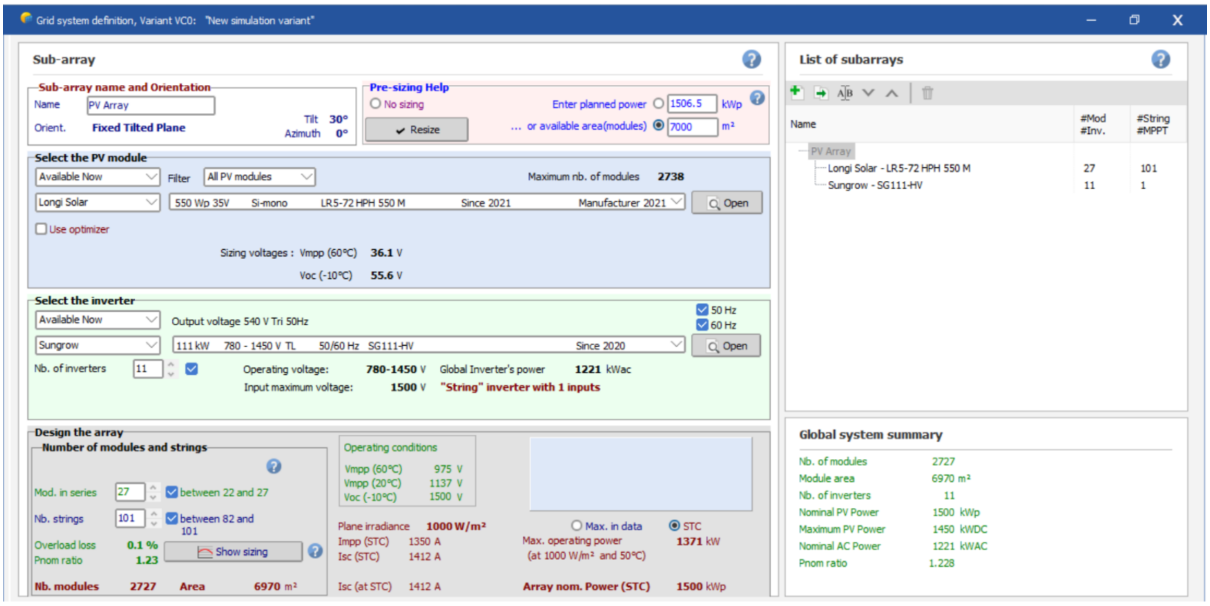
1. Solar-only scenario where the total PV covered area is 70% and is totally focused on Energy generation.
2. Agrevoltaic scenario where the PV coverage is only 40% of the land and is focused on both energy generation and crop cultivation.

Each of these scenarios is evaluated based on energy generation, agricultural productivity, resource efficiency, and environmental sustainability. Comparing these approaches will aims to identify the most effective land-use strategy for the region, considering the competing demands of energy production and food security.

Simulation Results and Analysis

Full PV Coverage Scenario

The photovoltaic simulation scenario defined in this paper is premised on a 70% coverage rate. It is configured with 2727 LONGi LR5-72 HPH 550M modules, each with a rated power of 550W. The modules are grouped into 101 strings of 27 modules each, bringing the system's total coverage area to 6970 ㎡ and total installed capacity to 1500kWp. The system is paired with 11 Sungrow SG111-HV inverters, each with a rated power of 111kW, resulting in a total alternating current (AC) capacity of 1221kW. The modules are installed with a tilt angle of 30° and an azimuth angle of 0°. The system has an annual internal fixed power load of 100MWh, and all surplus electricity is fed into the grid.



Grid system definition, Variant VC0: "New simulation variant"

Sub-array

Sub-array name and Orientation
Name: PV Array
Orient.: Fixed Tilted Plane
Tilt 30°
Azimuth 0°

Pre-sizing Help
○ No sizing
Enter planned power ○ 1506.5 kWp
... or available area(modules) ● 7000 m²

Select the PV module
Available Now | Filter: All PV modules | Maximum nb. of modules 2738
Longi Solar | 550 Wp 35V Si-mono LR5-72 HPH 550 M Since 2021 Manufacturer 2021
☐ Use optimizer
Sizing voltages : Vmpp (60°C) 36.1 V
Voc (-10°C) 55.6 V

Select the inverter
Available Now | Output voltage 540 V Tri 50Hz
☑ 50 Hz
☑ 60 Hz
Sungrow | 111 kW 780 - 1450 V TL 50/60 Hz SG111-HV Since 2020
Nb. of inverters: 11 ☑
Operating voltage: 780-1450 V
Global Inverter's power 1221 kWac
Input maximum voltage: 1500 V
"String" inverter with 1 inputs

Design the array
Number of modules and strings
Mod. in series: 27 ☑ between 22 and 27
Nb. strings: 101 ☑ between 82 and 101
Overload loss 0.1 %
Pnom ratio 1.23
Nb. modules 2727 Area 6970 m²

Operating conditions
Vmpp (60°C) 975 V
Vmpp (20°C) 1137 V
Voc (-10°C) 1500 V

Plane irradiance 1000 W/m²
Impp (STC) 1350 A
Isc (STC) 1412 A
Isc (at STC) 1412 A
○ Max. in data ● STC
Max. operating power (at 1000 W/m² and 50°C) 1371 kW
Array nom. Power (STC) 1500 kWp

List of subarrays

Name	#Mod #Inv.	#String #MPPT
PV Array		
Longi Solar - LR5-72 HPH 550 M	27	101
Sungrow - SG111-HV	11	1

Global system summary

Nb. of modules	2727
Module area	6970 m²
Nb. of inverters	11
Nominal PV Power	1500 kWp
Maximum PV Power	1450 kWDC
Nominal AC Power	1221 kWAC
Pnom ratio	1.228

Figure (5) Full Pv Simulation Settings

Source:(Pvsys Simulation)

Balances And Main Results for The Full Coverage Scenario

Under the simulated scenario with 70% photovoltaic coverage, results from PVsyst simulations show that the system array produces an annual output of 2626.9 MWh/year, with 2490.7 MWh/year of electricity injected into the grid. An average performance ratio (Performance Ratio, PR) of 82.0% confirms that the system operates well, and all related results and updated revenue and expenditure records are listed in Table 3.

Table 3: Balance And Main Results of The Full Coverage System

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (MWh)	E_User (MWh)	E_Solar (MWh)	E_Grid (MWh)
January	93.40	46.21	13.49	131.00	125.40	175.9	8.493	3.231	152.5
February	105.00	55.15	14.75	132.10	126.30	175.9	7.671	3.279	170.6
March	156.10	71.34	17.81	179.90	171.90	233.5	8.493	4.059	226.7
April	183.70	82.40	21.15	189.70	180.80	242.3	8.219	4.119	235.3
May	215.00	89.83	25.05	203.80	193.70	256.0	8.493	4.391	231.3
June	225.10	79.41	27.52	203.40	193.00	252.1	8.219	4.371	222.7
July	224.50	79.30	29.62	206.70	196.10	253.9	8.493	4.864	245.9
August	202.70	78.79	29.71	201.90	191.90	248.3	8.493	4.351	241.0
September	165.80	60.38	27.20	182.80	174.20	226.0	8.219	4.052	219.2
October	134.50	56.75	24.20	167.90	160.60	213.2	8.493	3.860	206.7
November	100.00	46.09	19.43	137.40	131.60	180.1	8.219	3.403	174.5
December	87.30	41.18	15.33	127.20	121.80	169.9	8.493	3.446	164.4
Year	1893.10	786.85	22.15	2063.70	1967.20	2626.9	100.000	47.428	2490.7

Source:(Pvsys Simulation)

Where:

- **GlobHor** - Global Horizontal Irradiance
- **DiffHor** - Horizontal Diffuse Irradiance
- **T_Amb** - Ambient Temperature
- **GlobInc** - Global Incident on the Horizontal Plane
- **GlobEff** - Effective Global, considering IAM and Shadings
- **EArray** - Effective Energy at the Output of the Array
- **E_User** - Energy Consumed by the System
- **E_Solar** - Energy Consumed from Solar Generation
- **E_Grid** - Energy Injected into the Grid

Scenario simulations conducted for this study show that even if the land coverage rate of this solar energy system reaches 70%, it still delivers considerable energy output, most of the electricity it generates can be connected to the grid for off-site sale, and the system can be implemented as a large-scale solution in Beheira Province.

Normalized Production Per Installed KWP For Full Coverage Scenario

Figure (6) presents the normalized power generation data for the scenario with 70% photovoltaic (PV) coverage, with the unit of kWh/kWp/day. The average values of the three core indicators are collection loss (Lc) = 0.86 kWh/kWp/day, system loss (Ls) = 0.16 kWh/kWp/day and effective power generation (Yf) = 4.64 kWh/kWp/day.

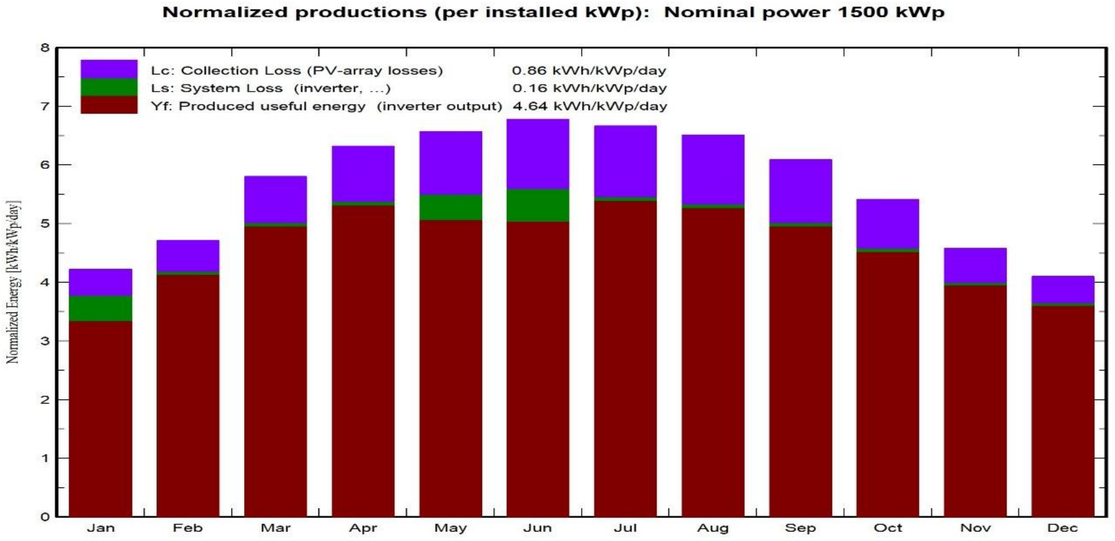


Figure (6) Normalized Energy Production of The Full Coverage System

Source:(Pvsys Simulation)

Array Loss Diagram for The Full Coverage Scenario

The loss diagram of the 70% coverage system in Figure (7) illustrates the energy conversion stages and system losses. The total global horizontal irradiation is 1,893 kWh/m², with a 9.0% gain in the collector plane. After considering the IAM factor of -1.73% and the soiling loss factor of -3.00%, the effective irradiation on the collectors reaches 1,967 kWh/m² × 3,987 m². This results in an array nominal energy of 1,691 MWh at STC efficiency. The energy is then affected by +0.34% due to irradiance level, -8.76% due to temperature, +0.25% module quality loss, -2.10% mismatch loss, and -1.06% ohmic wiring loss. After these losses, the array virtual energy at the maximum power point (MPP) is 2628 MWh. Further inverter-related losses, mainly -1.19% during operation and -0.07% over nominal inverter power, reduce the available energy at the inverter output to 2595 MWh. After applying a system unavailability loss of -2.20%, the system injects approximately 2491 MWh into the grid.

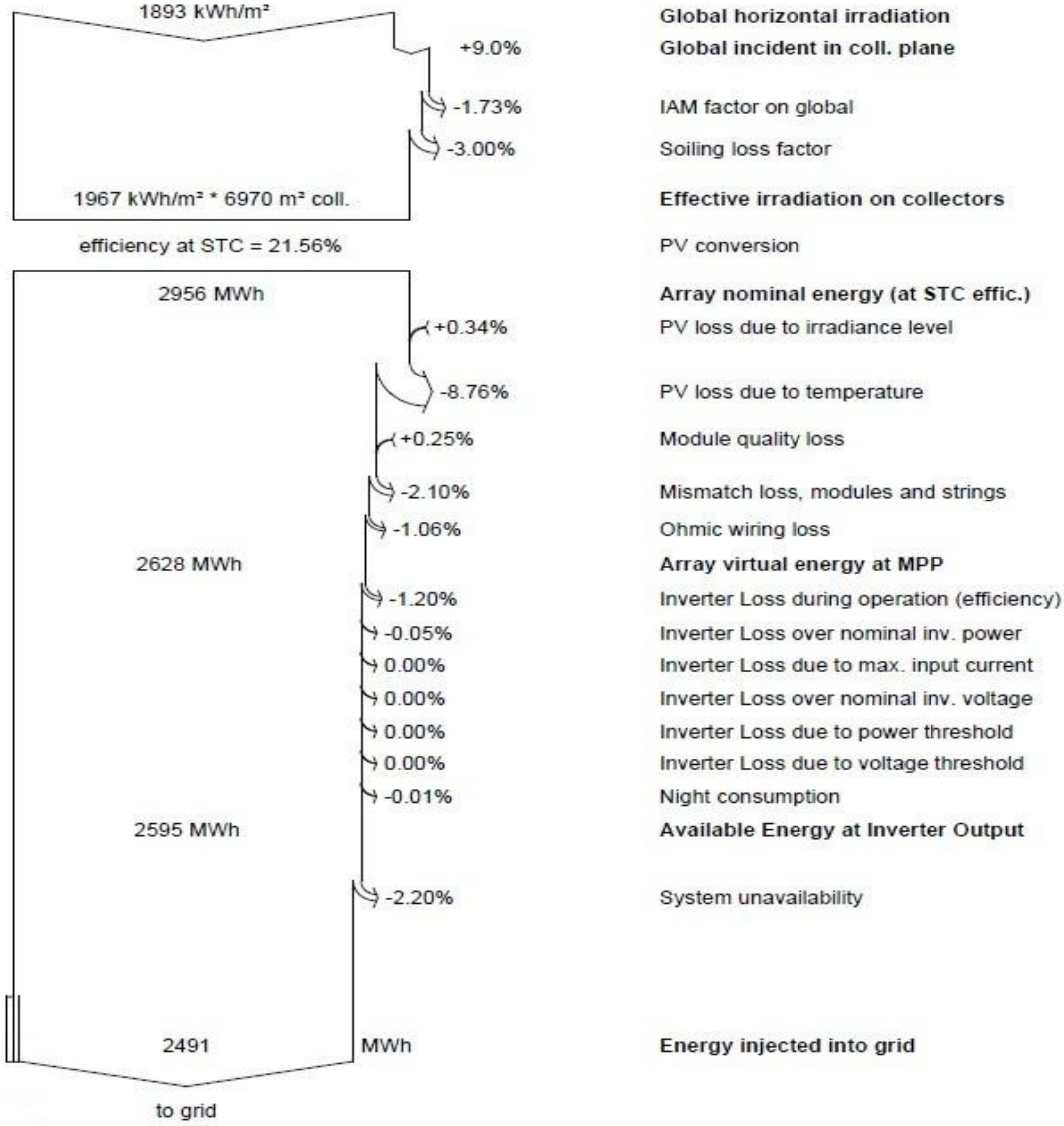


Figure (7) Loss Diagram of The Full Coverage System
Source:(Pvsys Simulation)

Performance Ratio of The Full Coverage Scenario

The simulation defines the core indicator Performance Ratio (PR) as the ratio of a system's actual performance to its theoretical maximum performance. Drawing on the monthly PR data in Figure 8, measurements show that the system with a 70% photovoltaic (PV) coverage rate has an average PR of 0.820. Its overall monthly PR values are stable, with only minor fluctuations: lower-than-typical values recorded in June, and higher-than-typical values in February, November and December, which stem from fluctuations in air temperature, irradiance, and system losses.

.

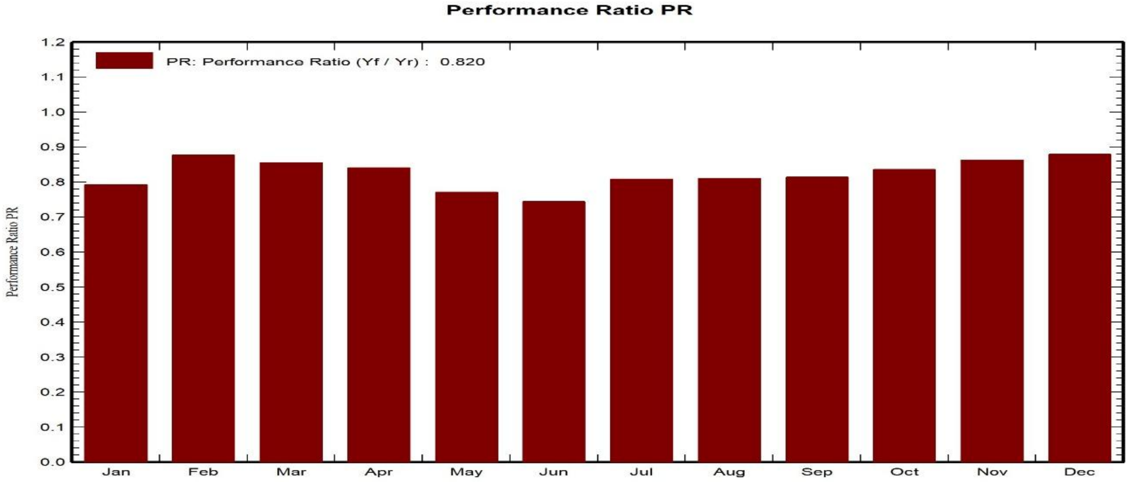


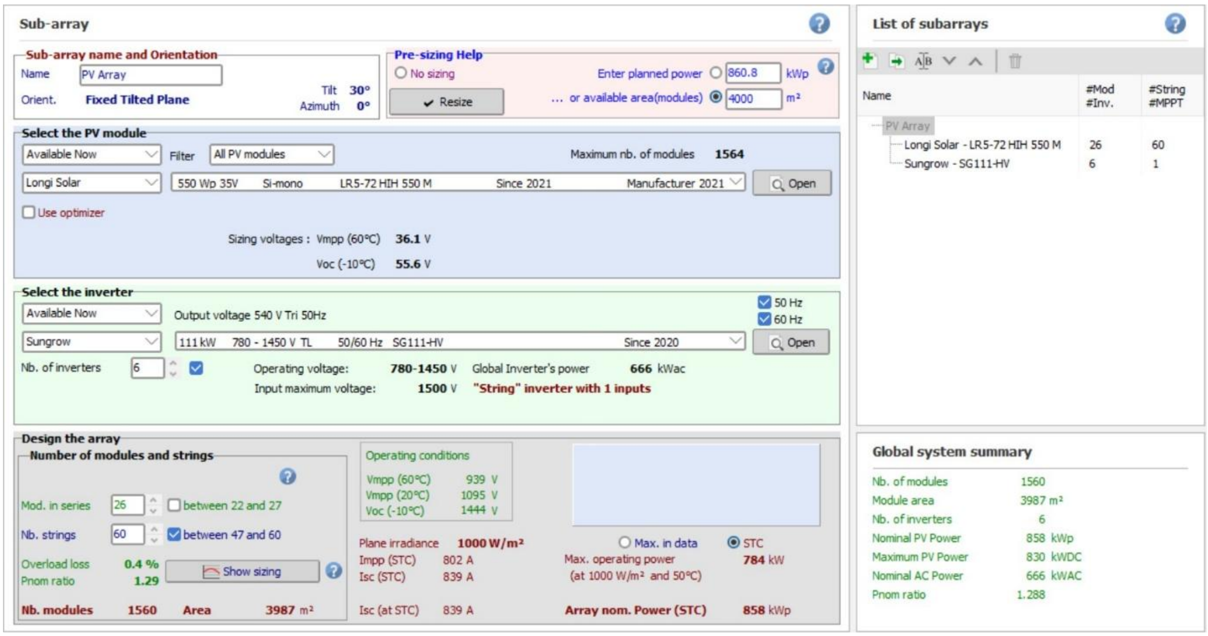
Figure (8) Performance Ratio Graph for The Full Coverage Scenario

Source:(Pvsys Simulation)

Agrivoltaics Scenario

PV Simulation Part

Under the agrivoltaic scenario set for this study, a total of 1560 LONGi Green Energy LR5-72 HIH 550M photovoltaic modules are deployed. Each module has a rated power of 550W and is installed in a fixed setup with a tilt angle of 30° and an azimuth angle of 0°. Every 26 modules are connected in series to form one string, adding up to 60 strings in total. Of the 1-hectare total land area used for the project, the area covered by modules is 3987 m², accounting for 40% of the total land. The system has a rated capacity of 858kWp and a maximum DC power of 830kW. It is equipped with 6 Sungrow SG111-HV inverters, each with a rated power of 111kW, bringing the total rated AC power to 666kW, with a Pnom ratio of 1.288.



Sub-array

Sub-array name and Orientation
Name: PV Array
Orient.: Fixed Tilted Plane
Tilt 30°
Azimuth 0°

Pre-sizing Help
○ No sizing
Enter planned power ○ 860.8 kWp
… or available area(modules) ● 4000 m²

Select the PV module
Available Now
Filter: All PV modules
Maximum nb. of modules 1564
Longi Solar
550 Wp 35V Si-mono LR5-72 HIH 550 M Since 2021 Manufacturer 2021
☐ Use optimizer
Sizing voltages : Vmpp (60°C) 36.1 V
Voc (-10°C) 55.6 V

Select the inverter
Available Now
Output voltage 540 V Tri 50Hz
☑ 50 Hz
☑ 60 Hz
Sungrow
111 kW 780 - 1450 V TL 50/60 Hz SG111-HV Since 2020
Nb. of inverters 6 ☑
Operating voltage: 780-1450 V
Global Inverter's power 666 kWac
Input maximum voltage: 1500 V
"String" inverter with 1 inputs

Design the array
Number of modules and strings
Mod. in series 26 ☐ between 22 and 27
Nb. strings 60 ☑ between 47 and 60
Overload loss 0.4 %
Pnom ratio 1.29
Nb. modules 1560
Area 3987 m²

Operating conditions
Vmpp (60°C) 939 V
Vmpp (20°C) 1095 V
Voc (-10°C) 1444 V

Plane irradiance 1000 W/m²
Impp (STC) 802 A
Isc (STC) 839 A
Isc (at STC) 839 A

○ Max. in data ● STC
Max. operating power (at 1000 W/m² and 50°C) 784 kW
Array nom. Power (STC) 858 kWp

List of subarrays

Name	#Mod #Inv.	#String #MPPT
PV Array		
Longi Solar - LR5-72 HIH 550 M	26	60
Sungrow - SG111-HV	6	1

Global system summary

Nb. of modules	1560
Module area	3987 m²
Nb. of inverters	6
Nominal PV Power	858 kWp
Maximum PV Power	830 kWDC
Nominal AC Power	666 kWAC
Pnom ratio	1.288

Figure (9) Simulation Sittings for The Agrivoltaics Scenario

Source:(Pvsys Simulation)

the agrivoltaics photovoltaic (PV) array set up contains 18 rows of PV panels, with 87 modules arranged in each row. Calculations performed using PVsyst software show that the total area of all modules is 3987 m², which accounts for 40% of the project's total 1-hectare land parcel. Assuming the site is 100 meters long, the total usable spacing between all rows is derived as 60 meters.

$$\text{Remaining space length} = 100 - 40 = 60\,\text{meters}$$

Since 18 PV rows create 17 spaces between rows, the spacing between each row is calculated as:

$$\text{Space between rows} = \frac{60}{17} = 3.53\,\text{meters}$$

Therefore, the approximate distance between each PV row is 3.53 m. This spacing provides sufficient area for wheat cultivation between the PV rows while also allowing access for maintenance and field operations.

Balance and main results for agrivoltaics scenario

Under the simulated scenario with 40% photovoltaic coverage, results from PVsyst simulations show that the system array produces an annual output of 1502.5 MWh/year, with 1404.8 MWh/year of electricity injected into the grid. An average performance ratio (Performance Ratio, PR) of 81.990% confirms that the system operates well, and all related results and updated revenue and expenditure records are listed in Table 4.

Table 4: Balance And Main Results of The Agrivoltaics System

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (MWh)	E_User (MWh)	E_Solar (MWh)	E_Grid (MWh)
January	93.4	46.2	13.5	131.0	125.4	100.6	8.494	3.220	85.8
February	105.0	55.2	14.8	132.1	126.3	100.7	7.672	3.260	96.2
March	156.1	71.3	17.8	179.9	171.9	133.4	8.494	4.028	127.8
April	183.7	82.4	21.2	189.7	180.8	138.6	8.220	4.115	132.9
May	215.0	89.8	25.1	203.8	193.7	146.4	8.494	4.293	130.5
June	225.1	79.4	27.5	203.4	193.0	144.2	8.220	4.357	125.6
July	224.5	79.3	29.6	206.7	196.1	145.3	8.494	4.781	138.7
August	202.7	78.8	29.7	201.9	191.9	142.0	8.494	4.307	136.0
September	165.8	60.4	27.2	182.8	174.2	129.1	8.220	4.038	123.6
October	134.5	56.8	24.2	167.9	160.6	121.9	8.494	3.818	116.6
November	100.0	46.1	19.4	137.4	131.6	103.0	8.220	3.379	98.4
December	87.3	41.2	15.3	127.2	121.8	97.2	8.494	3.414	92.6
Year	1893.1	786.9	22.2	2063.7	1967.2	1502.5	100.004	47.009	1404.8

Source:(Pvsys Simulation)

The system's energy consumption was set at a fixed 100 MWh/year, with the remaining energy being exported to the grid. In total, the system exported 1404.8 MWh to the grid, showing a strong capacity for energy export and revenue generation.

Normalized Production Per Installed KWP For Agrivoltaics Scenario

The graph in figure (10) the normalized energy throughout the year for the agrivoltaics scenario, with contributions from collection losses (Lc), system losses (Ls), and productive output (Yf). The system's productive output averages 4.64 kWh/kWp/day. Collection losses (Lc) average 0.86 kWh/kWp/day and remain relatively steady across months. System losses (Ls) from the inverter contribute 0.16 kWh/kWp/day, with minimal variation throughout the year.

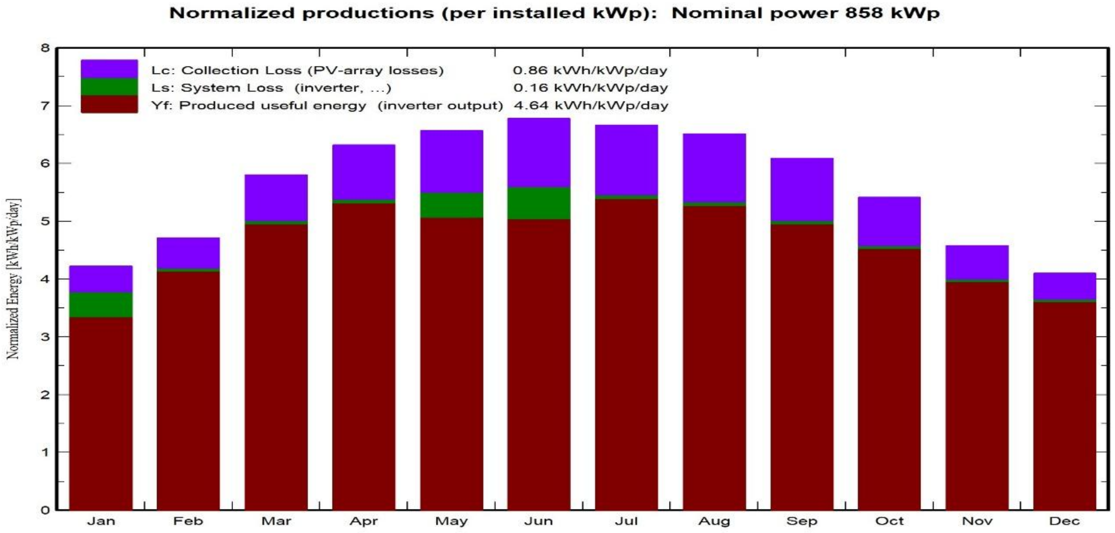


Figure (10) Normalized Energy Production of The Agrivoltaics Scenario

Source:(Pvsys Simulation)

Array Loss Diagram for The Agrivoltaics System

The loss diagram of the agrivoltaics PV system in Figure (11) illustrates the energy conversion stages and system losses. The total global horizontal irradiation is 1,893 kWh/m², with a 9.0% gain in the collector plane. After considering the IAM factor of -1.73% and the soiling loss factor of -3.00%, the effective irradiation on the collectors reaches 1,967 kWh/m² × 3,987 m². This results in an array nominal energy of 1,691 MWh at STC efficiency. The energy is then affected by +0.34% due to irradiance level, -8.76% due to temperature, +0.25% module quality loss, -2.10% mismatch loss, and -1.06% ohmic wiring loss. After these losses, the array virtual energy at the maximum power point (MPP) is 1,504 MWh. Further inverter-related losses, mainly -1.19% during operation and -0.07% over nominal inverter power, reduce the available energy at the inverter output to 1,484 MWh. After applying a system unavailability loss of -2.20%, the system injects approximately 1,405 MWh into the grid.

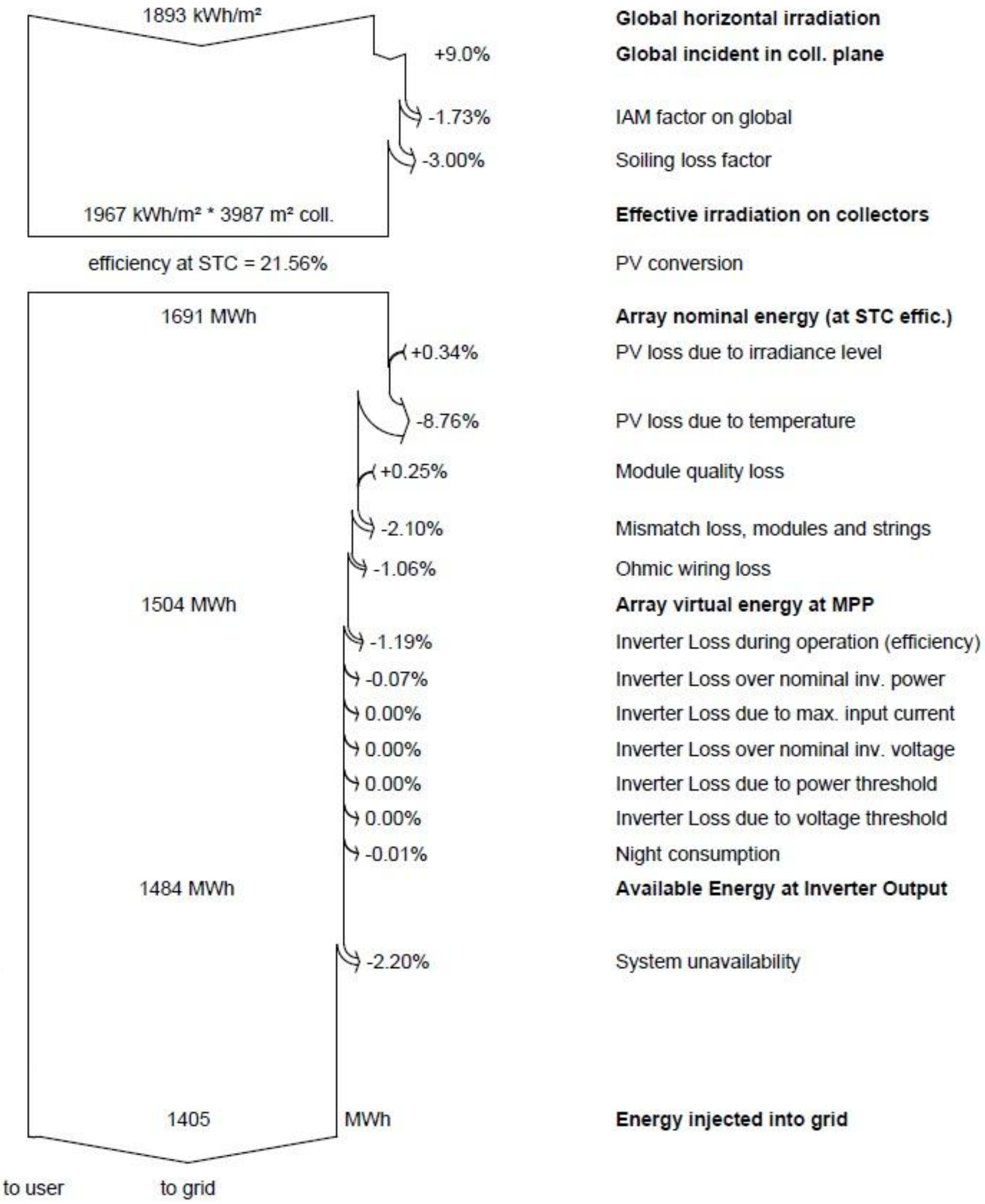


Figure (11) Loss Diagram of The Agrivoltaics Scenario
Source:(Pvsys Simulation)

Performance Ratio of The Agrivoltaics Scenario

The Performance Ratio (PR) shown in figure (12) represents the system's actual performance relative to the theoretical maximum throughout the year. The system maintains an average PR of 81.99%, with monthly values fluctuating between 75% and 90%.

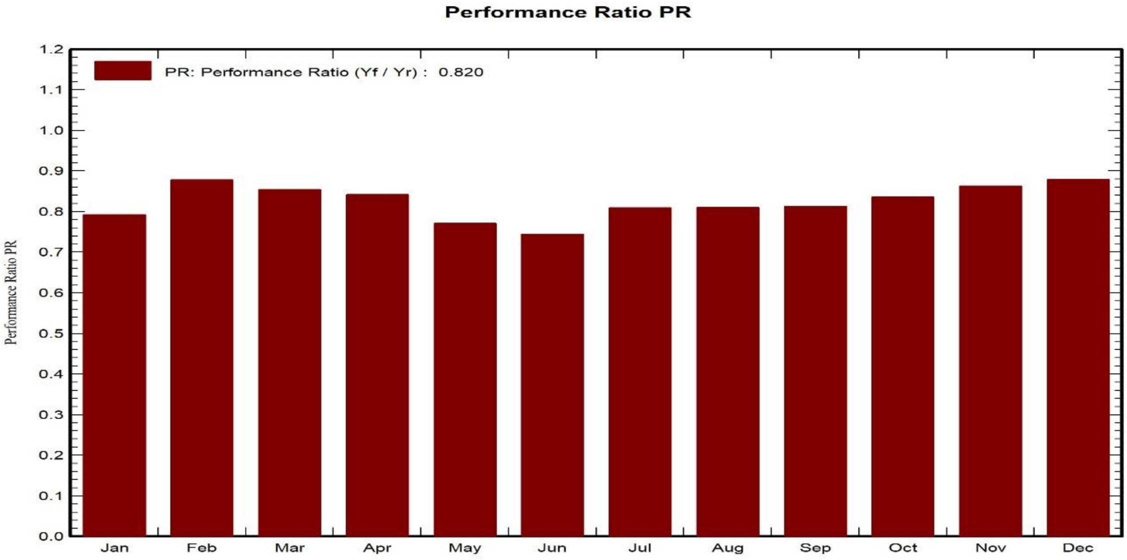


Figure (12) Performance Ratio Graph for The Agrivoltaics Scenario
Source:(Pvsys Simulation)

Agriculture Part

The agricultural component of the agrivoltaics scenario focuses on bread wheat (*Triticum aestivum* L.) production under partial PV shading. Bread wheat was selected because it is a strategic cereal crop in Egypt and is widely used for local food consumption, particularly for bread-based diets (Emam et al., 2022)(Alshallash et al., 2022). Previous Egyptian wheat studies have evaluated several bread wheat cultivars under local growing conditions, including Misr, Giza, Sakha, Gemmiza, Shandawel, and Sids cultivars(Emam et al., 2022)(Darwish et al., 2023). However, since the present study is simulation-based and does not include field experiments, no single cultivar was selected for modelling. Instead, the crop was represented as an average Egyptian bread wheat crop to estimate the likely yield response under the 40% agrivoltaics coverage scenario. This approach is suitable for a preliminary feasibility assessment because the main objective is to compare land-use scenarios rather than to evaluate cultivar-specific agronomic performance.

The agrivoltaics PV system consists of 1,560 Longi Solar LR5-72 HIH 550 M modules covering 3,987 m², which represents approximately 40% of the 1-hectare land area. This arrangement provides partial shade over the cultivated area and may reduce the amount of photosynthetically active radiation received by the wheat crop. Due to the limited availability of actual field-based agrivoltaics studies on wheat in Egypt, especially in Beheira Governorate, the expected yield reduction was estimated using findings from similar agrivoltaics and crop-shading studies. Based on these studies, a 22% reduction in wheat yield was assumed under the 40% PV coverage scenario (GENG Xiayun et al., 2025)(Prakash et al., 2023). This assumption is also consistent with the broader crop-shading approach used in agrivoltaics research, where reduced light availability is linked to changes in crop productivity.(Laub et al., 2022)

The baseline full-sun wheat yield was taken as 6.59 t/ha, based on reported wheat productivity data for Egypt (Abdelbaki & Said, 2024).The reduced yield under the agrivoltaics scenario was calculated using the following equation:

Reduced Yield = Full Sun Yield × (1−Reduction Percentage)(Laub et al., 2022)

$$Reduced\ Yield = 6{,}590 \times (1 - 0.22) = 5{,}140\ kg/hectare$$

Therefore, the estimated wheat yield under the 40% simulated agrivoltaics scenario is approximately 5.14 t/ha.

Domestic Egyptian farmers who sell wheat to the government rely entirely on the government-set official purchase price for their income. According to information released in 2025 by third-party media outlet Masrawy, (Masrawy, 2025) the wheat purchase price for the 2025/2026 season is set at 15,000–15,850 Egyptian pounds per ton. When calculated based on a per-ton production cost of 7,333 Egyptian pounds and an exchange rate of 1 US dollar to 47.3 Egyptian pounds, this policy can stabilize grain prices and guarantee profits for farmers. Under the defined scenario where farmers sell wheat for domestic sale to the government, our calculations show an average per-ton revenue of 317.24–335.47 US dollars, a per-ton cost of 155.44 US dollars, and a per-ton gross profit of 161.80–179.03 US dollars. Government-set prices can guarantee price stability, which is critically important for this group of farmers that rely on domestic sales.

Using the gross profit per ton range (USD 161.80 to USD 179.03), the total gross profit for one hectare can be calculated.

For the lower gross profit (USD 161.80 per ton):

$$Profit\ per\ hectare = 5.14\ tons/hectare \times 161.80\ USD/ton = USD\ 831.13$$

For the higher gross profit (USD 179.03 per ton):

$$\text{Profit per hectare} = 5.14\ \text{tons/hectare} \times 179.03\ \text{USD/ton} = \text{USD } 920.47$$

Total gross profit per hectare is estimated to range between USD 831.13 and USD 920.47, depending on the actual market price for wheat.

Comparison Of Profit from Solar-Only PV System Vs. Agrivoltaics System

The solar-only PV system is designed mainly for electricity generation and export to the grid. Based on the PVsyst simulation, the 70% PV coverage system exported 2,490.7 MWh/year to the grid. This is equivalent to 2,490,700 kWh/year. Using a feed-in tariff of USD 0.04/kWh, the annual electricity revenue from the solar-only PV system is calculated as follows:

$$\begin{aligned} Annual\ electricity\ revenue &= 2{,}490{,}700\ kWh/year \times USD\ 0.04/kWh \\ &= USD\ 99{,}628/year \end{aligned}$$

Therefore, the solar-only PV system generates an estimated annual electricity revenue of USD 99,628 from grid-exported electricity.

The agrivoltaics system combines electricity generation with wheat cultivation. Based on the simulation, the 40% agrivoltaics PV system exported 1,404.8 MWh/year to the grid, which is equivalent to 1,404,800 kWh/year. Using the same feed-in tariff of USD 0.04/kWh, the annual electricity revenue from the agrivoltaics system is calculated as follows:

$$\begin{aligned} Annual\ electricity\ revenue &= 1{,}404{,}800\ kWh/year \times USD\ 0.04/kWh \\ &= USD\ 56{,}192/year \end{aligned}$$

In addition to electricity revenue, the agrivoltaics system also provides income from wheat production. The estimated gross profit from wheat cultivation under the 40% PV coverage scenario ranges from USD 831.13 to USD 920.47 per hectare. Therefore, the total annual return from the agrivoltaics system is calculated as follows:

$$\begin{aligned} Total\ annual\ return, low\ estimate &= USD\ 56{,}192 + USD\ 831.13 \\ &= USD\ 57{,}023.13/year \end{aligned}$$

$$\begin{aligned} Total\ annual\ return, high\ estimate &= USD\ 56{,}192 + USD\ 920.47 \\ &= USD\ 57{,}112.47/year \end{aligned}$$

The results show that the solar-only PV system provides higher direct electricity revenue than the agrivoltaics system. However, the agrivoltaics system produces both electricity and wheat on the same land area, which gives it an added land-use advantage. This makes the agrivoltaics system less competitive in direct electricity revenue, but more balanced in terms of food-energy production and land-use efficiency.

Land Equivalent Ratio (LER) Assessment

The Land Equivalent Ratio (LER) was used to evaluate whether the agrivoltaics system provides better land-use efficiency than producing wheat and solar energy separately. The LER compares the crop yield and energy output of the agrivoltaics system with the open-field wheat yield and the solar-only PV energy output. The LER is calculated as follows:

$$LER = \frac{Y_{crop,\ APV}}{Y_{crop,\ ref}} + \frac{Y_{energy,\ APV}}{Y_{energy,\ ref}}$$

Where $Y_{\text{crop, APV}}$and $Y_{\text{energy, APV}}$represent the crop yield and energy output in the agrivoltaics system, respectively, and $Y_{\text{crop, ref}}$and $Y_{\text{energy, ref}}$represent the yields in open-field (full-sun) crop cultivation and the full PV coverage scenario.

Using the simulation data:

- Wheat yield under 40% PV coverage: 5.14 t/ha
- Open-field wheat yield: 6.59 t/ha
- Energy yield in agrivoltaics: 1,502.5 MWh/year
- Energy yield in full PV system: 2,626.9 MWh/year

The LER based on the equation is:

$$LER = \frac{5.14}{6.59} + \frac{1{,}502.5}{2{,}626.9} \approx 0.78 + 0.572 = 1.35$$

The updated LER value of approximately 1.35 indicates that the agrivoltaics system improves land-use efficiency by about 35% compared with separate wheat cultivation and solar PV production. This means that one hectare of agrivoltaics can produce the equivalent output of about 1.35 hectares of separate land use. The result supports the potential of agrivoltaics as a dual-use strategy for Beheira Governorate, especially in areas where agricultural land is valuable and renewable energy expansion is also needed.

Financial and Environmental Performance Indicators

In addition to annual revenue and Land Equivalent Ratio (LER), the two scenarios were further evaluated using financial and environmental performance indicators. The financial assessment was based on the PVsyst economic simulation, using a 25-year project lifetime, 3.0% annual inflation, an 8.0% discount rate, and a feed-in tariff of USD 0.04/kWh. The indicators considered include total installation cost, annual operating cost, Levelized Cost of Energy (LCOE), payback period, Net Present Value (NPV), and Return on Investment (ROI).

Table 5: Financial And Environmental Performance Indicators of The Two Scenarios

Indicator	**70% Solar-only PV Scenario**	**40% Agrivoltaics Scenario**
Installed PV capacity	1,500 kWp	858 kWp
Energy exported to grid	2,491 MWh/year	1,405 MWh/year
Total installation cost	USD 956,545.00	USD 613,790.15
Operating cost, including 3% inflation	USD 21,875.56/year	USD 21,875.56/year
Feed-in tariff	USD 0.04/kWh	USD 0.04/kWh
LCOE	USD 0.042/kWh	USD 0.053/kWh
Payback period	11.7 years	16.6 years
Net Present Value (NPV)	USD 684,422.64	USD 90,272.63
Return on Investment (ROI)	71.60%	14.70%
CO_2 emission balance	23,174.3 tCO_2	12,118.9 tCO_2
Replaced grid emissions	29,064.2 tCO_2	16,624.4 tCO_2

Source:(PVsys Simulation)

The study conducts a cross-dimensional quantitative comparison between two photovoltaic (PV) scenarios: a pure solar PV scenario accounting for 70% of total installed capacity, and an agrivoltaic (farm-solar complementary) PV scenario accounting for 40% of total installed capacity. Assessment from the financial dimension shows that the pure PV scenario performs better: the pure PV scenario has an installation cost of 956,545 USD, a levelized cost of energy of 0.042 USD per kilowatt-hour, an investment payback period of 11.7 years, a net present value of 684,422.64 USD, and a return on investment of 71.6%; the agrivoltaic scenario has a total investment of 613,790.15 USD, a levelized cost of energy of 0.053 USD per kilowatt-hour, a payback period of 16.6 years, a net present value of 90,272.63 USD, and a return on investment of 14.7%. Judging the advantages and disadvantages of the scenarios solely based on financial indicators is one-sided, so this study further introduces an assessment from the comprehensive sustainability dimension: over a 25-year cycle, the pure PV scenario achieves 23,174.3 tons of carbon dioxide emission reductions, while the agrivoltaic scenario achieves 12,118.9 tons of carbon dioxide emission reductions. The latter scenario enables the simultaneous operation of wheat cultivation and solar power generation on the same plot of land, balancing both grain production and energy generation, which corrects the bias of single-dimensional assessment.

Conclusion

This study evaluated the feasibility of agrivoltaics as a sustainable land-use strategy in Beheira Governorate, Egypt, by comparing a 70% solar-only PV scenario with a 40% agrivoltaics scenario on a 1-hectare land area. The results show that the solar-only PV scenario produced stronger direct energy and financial performance. It recorded an annual PV array output of 2,626.9 MWh/year and exported 2,490.7 MWh/year to the grid. Based on the assumed feed-in tariff of USD 0.04/kWh, the solar-only system generated an estimated annual electricity revenue of USD 99,628. It also achieved an LCOE of USD 0.042/kWh, a payback period of 11.7 years, an NPV of USD 684,422.64, and an ROI of 71.6%. These results indicate that the solar-only system is more financially attractive when the land is evaluated mainly for electricity generation and grid-export revenue.

The 40% agrivoltaics scenario produced lower direct electricity revenue because a smaller portion of land was allocated to PV modules. The agrivoltaics system recorded an annual PV array output of 1,502.5 MWh/year and exported 1,404.8 MWh/year to the grid, generating an estimated electricity revenue of USD 56,192/year. When wheat production was included, the total annual return increased to approximately USD 57,023.13–57,112.47. Under the assumed 22% shading-related yield reduction, wheat yield was estimated at 5.14 t/ha compared with 6.59 t/ha under open-field conditions. Although this shows a reduction in crop yield, the agrivoltaics system still enables simultaneous food and energy production on the same land area.

The LER value of approximately 1.35 demonstrates that the agrivoltaics system improves land-use efficiency by about 35% compared with separate wheat cultivation and solar PV production. This finding is important for regions such as Beheira, where agricultural land is valuable and renewable energy expansion must be balanced with food production. From an environmental perspective, both scenarios contribute to carbon-emission reduction by replacing grid electricity. The solar-only system achieved a higher PVsyst CO_2 emission balance due to its larger installed capacity, while the agrivoltaics scenario still provided meaningful environmental benefits alongside agricultural production.

Overall, the results suggest that solar-only PV is more suitable when the main objective is maximizing electricity revenue, while agrivoltaics provides a more balanced strategy for food-energy integration, land-use efficiency, and sustainable agricultural planning. Since the agricultural assessment was based on simulation and yield-reduction assumptions from similar studies, future field experiments in Beheira are needed to validate wheat response under PV shading. Further research should include measured irrigation water use, soil moisture, evapotranspiration, crop variety performance, and long-term economic analysis using different crop types. These improvements would provide stronger evidence for the practical implementation of agrivoltaics in Egypt's agricultural regions.

Acknowledgements: The authors would like to express their sincere gratitude to [University Malaysia Perlis (Unimap)] for providing the necessary resources and support throughout the course of this research. Special appreciation is extended to colleagues and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper.

Funding Statement: No funding

Conflict of Interest Statement: The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Innovation and Industrial Revolution (IJIREV).

Ethics Statement: This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.

Author Contribution Statement: All authors contributed to the development of this manuscript. [Mohammed Elsayed Samier Madboli Ibrahim] was responsible for carrying out the main work of the study, including the research process, data collection, analysis, and manuscript preparation. [Mohd Rafi Adzman] served as the supervisor and provided guidance, feedback, and overall supervision throughout the study. [Elsayed Madbouly] was responsible for reviewing and improving the grammar, language, and clarity of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

References

Abdelbaki, G. A. A. & Said, H. Q. S. (2024). Economics of Wheat Production and Marketing in Egypt (Case Study of Fayoum Governorate). *International Journal of Sustainable Development and Science*, *7*(1), 146–174. https://doi.org/10.21608/ijsrsd.2024.351168

Abouaiana, A. & Battisti, A. (2022). Multifunction Land Use to Promote Energy Communities in Mediterranean Region: Cases of Egypt and Italy. *Land*, *11*(5), 673. https://doi.org/10.3390/land11050673

Adly, G. S., Anis, W. R., Riad, P. H. S., Samaan, M. S. F., Saadany, E. R. & Abdellatif, S. O. (2024). Techno-economic study for photovoltaic battery-free irrigation systems in an arid area for olive fields in Western West Al Minya, Egypt. *Discover Sustainability*, *5*(1), 366. https://doi.org/10.1007/s43621-024-00566-y

Agostini, A., Colauzzi, M. & Amaducci, S. (2021). Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment. *Applied Energy*, *281*, 116102. https://doi.org/10.1016/j.apenergy.2020.116102

Ahmad, A., Irshad, K., Ghazy, M., Zayed, M. E., Rehman, S. & Alam, M. A. (2025). Comprehensive Assessment of Solar Agrivoltaics Potential: Systematic Review and Techno-Economic Assessment Modeling Toward Sustainable Food and Energy Production. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-025-10911-6

Al-Fadhli, F. M., Alhajeri, N. S., Gabr, M., Jabri, S. Al & El-Halwagi, M. M. (2025a). Sustainable Agricultural Practices in Arid Regions: Agrivoltaics and Solar Desalination. *Air, Soil and Water Research*, *18*. https://doi.org/10.1177/11786221251390645

Al-Fadhli, F. M., Alhajeri, N. S., Gabr, M., Jabri, S. Al & El-Halwagi, M. M. (2025b). Sustainable Agricultural Practices in Arid Regions: Agrivoltaics and Solar Desalination. *Air, Soil and Water Research*, *18*. https://doi.org/10.1177/11786221251390645

Alhejji, A., Kuriqi, A., Jurasz, J. & Abo-Elyousr, F. K. (2021). Energy Harvesting and Water Saving in Arid Regions via Solar PV Accommodation in Irrigation Canals. *Energies*, *14*(9), 2620. https://doi.org/10.3390/en14092620

Ali Abaker Omer, A., Li, M., Zhang, F., Hassaan, M. M. E., El Kolaly, W., Zhang, X., Lan, H., Liu, J. & Liu, W. (2025a). Impacts of agrivoltaic systems on microclimate, water use efficiency, and crop yield: A systematic review. *Renewable and Sustainable Energy Reviews*, *221*, 115930. https://doi.org/10.1016/J.RSER.2025.115930

Ali Abaker Omer, A., Li, M., Zhang, F., Hassaan, M. M. E., El Kolaly, W., Zhang, X., Lan, H., Liu, J. & Liu, W. (2025b). Impacts of agrivoltaic systems on microclimate, water use efficiency, and crop yield: A systematic review. *Renewable and Sustainable Energy Reviews*, *221*, 115930. https://doi.org/10.1016/j.rser.2025.115930

Alshallash, K. S., Makled, K. M., Saeed, K. F., Shehab, A. A., Farouk, A. S. M. & Hamdy, A. E. (2022). Drip Irrigation and Compost Applications Improved the Growth, Productivity, and Water Use Efficiency of Some Varieties of Bread Wheat. *Agronomy*, *13*(1), 139. https://doi.org/10.3390/agronomy13010139

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

Ansari, A., Wuryandani, S., Pranesti, A., Telaumbanua, M., Ngadisih, Hardiansyah, M. Y., Alam, T., Supriyanta, Martini, T. & Taryono. (2023). Optimizing water-energy-food nexus: achieving economic prosperity and environmental sustainability in agriculture. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1207197

Ayadi, O., Al-Bakri, J. T., Abdalla, M. E. B. & Aburumman, Q. (2024). The potential of agrivoltaic systems in Jordan. *Applied Energy*, *372*, 123841. https://doi.org/10.1016/j.apenergy.2024.123841

Barron-Gafford, G. A., Pavao-Zuckerman, M. A., Minor, R. L., Sutter, L. F., Barnett-Moreno, I., Blackett, D. T., Thompson, M., Dimond, K., Gerlak, A. K., Nabhan, G. P. & Macknick, J. E. (2019). Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nature Sustainability*, *2*(9), 848–855. https://doi.org/10.1038/s41893-019-0364-5

Damien Fumey, Jérôme Chopard & Gerardo Lopez. (2023, June 23). Dynamic agrivoltaics, climate protection for grapevine driven by artificial intelligence. *GiESCO 2023*. https://doi.org/10.58233/mTZfKUqj

Darwish, M., Elkot, A., Elfanah, A., Selim, A., Yassin, M., Abomarzoka, E., El-Maghraby, M., Rebouh, N. & Ali, A. (2023). Evaluation of Wheat Genotypes under Water Regimes Using Hyperspectral Reflectance and Agro-Physiological Parameters via Genotype by Yield*Trait Approaches in Sakha Station, Delta, Egypt. *Agriculture*, *13*(7), 1338. https://doi.org/10.3390/agriculture13071338

El Ghetany, H., AbedElhakaim, A., Elsayed, A. & Zedan, I. (2021). Theoretical analysis of different solar water pumping irrigation systems for seasonal crops in three geographical locations in Egypt. *Egyptian Journal of Chemistry*, *0*(0), 0–0. https://doi.org/10.21608/ejchem.2021.78302.3834

Elhini, M., Hassaballa, H., Simpson, N. P., Balbaa, M., Ibrahim, R., Mansour, S., Abou-Kota, M. E. & Ganzour, S. (2024). The land degradation and desertification-socioeconomic nexus in Egypt's delta region: A case study on Alexandria and Beheira. *Heliyon*, *10*(10), e31165. https://doi.org/10.1016/j.heliyon.2024.e31165

Emam, M. A., Abd EL-Mageed, A. M., Niedbała, G., Sabrey, S. A., Fouad, A. S., Kapiel, T., Piekutowska, M. & Mahmoud, S. A. (2022). Genetic Characterization and Agronomic Evaluation of Drought Tolerance in Ten Egyptian Wheat (Triticum aestivum L.) Cultivars. *Agronomy*, *12*(5), 1217. https://doi.org/10.3390/agronomy12051217

Farghally, H. M., Sweelem, E. A., El-Sebah, M. I. A. & Syam, F. A. (2022). Agricultural Grid Connected Photovoltaic System Design and Simulation in Egypt by using PVSYST Software. *WSEAS TRANSACTIONS ON CIRCUITS AND SYSTEMS*, *21*, 306–315. https://doi.org/10.37394/23201.2022.21.33

GENG Xiayun, ZHANG Long & BAO Encai. (2025). Effects of photovoltaic array shading on light environment and wheat yield. *Transactions of the Chinese Society of Agricultural Engineering*, *41*(15), 227–235. https://doi.org/10.11975/j.issn.1002-6819.202503182

Laub, M., Pataczek, L., Feuerbacher, A., Zikeli, S. & Högy, P. (2022). Contrasting yield responses at varying levels of shade suggest different suitability of crops for dual land-use systems: a meta-analysis. *Agronomy for Sustainable Development*, *42*(3), 51. https://doi.org/10.1007/s13593-022-00783-7

Longi solar. (2025). *Longi solar*. Https://Static.Longi.Com/Hi_MO_5m_LR_5_72_HPH_540_560_M_35_35_and_15_G2_V16_b8597c604e.Pdf.

Makar, R. S., Li, S. & Shahin, S. A. (2024). Evaluating the Climate Change Trends and Spatiotemporal Variations of Evapotranspiration: A Case Study in El-Beheira Governorate, Egypt. *Asian Research Journal of Agriculture*, *17*(2), 76–88. https://doi.org/10.9734/arja/2024/v17i2424

Makar, R. S., Shahin, S. A., El-Nazer, M., Wheida, A. & Abd El-Hady, M. (2022). Evaluating the Impacts of Climate Change on Irrigation Water Requirements. *Sustainability*, *14*(22), 14833. https://doi.org/10.3390/su142214833

Mamun, M. A. Al, Dargusch, P., Wadley, D., Zulkarnain, N. A. & Aziz, A. A. (2022). A review of research on agrivoltaic systems. *Renewable and Sustainable Energy Reviews*, *161*, 112351. https://doi.org/10.1016/j.rser.2022.112351

Masrawy. (2025). *the government announces the prices for exporting wheat and sugar cane*. Https://Www.Masrawy.Com/News/News_egypt/Details/2025/8/27/2844023. https://www.masrawy.com/news/news_egypt/details/2025/8/27/2844023

Mohamed, S. A. (2020). Coastal vulnerability assessment using GIS-Based multicriteria analysis of Alexandria-northwestern Nile Delta, Egypt. *Journal of African Earth Sciences*, *163*, 103751. https://doi.org/10.1016/j.jafrearsci.2020.103751

Nashwan, M. S., Shahid, S. & Wang, X. (2019). Assessment of Satellite-Based Precipitation Measurement Products over the Hot Desert Climate of Egypt. *Remote Sensing*, *11*(5), 555. https://doi.org/10.3390/rs11050555

Osama, M., Abdel-Salam, M. & Elnozahy, A. (2023). Bi-objective Optimization based Sizing of a Standalone Solar PV Pumping System for Water Demand of an Agricultural Farm. *2023 24th International Middle East Power System Conference (MEPCON)*, 1–8. https://doi.org/10.1109/MEPCON58725.2023.10462349

Prakash, V., Lunagaria, M. M., Trivedi, A. P., Upadhyaya, A., Kumar, R., Das, A., Kumar Gupta, A. & Kumar, Y. (2023). Shading and PAR under different density agrivoltaic systems, their simulation and effect on wheat productivity. *European Journal of Agronomy*, *149*, 126922. https://doi.org/10.1016/j.eja.2023.126922

Ruth Muir. (2025). *CLIMATE-SMART CROP SUCCESS IN ARID AGRIVOLTAIC CONDITIONS* [Master thesis, UNIVERSITY OF ARIZONA]. https://www.proquest.com/openview/2114b6ea4bd6201e254de265e173658b/1?pq-origsite=gscholar&cbl=18750&diss=y

Sungrow. (2025). *Sungrow*. Https://En.Sungrowpower.Com/ProductDetail/736/String-Inverter-Sg111hv. https://en.sungrowpower.com/productDetail/736/string-inverter-sg111hv

Trommsdorff, M., Kang, J., Reise, C., Schindele, S., Bopp, G., Ehmann, A., Weselek, A., Högy, P. & Obergfell, T. (2021). Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. *Renewable and Sustainable Energy Reviews*, *140*, 110694. https://doi.org/10.1016/j.rser.2020.110694

Zubair, M. (2024). PV energy penetration in Saudi Arabia: current status, residential, and commercial users, local investment, use in modern agriculture. *International Journal of Sustainable Engineering*, *17*(1), 39–51. https://doi.org/10.1080/19397038.2023.2297262