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TECHNO-ECONOMIC AND AGRICULTURAL VIABILITY ASSESSMENT OF AGRIVOLTAIC SYSTEMS IN HOT ARID REGIONS: A SIMULATION-BASED CASE STUDY IN ASWAN, EGYPT

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Abstract:

Agrivoltaic systems are increasingly recognized as a dual-use strategy for combining crop production and photovoltaic electricity generation on the same land. However, their integrated technical, agricultural, and economic performance under the hot-arid conditions of southern Egypt remains insufficiently investigated. This study evaluates the viability of a tomato-based agrivoltaic system in Aswan, Egypt, using a comparative simulation framework based on a fixed land area of 1 hectare. A 70% photovoltaic-coverage scenario was used as the PV-only reference, while a 50% coverage scenario represented the agrivoltaic system. Photovoltaic performance and financial outcomes were simulated using the System Advisor Model (SAM), whereas tomato productivity was estimated through a literature-based approach using yield-reduction factors derived from published agrivoltaic experiments. Land-use productivity was assessed using the Land Equivalent Ratio (LER), while PV-system financial performance was evaluated using installed cost, Net Present Value (NPV), Internal Rate of Return (IRR), and Levelized Cost of Energy (LCOE) over a 25-year analysis period. The agricultural revenue was estimated separately using projected tomato yield, market price, and farming costs. The 70% PV-only system generated 3,133.9 MWh annually, compared with 2,226.5 MWh for the 50% agrivoltaic system, representing an approximately 29.0% reduction in electricity generation resulting from the lower installed PV capacity. Under the literature-derived base-case assumption of a 29%

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shading-related yield reduction, tomato production was estimated at 28.4–29.8 t/ha. The agrivoltaic system achieved an LER of 1.39–1.42, indicating a 39–42% improvement in combined land productivity relative to separate crop and photovoltaic production. Both scenarios achieved an IRR of 11.8% and an LCOE of 3.8 cents/kWh, while the PV-only and agrivoltaic systems recorded positive NPVs of USD 129,800 and USD 91,800, respectively. These findings indicate that agrivoltaics can provide a technically feasible, economically viable, and land-efficient food–energy option for hot-arid regions.

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Keywords:

Economic Feasibility, Land Equivalent Ratio (LER), Photovoltaic Simulation, System Advisor Model (SAM), Ground Cover Ratio (GCR), Tomato yield.

Introduction

Agrivoltaic systems are increasingly recognized as a dual-use strategy that enables agricultural production and photovoltaic electricity generation on the same land (Chopdar et al., 2024a). However, despite growing international research interest, their combined technical, agricultural, and economic performance in southern Egypt remains insufficiently investigated. The existing studies focused on individual aspects of agrivoltaic performance leaving a clear need for a location-specific evaluation. Addressing this gap is essential for determining if agrivoltaics can be successfully implemented in the region.

Agrivoltaics are well suited to hot arid climates like Egypt, where solar potential is high and agricultural stress from heat, evaporation, crop transpiration, and water demand are growing. (Santos Rocha et al., 2023). These conditions are well represented in Aswan in southern Egypt, where it is a hot desert with very little rainfall, and high solar exposure (Climate data, 2026).The high solar irradiation in Egypt, as confirmed by the Global Solar Atlas and data from the World Bank, leads to high PV potential in the country (Global Solar Atlas, 2026a). In such extreme climate conditions, it is crucial to choose a heat-sensitive crop to assess the potential benefits of agrivoltaics systems.

The crop (tomato) was chosen as the primary crop in this study because it is sensitive to heat stress, especially in the reproductive stage. High temperatures can reduce pollen viability, fruit set, fruit quality, and overall yield, making tomato an appropriate crop for evaluating whether partial shading from photovoltaic panels can improve growing conditions in hot environments (Hoshikawa et al., 2021a). However, shading can also reduce the radiation available for photosynthesis, so agrivoltaics design must balance crop protection with sufficient light availability.

Considering these challenges and trade-offs, this study therefore aims to assess the techno-economic and agricultural viability of an agrivoltaics system for tomato production in Aswan, Egypt. Photovoltaic performance and financial outcomes were simulated using the System Advisor Model (SAM) (SAM, 2026a). Tomato productivity under agrivoltaic conditions was estimated using a literature-based approach derived from published experimental studies. The study also calculated the Land Equivalent Ratio (LER) and compared conventional tomato cultivation, standalone photovoltaic generation, and integrated agrivoltaic production.

Literature Review

Agrivoltaics Systems and Dual Land Use

Agrivoltaic systems combine crop cultivation and photovoltaic electricity generation within the same land area. Agrivoltaics reduces land-use competition by combining food and energy production. Its configurations—including fixed, elevated, vertical, semi-transparent, and tracking systems—are selected according to crop, climate, land constraints, and the desired yield–energy balance (Chopdar et al., 2024b). Agrivoltaic design shapes the crop microclimate. In arid regions, panel shading can reduce heat stress and evaporation also water use but can also limit photosynthesis. For that performance depends on system design, crop light requirements, and local climate (Ali Abaker Omer et al., 2025)(Warmann et al., 2024).

Agrivoltaics in Hot Arid Regions

Hot arid regions are ideal for agrivoltaic research because abundant solar energy coincides with severe agricultural challenges, including high evapotranspiration, rapid soil drying, and crop heat stress (Zhang et al., 2025). A recent systematic review reported that agrivoltaic systems can improve water-use efficiency by **20–47%**, reduce evapotranspiration, and lower air or soil temperature by about **1–4 °C**, although the benefits depend on local climate, crop type, and PV design(Ali Abaker Omer et al., 2025). The same review also highlighted that arid and tropical climates remain underrepresented in agrivoltaic research, which supports the need for more studies in regions such as southern Egypt. Agrivoltaics may be especially useful in dryland agriculture because partial PV shading can reduce midday stress and improve crop water relations. A study done by Barron-Gafford et al.(Barron-Gafford et al., 2025) found that agrivoltaic conditions in hot and arid environments helped reduce midday photosynthetic depression, lowered water stress, and supported equal or greater daily carbon assimilation across studied crops. These findings suggest that agrivoltaics can act not only as an energy-production strategy, but also as a climate-adaptation approach for agriculture in water-limited environments.

Egypt provides a prime, highly relevant context for implementing these strategies, as its domestic agriculture is increasingly exposed to these exact climate-related pressures. The Food and Agriculture Organization (FAO) notes that heat waves in Egypt are becoming more frequent and severe, raising evaporation, crop transpiration, soil aridity, and water requirements for both human and agricultural consumption. Conversely, this harsh climatic profile is paired with an exceptional solar-resource potential; the Global Solar Atlas and World Bank datasets confirm substantial solar irradiation and PV power-potential data across the country(Santos Rocha et al., 2023), making the region uniquely suited for dual-use land optimization.

Crop Response to Shading and Tomato Suitability

Crop performance in agrivoltaic systems depends on changes in radiation, temperature, humidity, evapotranspiration, and soil moisture. Although PV panels can reduce heat stress and water loss, excessive shading may limit photosynthetically active radiation and reduce crop yield and quality (Naim et al., 2025). Tomato is suitable for this study because it is economically important and highly sensitive to heat stress, especially during reproductive growth. High temperatures can negatively affect plant development, fruit set, yield, and fruit quality (Hoshikawa et al., 2021b). Agrivoltaic experiments in southern Spain also found that shading altered the greenhouse microclimate, with greater shading causing larger yield reductions (Kujawa et al., 2025). Therefore, agrivoltaic design in Aswan must balance thermal-stress reduction with sufficient light availability for tomato growth.

Simulation and Modelling of Agrivoltaic Systems

Simulation is widely used in agrivoltaic research to predict energy and crop performance before field installation. Integrated models should consider shading, microclimate, crop response, electrical output, and agricultural productivity. PV modules can reduce ground-level solar radiation, alter energy balance, evapotranspiration, photosynthesis, wind, and rainfall distribution (Zainali et al., 2025). The need for reliable modelling is also emphasized by the International Energy Agency (IEA) The IEA Photovoltaic Power Systems Programme also identifies modelling as essential for optimizing agrivoltaic design and highlights the need for standardized indicators, consistent definitions, and improved design tools (Trommsdorff et al., 2025).

To address the electrical and economic dimensions of this integrated modelling requirement, this study utilizes the System Advisor Model (SAM). Developed by NREL, SAM is a robust, free techno-economic software tool designed for evaluating renewable energy projects ranging from small-scale applications to large utility-scale installations. The software features comprehensive financial models, including power purchase agreements, merchant plants, and levelized cost of electricity (LCOE) calculations that are essential for assessing long-term project feasibility(SAM, 2026b). However, because SAM is strictly an energy-focused tool, it cannot directly simulate agricultural outputs. Consequently, the tomato crop-yield component of this study is decoupled from the PV simulation and handled separately through a dedicated crop-yield estimation framework.

Land Equivalent Ratio (LER) and Economic Feasibility

Land Equivalent Ratio is one of the most common indicators used to evaluate whether agrivoltaics provides a land-use advantage over separate agriculture and PV production. In agrivoltaic studies, LER combines the relative crop yield and relative electricity yield of the integrated system. If the LER is greater than 1, the agrivoltaic system is considered more land-efficient than producing crops and solar electricity on separate land areas. Recent techno-economic agrivoltaic studies use LER together with financial indicators to compare integrated systems with standalone crop production and standalone PV systems(Garrod et al., 2024). Economic feasibility is critical because agrivoltaic systems often require higher initial investment than conventional ground-mounted PV systems. Additional costs may come from elevated structures, wider spacing, installation complexity, maintenance access, and the need to preserve agricultural operations underneath the panels.

Methodology

Research Framework

The study adopts a comparative simulation framework based on a fixed land area of 1 hectare to ensure that the photovoltaic and agrivoltaic systems are evaluated on an equal land-use basis. Two scenarios are considered. The first scenario represents a PV-only reference system, where photovoltaic modules occupy 70% of the 1 ha site and the system is used as the baseline for electricity generation. The second scenario represents an agrivoltaic tomato-production system, where photovoltaic coverage is reduced to 50% of the same 1 ha area to allow space and solar access for tomato cultivation. The comparison evaluates the energy–agriculture trade-off: the PV-only case provides the reference electricity yield, while the agrivoltaic case assesses the combined electricity and tomato output used to calculate the Land Equivalent Ratio under Aswan's hot-arid conditions

Study Area: Aswan, Egypt

Aswan is selected for its hyper-arid climate, severe heat, water scarcity, Nile-based agriculture, and high solar irradiance. These conditions make it suitable for evaluating agrivoltaics under hotter, drier conditions than northern Egypt's Mediterranean climate. Figure 1 shows the study location using Global Solar Atlas data (Global Solar Atlas, 2026b).

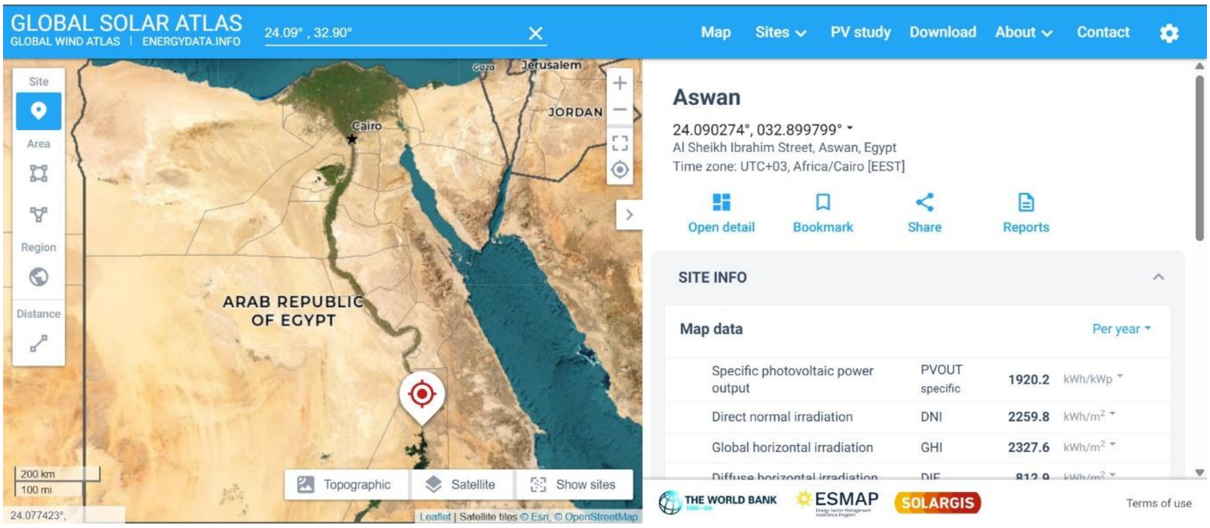

Figure 1: Global Solar Atlas Map for Aswan

Source: ((Global Solar Atlas, 2026b))

Aswan is well suited for agrivoltaic assessment, with an annual PV output of 1,920.2 kWh/kWp and global horizontal irradiation of 2,327.6 kWh/m².

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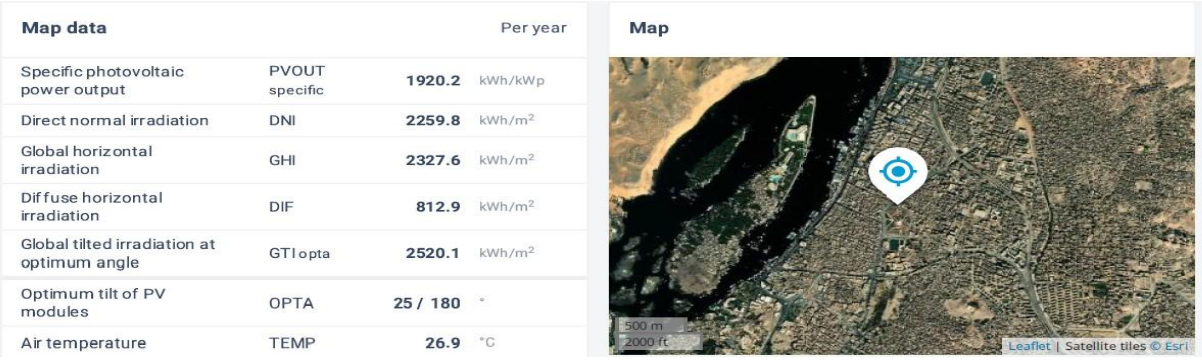

Map data			Per year
Specific photovoltaic power output	PVOUT specific	1920.2	kWh/kWp
Direct normal irradiation	DNI	2259.8	kWh/m²
Global horizontal irradiation	GHI	2327.6	kWh/m²
Diffuse horizontal irradiation	DIF	812.9	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	2520.1	kWh/m²
Optimum tilt of PV modules	OPTA	25 / 180	°
Air temperature	TEMP	26.9	°C

Figure 2: Global Solar Atlas Report Map Data for Aswan
Source: ((Global Solar Atlas, 2026b))

Aswan records DNI, DHI, and optimum-tilt irradiation of 2,259.8, 812.9, and 2,520.1 kWh/m², respectively. The optimal orientation is 25° tilt and the azimuth is 180°, with an average air temperature of 26.9°C. These conditions support assessing agrivoltaic benefits for tomato production with minimal energy losses.

Scenario Design

Two scenarios were simulated on the same 1-ha site: a 70% PV-only system as a high-density energy benchmark and LER reference, consistent with fixed-tilt systems at a ground cover ratio of 0.70 (Tonita et al., 2023). and a 50% agrivoltaic system balancing electricity generation with tomato access to land and sunlight. As higher PV coverage can reduce crop yield, particularly for light-sensitive tomatoes, the 50% design was adopted as a site-specific compromise rather than a universal optimum (Dupraz, 2024) (Naim et al., 2025).

PV System Configuration and SAM Simulation

PV Module and Inverter Selection

The SAM model used a 570.414 Wdc LONGi LR5-72HPH-570M monocrystalline module (22.91% efficiency; Vmp/Imp: 42.6 V/13.4 A; Voc/Isc: 50.5 V/14.2 A; temperature coefficient: −0.375%/°C) and a Sungrow SG125HV central inverter rated at 125 kWac and 127.418 kWdc.

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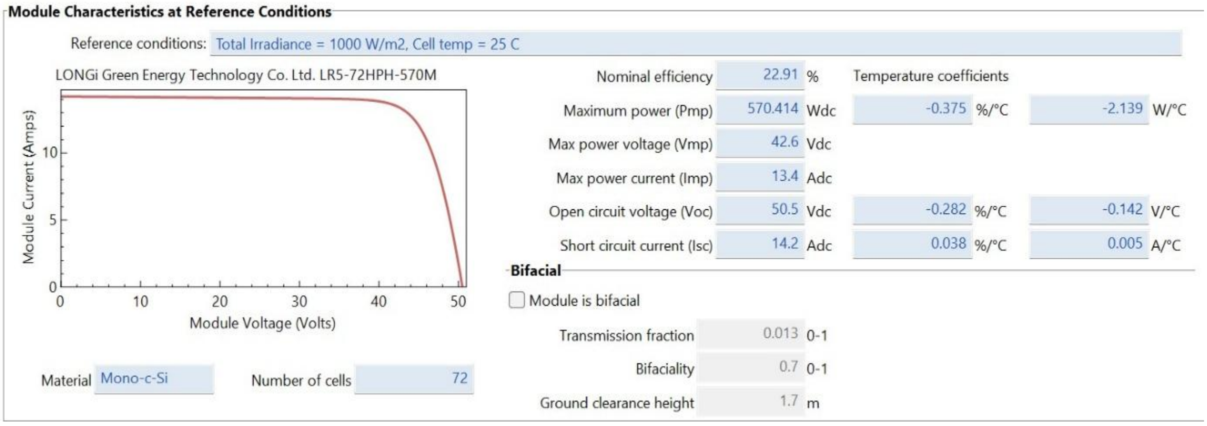

Figure 3: PV Module Characteristics for The Simulation
Source: (SAM Simulation)

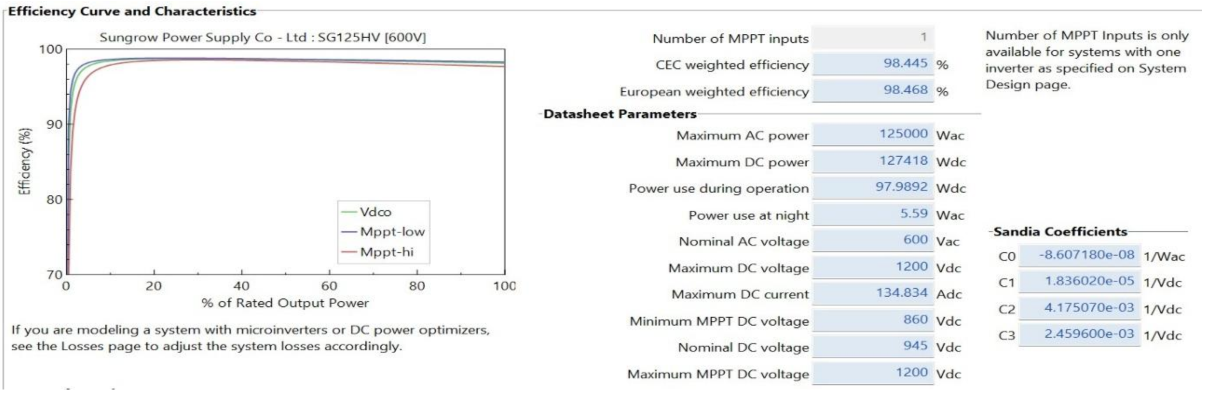

Figure 4: Inverter Characteristics for The Simulation
Source: (SAM Simulation)

System Design For The 70% Coverage

The PV scenario used 2,806 modules with array configuration of 23 modules per string and 122 parallel strings occupying 6,986.94 m² approximately 70% of the study area and Ten 125 kWac inverters used with DC-to-AC ratio of 1.28. This configuration maximizes energy production and serves as the benchmark for the agrivoltaic scenario.

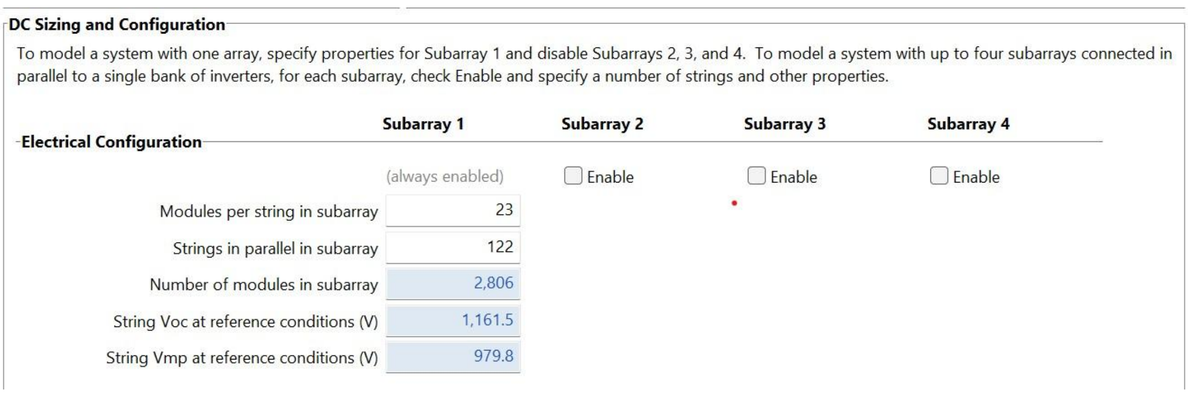

Figure 5: DC sizing and electrical configuration for the 70% PV-only scenario
Source: (SAM Simulation)

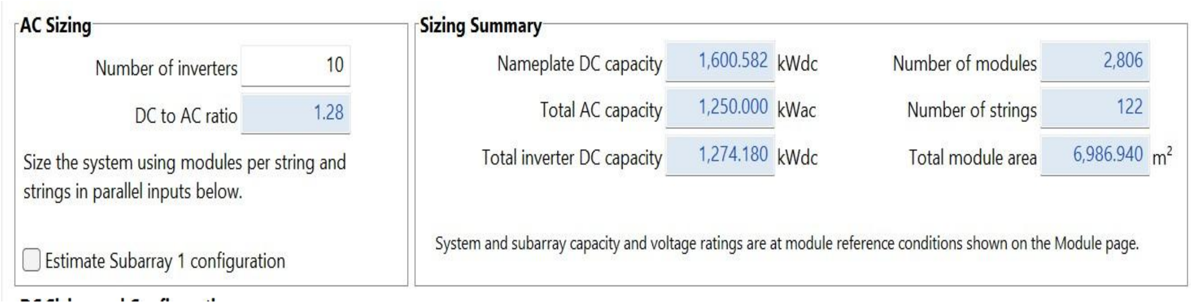

Figure 6: AC Sizing And System Summary For The 70% PV-Only Scenario
Source: (SAM Simulation)

System Design For The 50% Coverage

The agrivoltaic scenario used 2,001 modules with array configuration of 23 modules per string and 87 parallel strings occupying 4,982.49 m² approximately 50% of the study area and seven 125 kWac inverters used with DC-to-AC ratio of 1.30. This configuration reduces PV capacity relative to the PV-only system, providing space and sunlight for tomatoes while maintaining a viable electrical layout.

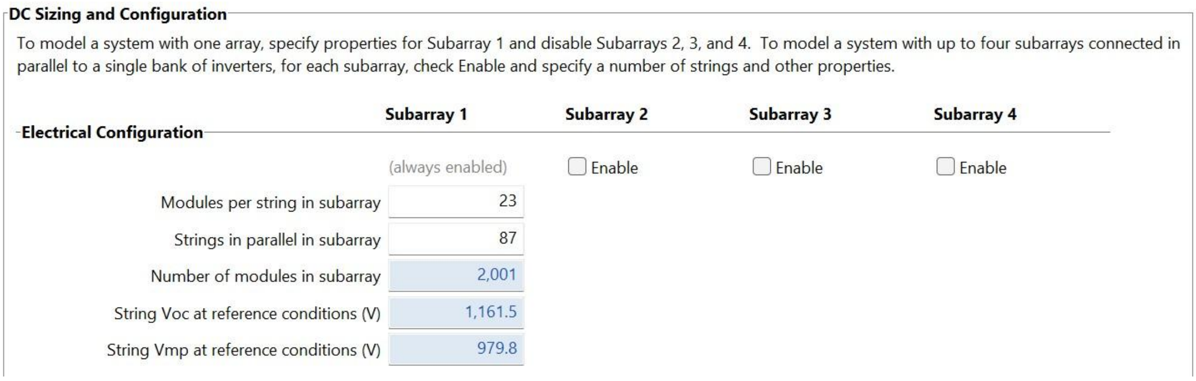

Figure 7: DC Sizing And Electrical Configuration For The 50% Agrivoltaic Scenario
Source: (SAM Simulation)

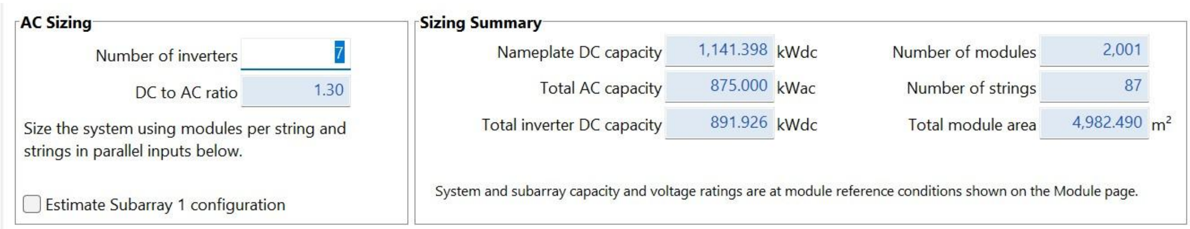

Figure 8: AC Sizing And System Summary For The 50% Scenario
Source: (SAM Simulation)

Losses and Degradation Assumptions

Both scenarios included realistic losses: 5% annual soiling, 4.44% DC, 1% AC, sub-hourly clipping, and 0.5% annual module degradation. These assumptions improve the accuracy of long-term energy and financial estimates.

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Techno-Economic Assessment and Financial Indicators

Both scenarios were analyzed over 25 years with the NPV, IRR, and LCOE derived from SAM, which are based on capital and operating costs, PPA price, inflation, discount rate, and annual energy output. The 70% PV-only system had total direct capital costs of $774,811.64, including $240,087.25 for 2,806 modules, $80,000.00 for 10 inverters, $192,069.80 for balance-of-system equipment, $160,058.17 for installation labour, and $80,029.08 for installer margin and overhead. A 3% contingency of $22,567.33 was also included. The cost of land purchase was not included as it was assumed that the project would be built on government land, but land preparation and transmission infrastructure cost were included. The land area used in SAM for this scenario is 2.466 acres and the land preparation and transmission cost is estimated at $16,005.82. Other indirect capital cost components were also included, namely permitting and environmental studies at $16,005.82, engineering and developer overhead at $16,005.82, and grid interconnection at $16,005.82. As a result, the total indirect capital cost for the 70% PV-only system was $64,023.27.

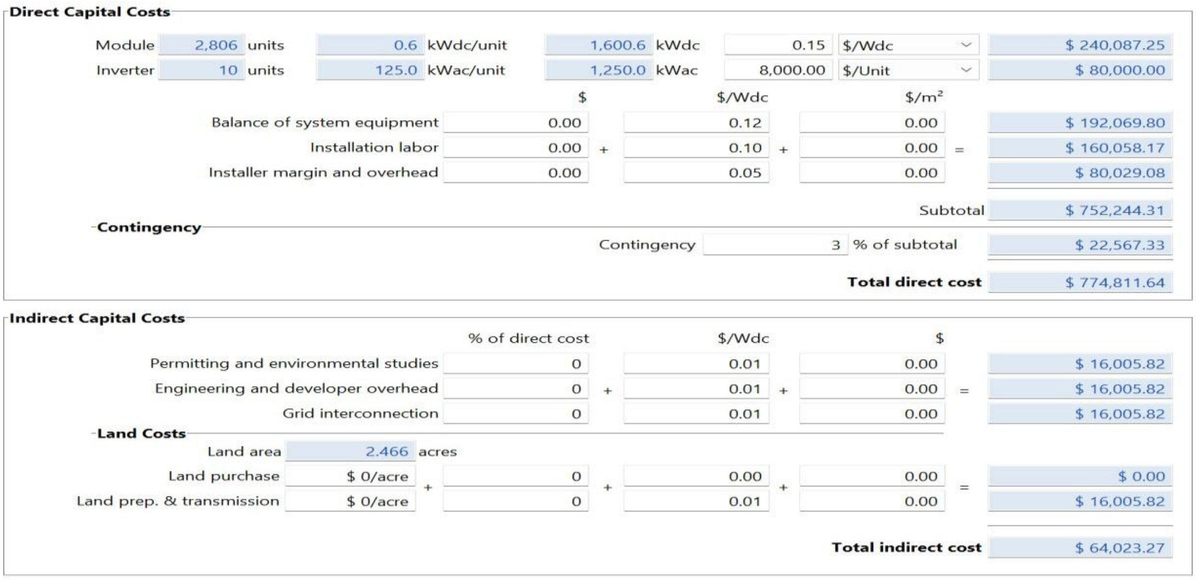

Figure 9: Direct and Indirect Costs for the 70% Scenario
Source: (SAM Simulation)

For the 50% agrivoltaic system, the direct capital costs were slightly lower at $551,448.95. This includes the cost of 2,001 modules and 7 inverters, resulting in a module cost of $171,209.76 and an inverter cost of $56,000.00. The balance of system equipment was $136,967.81, installation labour was $114,139.84, and installer margin and overhead was $57,069.92. A 3% contingency for this scenario amounted to $16,061.62. The same government-project assumption was applied, so no land purchase cost was included. The land purchase value was also set at $0.00/acre. Since the PV coverage was reduced, the land area considered in SAM decreased to 1.759 acres. The land preparation and transmission cost for this scenario was $11,413.98. The other indirect cost components were also lower than the 70% scenario, with permitting and environmental studies at $11,413.98, engineering and developer overhead at $11,413.98, and grid interconnection at $11,413.98. Therefore, the total indirect capital cost for the 50% agrivoltaic system was $45,655.94.

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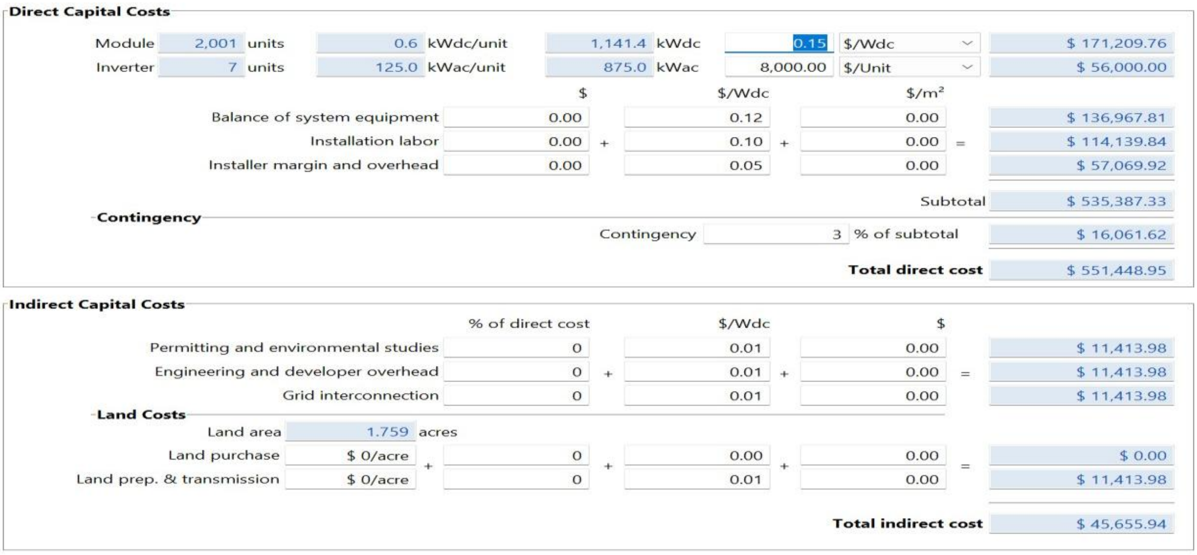

Figure 10: Direct and Indirect Costs for the 50% Scenario
Source: (SAM Simulation)

The sales tax rate of 5% was applied to the direct capital costs, resulting in the following:
70% PV-only: The sales tax was $38,740.58, bringing the total installed cost to $877,575.49.
50% agrivoltaic: The sales tax was $27,572.45, bringing the total installed cost to $624,677.34.
The total installed cost per capacity for both systems was $0.55/W$_{dc}$.

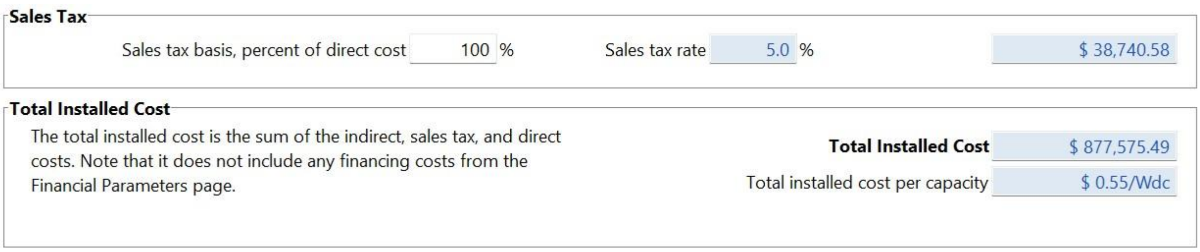

Figure 11: Sales Tax and Total Installed Costs for the 70% Scenario
Source: (SAM Simulation)

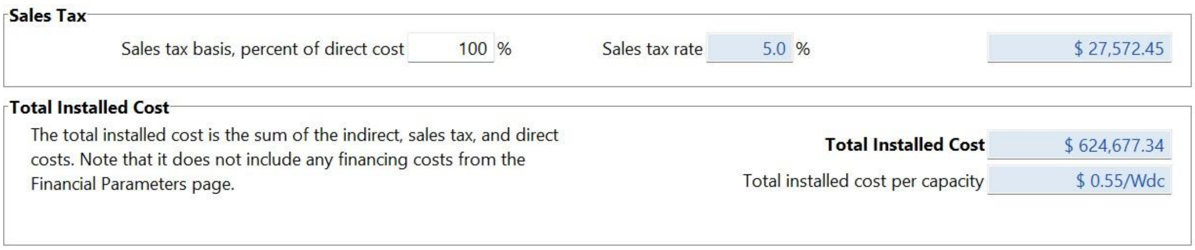

Figure 12: Sales Tax and Total Installed Costs for the 50% Scenario
Source: (SAM Simulation)

For both the 70% PV-only and 50% agrivoltaic scenarios, the financial model used a Power Purchase Agreement (PPA) price of $0.04/kWh as the initial selling price for electricity generated by the PV systems. The PPA price is set to increase by 1% annually to reflect energy-price inflation and its effect on long-term revenue. An IRR target of 11% by year 20 was applied, while a 25-year analysis period was used to assess the systems' financial viability under escalating electricity prices.

Figure 13: Power Purchase Agreement (PPA) Price and Escalation Rate
Source: (SAM Simulation)

The financial analysis covered 25 years for both scenarios to ensure a consistent comparison. An annual inflation rate of 2.5% and a real discount rate of 8% were applied, resulting in a nominal discount rate of 10.70%.

Figure 14: Analysis Period
Source: (SAM Simulation)

Literature-Based Crop-Yield Estimation

Tomato is commonly grown during the winter season from November to May and during the spring/summer season from March to June, with an average yield of about 40–43 t/ha (Fangary et al., 2026). Tomato also has strong economic importance in Egypt because it is widely consumed domestically and contributes to export markets in both fresh and processed forms. In relation to agrivoltaic systems, tomato can be considered a moderately shade-tolerant crop, making it suitable for evaluating the effect of partial PV shading on crop productivity under hot climatic conditions.

Due to the absence of locally calibrated field data for tomato production under agrivoltaic systems in Aswan, tomato yield was estimated using a literature-based method derived from published experimental studies. The approach applied experimentally reported shading-related yield-reduction factors to the conventional open-field tomato yield reported for Egypt. The main yield adjustment factor was derived from a study done by Scarano et al(Scarano et al., 2024), who compared tomato plants grown under PV panels with plants grown under full sunlight under high- and low-water supply conditions. Based on their reported yield values, PV shading reduced tomato yield by approximately 29% under high-water conditions and about 6% under low-water conditions. Therefore, a yield-reduction range of 6–29% was used to represent the possible impact of partial PV shading on tomato production, with the 29% value adopted as the base-case estimate for the agrivoltaic scenario. This range was considered suitable for preliminary simulation because it reflects observed tomato responses to PV shading, although actual yields in Aswan may vary with climate, soil, irrigation, and system layout. Supporting evidence shows that greater shading can reduce tomato yield while improving water productivity under shaded and deficit-irrigated conditions (Al-Agele et al., 2021).

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Land Equivalent Ratio (LER) Calculation

The Land Equivalent Ratio (LER) was used in this study as the main indicator for comparing land-use productivity between separate production and integrated agrivoltaic production. LER is commonly applied in agrivoltaic research because it shows whether combining crop cultivation and photovoltaic electricity generation on the same land area provides a productivity advantage over using separate land areas for each activity. In simple terms, LER compares the combined output of the agrivoltaic system with the output that would be obtained if tomato production and PV electricity generation were carried out independently.

In this study, the crop component of the LER represents the relative tomato yield under agrivoltaic shading compared with the baseline open-field tomato yield. Meanwhile, the energy component represents the relative electricity generation of the agrivoltaic PV system compared with the PV-only reference system. The LER can therefore be expressed as:

$$LER = \frac{Y_{AV}}{Y_{ref}} + \frac{E_{AV}}{E_{ref}}$$

where Y_{AV} is the estimated tomato yield under the agrivoltaic system, Y_{ref} is the tomato yield under conventional open-field cultivation, E_{AV} is the electricity generation from the agrivoltaic system, and E_{ref} is the electricity generation from the PV-only reference system. An LER value greater than 1 indicates that the agrivoltaic system produces more combined land output than separate crop and PV production on equivalent land areas. An LER equal to 1 means that the integrated system provides no land-use advantage, while an LER below 1 suggests that separate production would be more productive.

Results

PV Only Scenario 70% Coverage

The 70% PV-only scenario was simulated in SAM using a 1.6 MW_{dc} photovoltaic system. The site recorded average global horizontal irradiance of 6.41 kWh/m²/day. In the first year, the system generated 3,315,770 kWhdc at the inverter input and delivered 3,133,856 kWhac to the grid. It achieved a capacity factor of 22.4% and a performance ratio of 0.77 after accounting for system losses.

Annual Results (in Year 1)	
GHI kWh/m²/day	6.41
Net to inverter	3,315,770 DC kWh
Net to grid	3,133,856 AC kWh
Capacity factor	22.4
Performance ratio	0.77

Figure 15: Annual Results for the 70% coverage
Source: (SAM Simulation)

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Monthly electrical output remaines relatively stable throughout the year, with only moderate seasonal variation.

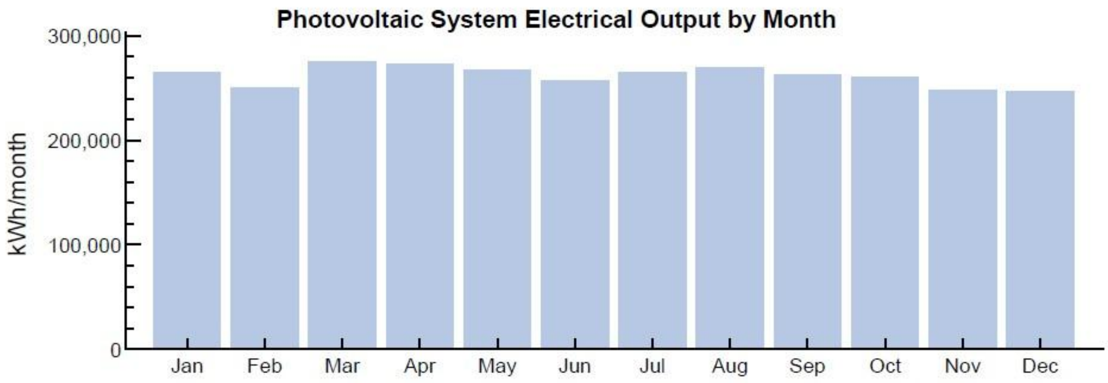

Figure 16: Photovoltaic System Electrical Output 70% coverage

Source: (SAM Simulation)

Losses from soiling (5%), STC deviation (8.587%), mismatch (2%), DC wiring (2%), inverter inefficiency (1.63%), AC wiring (1%), and availability/curtailment (2%) reduced nominal generation from 3,797,630 kWh to 3,133,856 kWhac.

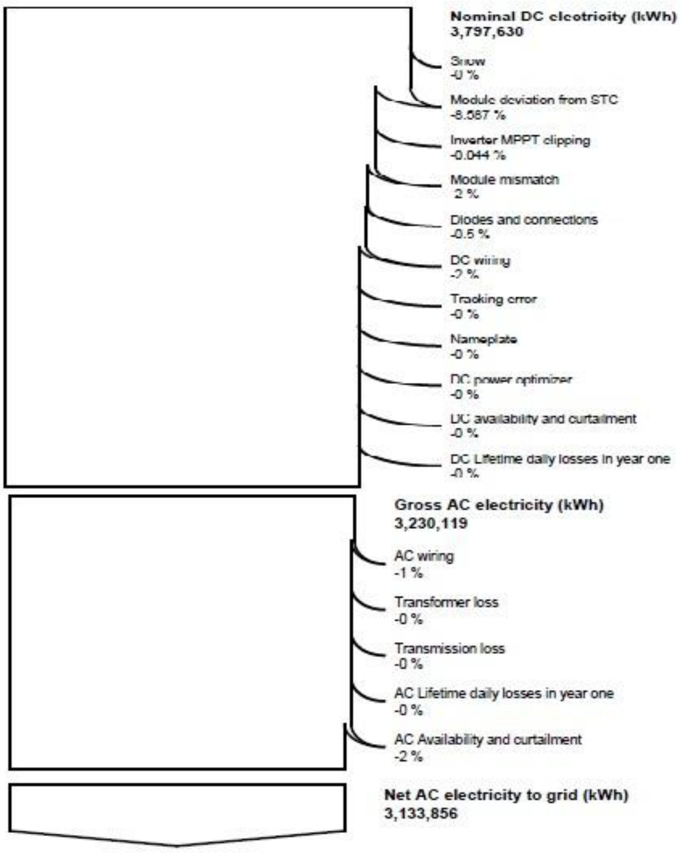

Figure 17: Simulation Loss Diagram for the 70% Coverage

Source: (SAM Simulation)

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Agrivoltaics Scenario 50% Coverage

The agrivoltaic scenario was simulated in SAM using a 1.14 MW_{dc} photovoltaic system. The site recorded average global horizontal irradiance of 6.41 kWh/m²/day. In the first year, the system generated 2,364,525 kWhdc at the inverter input and delivered 2,226,467 kWhac to the grid. It achieved a capacity factor of 22.3% and a performance ratio of 0.77 after accounting for system losses.

Annual Results (in Year 1)	
GHI kWh/m²/day	6.41
Net to inverter	2,364,524 DC kWh
Net to grid	2,226,467 AC kWh
Capacity factor	22 3
Performance ratio	0.77

Figure 18: Annual Results For The 50% Coverage
Source: (SAM Simulation)

Monthly electrical output remaines relatively stable throughout the year, with only moderate seasonal variation.

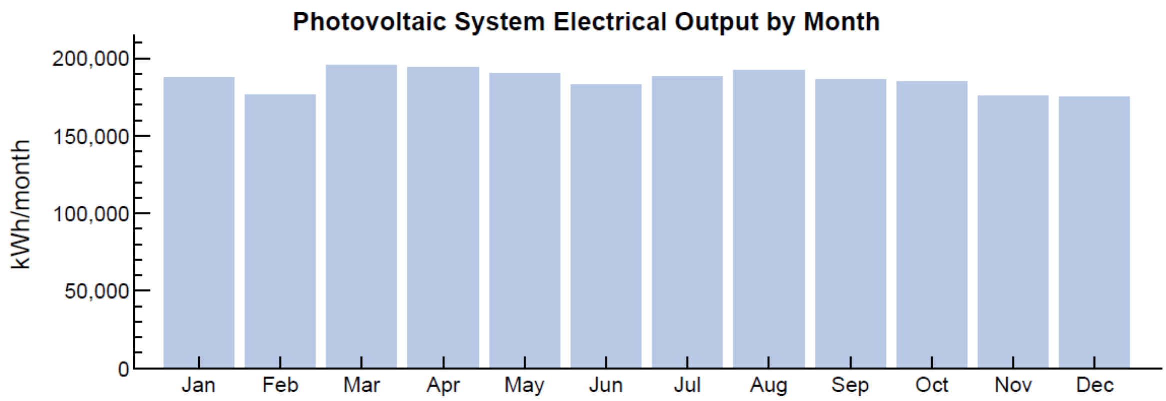

Figure 19: Photovoltaic System Electrical Output 50% coverage
Source: (SAM Simulation)

Losses from STC deviation (8.587%), mismatch (2%), DC wiring (2%), inverter inefficiency (1.65%), AC wiring (1%), and availability/curtailment (2%) reduced generation from 2,708,146 kWhdc to 2,226,467 kWhac.

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Although reducing PV coverage lowered annual output from 3,133,856 kWhac, the 50% agrivoltaic system maintained substantial generation while enabling assessment of land-use efficiency and combined food–energy productivity.

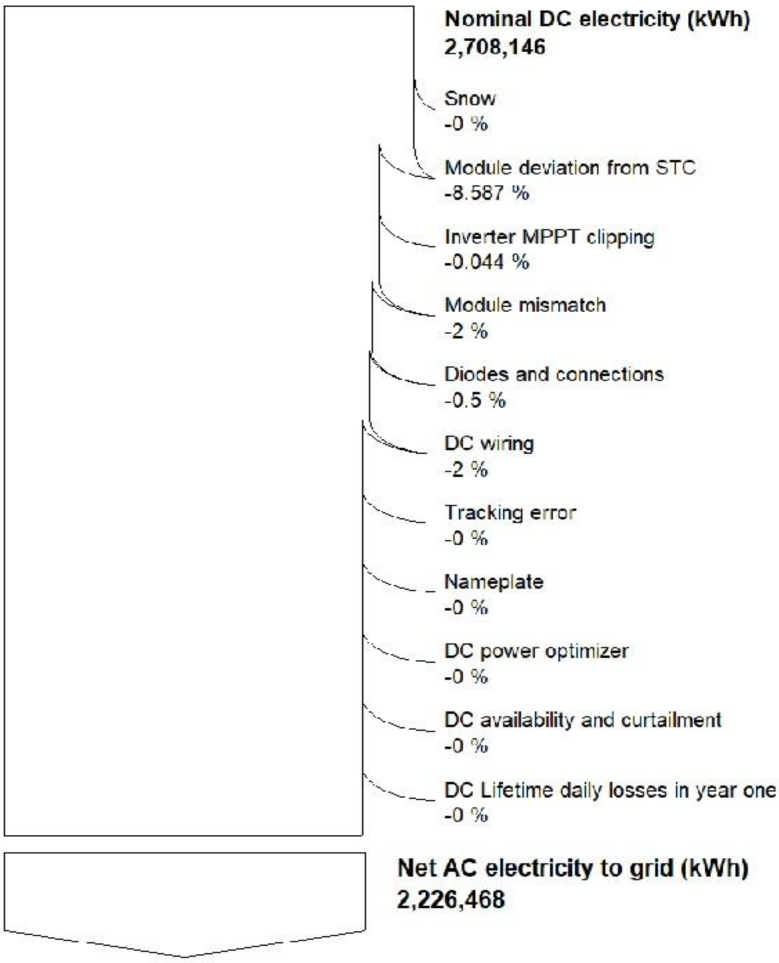

Figure 20: Simulation Loss Diagram for the 50% Coverage

Source: (SAM Simulation)

Financial Parameters

PV Financial Results For The 50% And The 70% Coverages

The 50% agrivoltaic system had a lower installed cost of $624,677 due to reduced PV, inverter, and balance-of-system requirements. Despite its lower energy output, it maintained a nominal LCOE of 3.8 cents/kWh against a first-year PPA price of 4 cents/kWh. The system achieved an 11.8% project IRR in year 20 and an NPV of $91,800, indicating financially acceptable returns.

Crop-Yield Results For The 50% Agrivoltaic Scenario

The tomato yield under 50% agrivoltaic scenario was estimated based on the literature-based yield reduction factor due to PV panel shading. The yield of tomatoes in open field in Egypt is about 40-42 t/ha per hectare. Applying a 29% yield reduction reported by Scarano (Scarano et al., 2024) the tomato yield under the agrivoltaic layout is estimated as:

$$Y_{AV} = Y_{open-field} \times (1 - 0.29)$$

$$Y_{AV} = Y_{open-field} \times 0.71$$

$$Y_{AV} = 28{,}400 - 29{,}820 kg/ha$$

The gross revenue per hectare is calculated as:

$$Revenue = Y_{AV} \times P_{tomato}$$

$$Revenue = 28{,}400 - 29{,}820 \times 25 EGP/kg = 710{,}000 - 745{,}500 EGP/ha$$

To determine the total farming cost for one hectare under agrivoltaic tomato cultivation, the primary cost components per acre are summarized in Table 1. These components include seeds and seedlings, fertilizers and pesticides, land rent, and service/labour/irrigation.

Table 1: Costs Scaling Between Acre And Hectar

Component	Cost (EGP/acre)	Scaled Cost for 1 hectare (EGP)
Seeds and seedlings	10,000–20,000	24,710–49,420
Fertilizers/pesticides	40,000–60,000	98,840–148,260
Land rent	10,000–15,000	24,710–37,065
Service, labour, irrigation	30,000–40,000	74,130–98,840
Total farming cost	90,000–135,000	222,390–333,585

Source: Manual Calculations

Scaling the costs from acre to hectare provides the total farming expanses for agrivoltaic tomato cultivation. Subtracting the total farming cost from the gross revenue yields the net revenue per hectare under the 50% PV coverage scenario:

$$Net\ Revenue = Revenue - Total\ Farming\ Cost$$

$$Net\ Revenue\ high = 745{,}500 - 222{,}390 = 523{,}110\ EGP/ha$$

$$Net\ Revenue\ low = 710{,}000 - 333{,}585 = 376{,}415\ EGP/ha$$

These calculations provide the estimated tomato yield, gross revenue, and net revenue per hectare for the 50% agrivoltaic scenario.

Land Equivalent Ratio (LER) Calculation

The Land Equivalent Ratio (LER) compares agrivoltaic productivity with separate PV and crop land use. Values above, equal to, or below 1 indicate an advantage, no advantage, or a disadvantage, respectively. Here, LER combines relative electricity output and shaded tomato yield against their respective PV-only and open-field benchmarks. It was calculated as:

$$LER = \frac{Y_{AV}}{Y_{crop}} + \frac{E_{AV}}{E_{PV}}$$

Using the results from the previous sections:

- Tomato yield under agrivoltaic shading: Y_{AV} = 28,400–29,820 kg/ha
- Open-field tomato yield: Y_{crop}= 40,000–42,000 kg/ha
- AC electricity under 50% PV coverage: E_{AV} = 2,226,467 kWh
- AC electricity under 70% PV-only: E_{PV} = 3,133,856 kWh

The crop component of LER is:

$$\frac{Y_{AV}}{Y_{crop}} = 0.68 - 0.71$$

The energy component of LER is:

$$\frac{E_{AV}}{E_{PV}} = \frac{2{,}226{,}467}{3{,}133{,}856} \approx 0.71$$

The LER for the 50% agrivoltaic scenario is:

$$LER\ high = 0.71 + 0.71 = 1.42$$

$$LER\ low = 0.68 + 0.71 = 1.39$$

LER greater than 1 indicates that the agrivoltaic scenario exceeds the sum of independent crop and PV production on the same land area. This indicates that integrating tomato cultivation with PV electricity generation can enhance overall land productivity, making the agrivoltaic approach more efficient in terms of land utilization.

The LER of 1.39–1.42 shows that the 50% agrivoltaic system outperformed separate PV and tomato production. Electricity contributed 0.71, while shaded tomato production contributed 0.68–0.71 and generated 376,415–523,110 EGP/ha, demonstrating strong land-use and economic potential in Aswan.

Revenue Analysis

70% PV-Only Scenario

The 70% PV-only system generates electricity exclusively, with an annual net AC energy output of 3,133,856 kWh. Assuming a PPA price of 0.04 USD/kWh and an exchange rate of 1 USD ≈ 53.3 EGP, the corresponding electricity revenue is:

$$RevenuePV\ 70\% \ = EPV \times PPA \times 53.3$$

$$RevenuePV = 3{,}133{,}856 \times 0.04 \times 53.3 \approx 6{,}682{,}400 EGP/year$$

50% Agrivoltaic Scenario

The 50% PV coverage system produces 2,226,467 kWh_{ac} of electricity annually, yielding PV revenue of:

$$RevenuePV\ 50\% = EPV \times PPA \times 53.3$$

$$RevenuePV\ 50\% = 2{,}226{,}467 \times 0.04 \times 53.3 \approx 4{,}743{,}700\ EGP/year$$

Tomato cultivation under this scenario yields an estimated 28.4–29.8 t/ha after a 29% shading-related reduction, the net agricultural revenue is 376,415–523,110 EGP/ha.

The total revenue, combining PV electricity and net tomato revenue, is therefore:

$$Revenuetotal\ high = 4{,}743{,}700 + 523{,}110 = 5{,}266{,}810\ EGP/year/ha$$

$$Revenuetotal\ low = 4{,}743{,}700 + 376{,}415 = 5{,}120{,}115\ EGP/year/ha$$

Although the 50% agrivoltaic system earns less from electricity than the 70% PV-only system, agricultural revenue increases total cash inflow and diversifies income.

Conclusion

The PV-only system was compared to a 50% tomato-based agrivoltaic system in this study on a 1-ha site in Aswan. The capacity factor of the PV-only system was 22.4%, and the performance ratio was 0.77, while the agrivoltaic system had a capacity factor of 22.3% and an estimated tomato yield of 28.4–29.8 t/ha, demonstrating the compromise between electricity generation and agricultural production. The PV-only system generated annual PV revenue of ~6,682,400 EGP and the agrivoltaic system generated annual PV revenue of ~4,743,700 EGP. In addition to an increase in total agrivoltaic income and diversification, tomato production yielded a total agrivoltaic revenue of 5,120,115-5,266,810 EGP/ha, which was still lower than the PV-only case. The PV-only system and the agrivoltaic system had positive NPVs of USD 129,800 and USD 91,800 respectively, and an IRR of 11.8% and LCOE of 3.8 cents/kWh for both systems. The LER of 1.39–1.42 indicates a 39–42% land-use advantage over separate PV and tomato production. Although reduced PV coverage lowered electricity output, tomato cultivation partly offset this loss, demonstrating that the agrivoltaic system primarily improves combined food–energy productivity rather than maximizing either output independently.

The study offers a site-specific approach to integrate PV simulation based on the SAM, tomato yield estimates derived from literature, LER analysis and 25-year financial evaluation, while maintaining consistent land and climatic assumptions. The results show that agrivoltaics with tomatoes are technically possible, economically viable, and land efficient for use in Aswan and can be applied to other hot-arid regions. Field trials are necessary, however, to confirm the tomato yield, water use, microclimatic effects and construction and operating costs before large-scale implementation because the performance of agriculture was estimated using published yield reduction factors instead of local measurements.

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