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Agrivoltaic: A Strategic Assessment Using SWOT and TOWS Matrix

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Abstract: New strategies and market segments considering integrated approaches have emerged as critical components in the energy transition. Agrivoltaics is one approach that has shown a lot of promise for offering advantages in the food-energy-water nexus. The agrivoltaic system involves the installation of photovoltaic panels above agricultural lands to generate electricity while also allowing for crop production. The paper "SWOT and TOWS Matrix Analysis of Agrivoltaic System" comprehensively analyses the potential strengths, weaknesses, opportunities, and threats (SWOT) associated with implementing an agrivoltaic system. This study utilizes a SWOT analysis framework to identify and evaluate the internal and external factors that could impact the implementation and success of the agrivoltaic system. A TOWS matrix analysis is also conducted to formulate strategic recommendations based on the identified SWOT factors. The analysis results reveal that the agrivoltaic system has numerous strengths, including its potential to generate renewable energy, increase crop yield, and provide economic benefits to farmers. However, the system also faces several weaknesses and threats, such as high initial investment costs, land use conflicts, and potential environmental impacts. Based on the TOWS matrix analysis, this study provides strategic recommendations to maximize the potential of the agrivoltaic system while mitigating its weaknesses and threats. These recommendations include adopting a flexible pricing strategy, researching the system's environmental impact, promoting collaboration between various stakeholders like government agencies, farmers, and energy service companies. Overall, this study provides valuable insights into the potential of agrivoltaic systems and the factors that should be considered when implementing such a system. The findings can help stakeholders make informed decisions and take appropriate actions to ensure the integration of agrivoltaic systems into agricultural practices.

Keywords: agrivoltaics; SWOT analysis; TOWS matrix; SDG7; precision agriculture

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1. Introduction

Fossil fuel has contributed majorly to the energy supply chain. Over the past two decades, climate change threats have pushed humankind to use non-conventional sources. Although the world's energy transition will take place, more effort is needed to reduce carbon emissions and the impact of climate change. The United Nation's Sustainable Development Goals (UN SDG 7) advocates on using clean energy sources that lead to the development of agriculture, business, communication, healthcare, and transportation [1]. Solar panels, wind turbines, and fuel cells generate clean and affordable energy to help the worlp achieve sustainable targets. Due to low cost, modularity, lifespan, and efficiency, Solar photovolatic systems play a pivotal role in the transition to decarbonization [2]. Solar farms use extensive land coverage with optimum designs for solar panels.

1.1. Background

Decarbonizing the energy sector demands urgent global action. Energy efficiency and renewable energy initiatives have the potential to achieve 94 percent of the required carbon reductions [3]. The widely recognized renewable energy in abundance is solar energy. Every year, almost 4,000,000 exajoules (1 EJ = 1018 J) of solar energy reach the planet, approximately 5×10^4 EJ of which is believed to be easily harvestable [4,5]. The utilization of solar power has gained prominence as a major worldwide solution in addressing the issues related to environmental, social, and economic considerations in recent times. As an illustration, 696,544 tonnes of CO_2 emissions from the installation of 113,533 residential appliances have decreased or prevented Californian solar power systems [6]. Urban areas are expanding rapidly; agricultural land has been taken up to build industry and shopping complexes. Due to the lack of agricultural land, deforestation has occurred, leading to the loss of green cover. Agrivoltaics (AV) systems, which merge agricultural production with photovoltaic (PV) electricity to optimize solar energy collection, offer advantages that align with the SDGs [7]. Rooftop agrivoltaics is a solution to address these challenges as it would generate green electricity, high-yield crops, and jobs [8].

1.2. Literature Review and State of Art

Solar energy is an excellent solution for sustainable agriculture since conventional fossil fuels release CO_2, which can be reduced using solar energy on agricultural land [9]. To meet the energy demand of livestock farms, poly-generation systems that optimize the net present value, primary energy consumption, and CO_2 emission have been proposed [10].

Researchers have attempted different applications of energy-efficient technologies based on investment, annual energy production, and savings [11], but they have also elaborated on the various challenges in the energy-efficient system [12]. This system is supported by a concentrated photovoltaic system with spectral splitting for agrivoltaic applications [12].

Agriculture is the primary source of delivering food, and it can contribute to the world's sustainable development goals by utilizing renewable energy sources, inclusive food systems, reducing poverty, and providing clean water [13,14].

To promote environmental sustainability, improve production, and avoid crop yield loss, the novel concept of agrivoltaic systems has been proposed, which reduces the use of traction and transport and thus reduces the negative impact on soil [14]. Yield loss can be mapped by unmanned aircraft systems [15].

To achieve precision agriculture, different techniques such as satellite images, UAV images, and sensor data have been used to determine favorable agricultural fields [16].

A researcher found that installing an agrivoltaic system was positive and reduced the impact on climate change, eutrophication, and fossil resource use, and it could contribute to renewable energy goals. However, crop yield was increased by providing good microclimatic conditions as supported by agrivoltaics [17].

To enhance the performance of agrivoltaic systems, hybrid PVT systems, concentrator PVT systems, MPPT trackers, cooling, and monitoring systems can be applied [18–22].

Overall, solar energy can help farmers reduce their reliance on fossil fuels and carbon footprints and provide a reliable energy source in remote areas where grid electricity is unavailable.

1.3. Novelty, Importance, Scientific Relevance, and Research Gap

To the authors' best knowledge, there is a research gap in agrivoltaics related to the SWOT analysis of the systems. Additionally, the authors have found minimal research focused on identifying the primary weaknesses and threats of utilizing integrated photovoltaic systems with an agricultural approach. Besides the aim of developing a

TWOS matrix for agrivoltaic systems, this study also aims to answer the following main research questions:

- What are the basic configurations and characteristics of the Agri-PV system?
- What are the strengths, weaknesses, threats, and opportunities of an Agri-PV system as an innovative approach?

1.4. Research Objective

- To identify the strengths, potential opportunities, weaknesses, and threats of agrivoltaic systems to generate renewable electricity and increase crop yield.
- To formulate strategic recommendations based on the SWOT and TOWS analysis to maximize the potential of agrivoltaic systems while mitigating their weaknesses and threats.

1.5. Structure of the Paper

This article addresses the basic concepts behind agrivoltaics and provides insight into present Agri-PV systems worldwide in Section 2. Section 3 discusses the SWOT analysis methodology (strengths, weaknesses, opportunities, and threats) and the TOWS matrix. Section 4 discusses the outcomes of the SWOT analysis and TOWS matrix applied to the Agri-PV system. Finally, recommendations, conclusions, and future scope are stated in Sections 5 and 6.

2. Concept of Agrivoltaics

2.1. What Are Agrivoltaic Systems and Their Components?

Agri Solar Power is a novel approach to addressing the energy-water-food nexus [23]. It is a new conceptual design that optimizes solar energy, reduces the need for irrigation, and protects crops from extreme conditions (Figure 1). The Agri-PV plant comprises a solar PV panel, mounting structure, civil foundation, control/monitoring system, and plants [24].

Agrivoltaics, or agro-photovoltaics, integrates solar panels with agricultural activities. The elements of an agrivoltaic system typically include:

Solar panels: They are used to convert sunlight into electricity. A solar panel uses sunlight to generate direct currents. These panels can be installed on the ground, on rooftops, or in unique structures designed for agrivoltaics [25].

Inverters: Direct current (DC) electricity generated by the solar panels is transformed into alternating current (AC) electricity via inverters, then used to power residences and commercial buildings [26].

Energy storage: Energy storage systems, such as batteries, store excess electricity generated by solar panels for use during periods of low sunlight or high energy demand [27].

Control systems: Control systems are used to manage the operation of the solar panels and the energy storage system and verify that the system runs at peak efficiency [28].

Civil foundation: This is used to transfer the load to the soil. Based on the soil type and capacity of the plant, the foundation could be a ballasted pile system [29].

Supporting structures: Supporting structures, such as mounts, frames, and racks, are used to hold the solar panels in place and to ensure they are correctly oriented towards the sun [27]. These structures help in the erection of solar panels at a designed inclination.

Shade structures: Shade structures can be implemented to reduce the impact of sunlight on crops, improving the growth and yield of plants [30].

Crop management: Crop management is a crucial component of agrivoltaics, as it involves the integration of solar panels with agricultural activities, optimizing the use of space, water, and other resources [31].

Monitoring Systems: Monitoring systems are used to measure and record the performance of the agrivoltaic system, including data on energy generation, crop growth, and water consumption [32].

Overall, agrivoltaic systems are composed of a combination of solar energy technology and crop management to produce both electricity and food efficiently and sustainably.

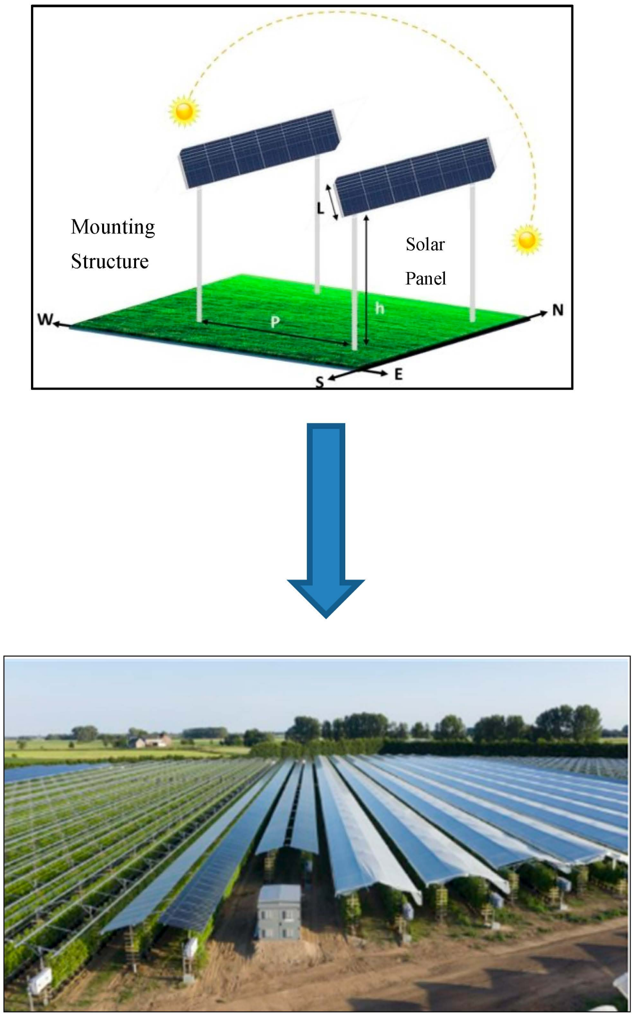


Figure 1. Basic components of agrivoltaic system.

2.2. Characteristics of Agrivoltaics

- **Adequate sunlight**: The land should receive sufficient sunlight to allow for the growth of both crops and solar panels [33]. The amount of sun required by the crops will depend on the crop type, while the solar panels will need direct sunlight to generate electricity [34].
- **Good soil quality**: The land should have fertile soil supporting plant growth. The earth should also have good water-holding capacity and drainage to avoid waterlogging.
- **Flat or gently sloping terrain**: The land should have a flat or gently sloping topography to facilitate the installation of solar panels and to ensure that the crops receive adequate sunlight [35].
- **Access to water**: The land should have water for irrigation and to maintain soil moisture levels.
- **Low wind risk**: The land should be sheltered from high winds to avoid damage to the solar panels and crops.
- **Suitable climate:** The land should have the right environment for growing crops. The temperature, rainfall, and humidity levels should be appropriate for the crops, and the land should not be prone to extreme weather events such as flooding, hailstorms, or cyclones [36].

- **Adequate space:** The land should have sufficient space to accommodate both the solar panels and the crops, with adequate spacing between the panels and crops to minimize shading and competition for resources [37].
- **Land suitable for agrivoltaics** should have specific characteristics to ensure the successful coexistence of crops and solar panels. Overall, the suitability of the land for agrivoltaics will depend on several factors, including the specific crop types, solar panel configurations, and local climatic and environmental conditions. Careful planning and design are required to ensure the optimal coexistence of crops and solar panels [38].

2.3. Examples of Agrivoltaics (Worldwide): A Few Examples of Agrivoltaics Projects from Around the World

Germany: The world's most extensive agrivoltaics system was built in the German state of Brandenburg, covering an area of around 13 hectares. The project combines a solar power plant with a crop field, producing electricity and food [39].

France: In Villers-sous-Châtillon, a project was implemented to install solar panels over a strawberry farm. The project generates electricity and provides shading for the strawberry plants, improving their growth and yield.

Japan: In Kuzu, a project was implemented to install solar panels over rice paddies. The project generates electricity and helps reduce the water needed for rice cultivation [40].

United States: The Agrivoltaics Consortium at the University of California, Davis, is researching the co-location of solar panels and crops. They are also developing new technologies to make agrivoltaics more efficient and cost-effective.

India: In Gujarat, a project was implemented to install solar panels over a salt farm. The project not only generates electricity but also helps to reduce the evaporation of saltwater, increasing the yield of salt. One example of an agrivoltaic project in India is the "Solar Power for Agriculture Irrigation" project, which the state government of Maharashtra launched in 2018. This project aims to increase the use of solar energy for irrigation in the state's agriculture sector. It includes the installation of solar panels on farmland to generate electricity while providing shade for crops. The project is being implemented in partnership with state nodal agencies [41] and has received funding from the World Bank. The project is expected to benefit around 10,000 farmers and reduce the state's carbon emissions by approximately 38,000 tons annually.

Australia: The University of New South Wales has a project where they are experimenting with installing PV panels over vineyards to generate electricity and reduce the impact of sunlight on the grapes, potentially increasing the quality of the grapes.

Malaysia: Multiple research and pilot projects are being conducted by universities and research centers in Malaysia related to agrivoltaics to explore the potential of agrivoltaics in the country, such as integrating solar panels with oil palm plantations, paddy fields, and rubber tree plantations. The research focuses on optimizing the co-location of solar panels to generate electricity, reduce water consumption, and improve energy and crop yield.

3. Methodology

3.1. SWOT Analysis

SWOT analysis is a valuable tool for determining a project's strengths and weaknesses, the opportunities available, and the threats it faces. SWOT analysis is an essential analytical tool in agrivoltaics because it provides a comprehensive understanding of this technology's strengths, weaknesses, opportunities, and threats.

Conducting a SWOT analysis involves evaluating the internal and external factors that can impact the success of a project. A SWOT analysis evaluates a project's or business venture's strengths, weaknesses, opportunities, and threats (SWOT). Strengths (S) and weaknesses (W) are seen as internal elements that are subject to some degree of control [42,43]. Threats (T) and opportunities (O) are viewed as external forces over which little control exists [44]. A step-by-step procedure to conduct a SWOT analysis is described below (Figure 2):

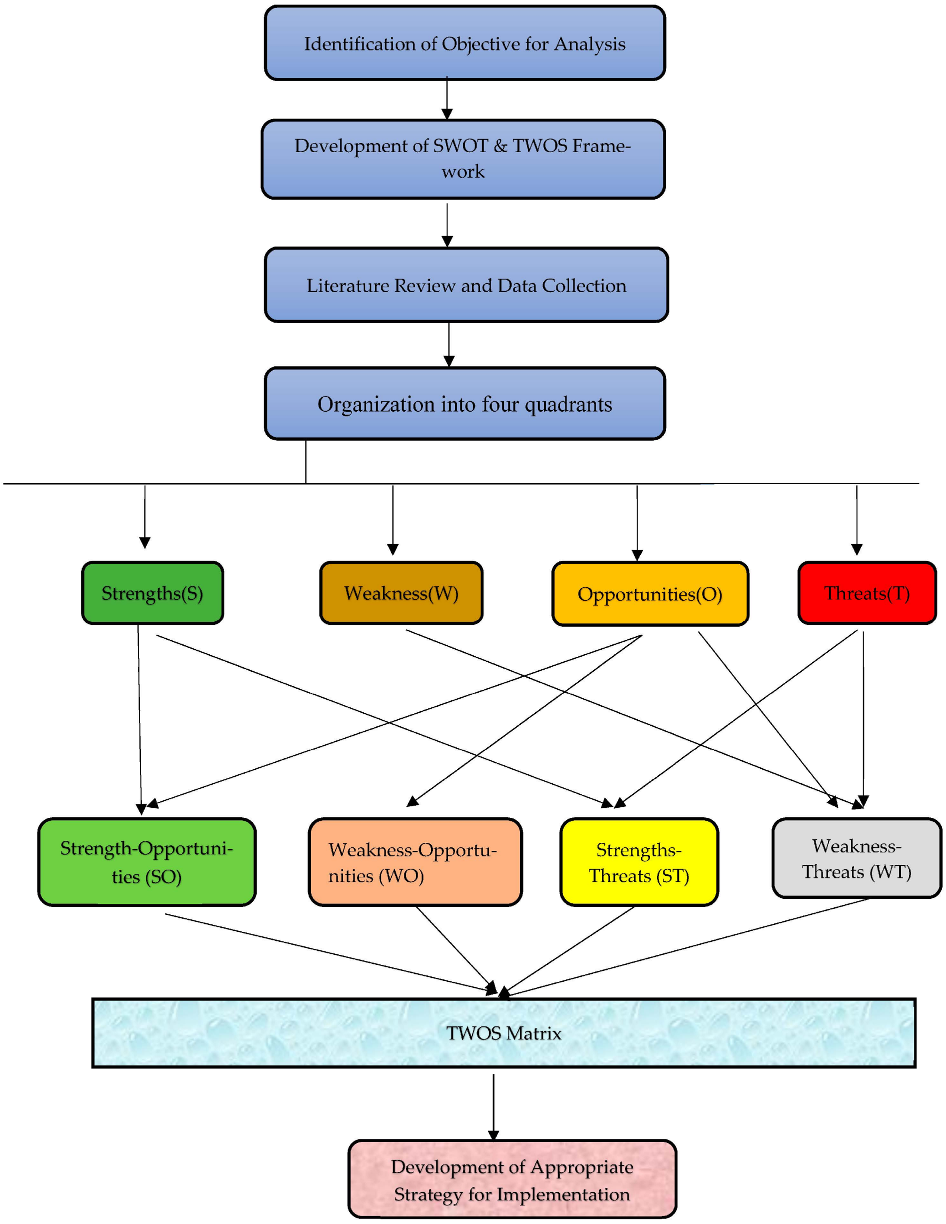


Figure 2. SWOT analysis framework of agrivoltaic system.

Identify the objective or goal of the analysis: This could be a specific project or the overall strategic direction of a business or organization. It is essential to be clear about the goal of the analysis, as this will help guide the data collection and interpretation process.
Gather data and information: Collect data on the internal and external factors that could impact the objective. This could include information on the organization's strengths, weaknesses, opportunities, and threats in the external environment. This information can be collected through research, surveys, interviews, and other data-gathering methods.
Organize the information into four quadrants: Once you have collected the data and information, organize it into four quadrants: strengths, weaknesses, opportunities, and threats.
Evaluate the information in each quadrant: Look at each of the four quadrants and evaluate the information you have collected. Identify which factors are most important to the objective's success and which are less critical.

Develop a strategy: Create a plan that builds on strengths, resolves weaknesses, seizes opportunities, and mitigates threats using the information from the SWOT analysis. It is essential to be realistic and consider the resources available and budget and time constraints.
Implement the strategy: Once the system has been developed, implement it and monitor progress to ensure it achieves the desired results.
Review and update: SWOT analysis should be continuous, so reviewing and updating the analysis as the environment changes periodically is essential.

3.2. TOWS Matrix

TOWS analysis is an extension of the SWOT analysis paradigm that identifies the strengths, weaknesses, opportunities, and threats. Still, it examines matches between the strengths and opportunities and the threats and weaknesses. The TOWS matrix is a tool used to evaluate the sustainability of various components of agricultural systems. The matrix can identify areas where improvements can be made to make the system more sustainable.

The primary purpose of a TOWS analysis is to:

- Reduce threats.
- Take advantage of opportunities.
- Exploit strengths.
- Remove flaws.

The TOWS matrix devised in Table 1 involves four types of strategies:

1. SO strategies—use internal strengths to capitalize on external opportunities.
2. WO strategies—aim to address internal deficiencies by capitalizing on external opportunities.
3. ST strategies—use strengths to avoid or mitigate the effects of external threats.
4. WT strategies—defensive methods to mitigate internal flaws and prevent external dangers.

Table 1. TOWS matrix.

TOWS Matrix	**External Opportunities (O)**	**External Threats (T)**
Internal Strength (S)	Strength Opportunities (SO)	Strength Threat (ST)
Internal Weaknesses (W)	Weakness Opportunities (WO)	Weakness Threats (WT)

4. Results and Discussions

4.1. SWOT Analysis Results

The SWOT analysis is the basis for assessing future opportunities and dangers from the external environment, internal potential, and shifting trends. It considers all internal and external and positive and negative project-related elements influencing success. Here is a SWOT analysis of agrivoltaics which integrates solar panels with agriculture. The summary of the SWOT analysis is presented in Figure 3.

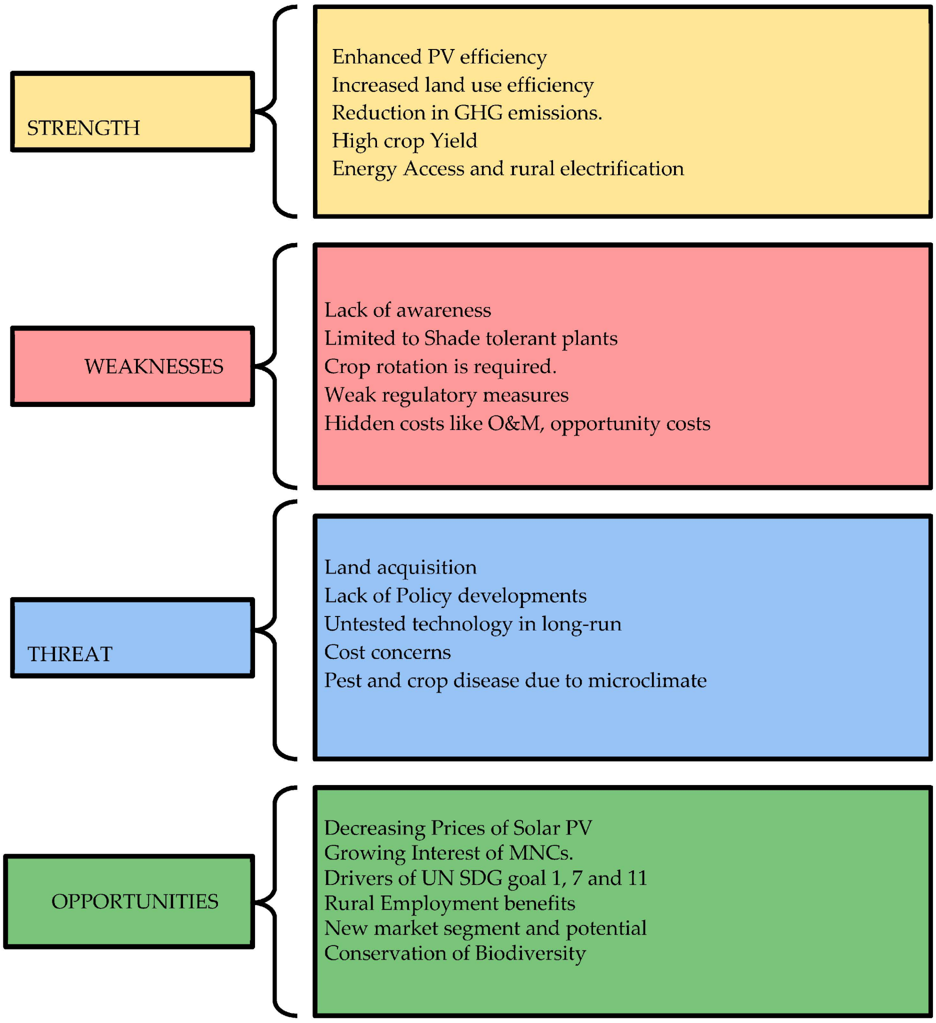


Figure 3. Summary of SWOT analysis.

4.2. Strength (Internal, Positive Factors)

(a) **Utilization of barren land farming to isolate the crops:** Agrivoltaic comprises the use of land and solar panels for crop production and electricity. A barren land could be a desert, wetland, etc., with insufficient plant growth nutrients. The concept of film farming is a Japanese technology that enables the growing of crops practically anywhere, including on contaminated soil, concrete, swamps, and arid terrain. Waterproof sheets are used in the film from the earth below [45].

(b) **Contribute to local agro-economics:** The installation and maintenance of agrivoltaic systems require specialized knowledge and skills, which can lead to job creation in the local economy [46]. This can provide employment opportunities for residents and contribute to the growth of the local economy.

(c) **Employment generation:** Activities such as periodic maintenance, vegetation control, monitoring, panel clearing, and corrective maintenance would employ many people [47].

(d) **Reduction in carbon emissions:** Plants keep the air fresh. Planting crops or flowering plants under the photovoltaic panel would increase oxygen in the air and reduce the carbon footprint. It is estimated that LC-CO_2 would decrease by 12% using organic photovoltaic allocation [48].

(e) **Circular economy:** The waste generated in eateries or outlets can be used as manure for crops. This will help eliminate waste and the continual use of resources, ensure savings in waste transportation and collection, and support the maintenance of a sustainable ecosystem [49].

(f) **Increasing efficiency of solar panels:** The crops under photovoltaic panels would circulate cool air to reduce the temperature to make panels work optimally. High insolation, light winds, moderate temperature, and low humidity keep the panel's microclimate suitable for growing crops and increase panel efficiency [50].
(g) **High crop yield per unit area:** The photovoltaic panel provides shade to the plants and reduces the temperature to be suitable for plant growth [51].
(h) **Protection of plants from high temperatures and extreme weather conditions:** The microclimate found under the solar panel can benefit crops since the PV shields them from excessive solar radiation and bad weather such as hail or strong winds. It also enhances the performance of the PV because the crops below create lower operating temperatures [52–56].
(i) **Solar potential resource:** Malaysia has abundant solar energy potential. Due to its location and climate, it has found application in solar thermal and solar PV. The sustainable energy development authority (SEDA) has proposed a potential of 6500 MW [57].
(j) **Energy access:** Off-grid agrivoltaic projects, also known as rural electrification projects, have been essential in increasing energy access in rural parts of Malaysia. These projects typically involve installing small-scale renewable energy systems, such as solar panels or wind turbines, to generate electricity for remote or underserved communities. This can be particularly useful in rural areas, where traditional grid-connected electricity may be unavailable or unreliable. In addition to electricity generation, it can contribute to food production and meet the daily needs of rural communities.

4.3. Opportunities (External, Positive Factors)

(a) **Shade-intolerant plants**: Plants that require more intense sunlight for their growth are prohibited in this spatial arrangement. Mostly leafy greens such as spinach, chard, and kale are some examples [58,59].
(b) **Land resource efficiency**: One of the critical benefits of agrivoltaics is that it allows for the efficient use of limited land resources. By incorporating solar panels into agricultural landscapes, agrivoltaics can help maximize land utilization, as the same land is used for food production and energy generation. This is particularly relevant in regions with limited available land for agriculture and renewable energy development.
(c) **Human resource**: Local government targets promoting solar PV by giving capacity-building training and workshops [59,60].
(d) **Support structure**: The racking structure is elevated to allow agricultural machinery to pass and grow fruit and vegetables [61,62].
(e) **The emergence of new markets and investments**: The emergence of agrivoltaic systems has created new markets and investment opportunities in several countries, including India, China, Japan, Italy, and Spain.
(f) **Biodiversity**: The role of AV-habitat systems that combine native habitat improvement to protect biodiversity and restore associated ecosystem services has recently received attention [63–67]. Most of the attention within the Agrivolatic infrastructure has been focused on the production and management of pollinator-friendly seed varieties. These seed mixes typically consist of locally native grasses, forbs, and wildflowers that serve as a source of food for natural insect pollinators, while also providing refugia and nesting habitats to help maintain biodiversity [67].
(g) **Agrivoltaic system driver of SDGs**: AV systems' potential environmental service advantages can be converted into various alignments with the UN's Sustainable Development Goals (SDGs). The ability of AV systems to (a) offer food and energy security to impoverished or developing populations, (b) efficiently utilize water and other resources, (c) reduce climate change, and (d) enhance biodiversity are the qualities of these systems that enable them to accomplish these goals. SDG 7 stands for Sustainable Development Goal 7 [68], one of the 17 global goals adopted by the United Nations in 2015 to achieve a sustainable future for all. The goal of SDG 7 is to ensure access to affordable, reliable, sustainable, and modern energy for all. Concerning

SDG 7 [69], agrivoltaic systems can contribute to achieving this goal by providing access to sustainable energy for rural communities. Farmers can generate electricity and reduce their reliance on fossil fuels by integrating solar panels into agricultural landscapes. This can improve energy security, reduce energy costs, and increase economic opportunities for rural communities. Moreover, agrivoltaics systems have the potential to enhance the productivity and sustainability of agriculture. By providing shade to crops, reducing water loss from evaporation, and improving soil health, agrivoltaic systems can help farmers to produce more food using less land, water, and other resources. This can contribute to achieving SDG 2 (Zero Hunger) and SDG 12 (Sustainable Consumption and Production). Specific goals can be addressed by any of the three AV kinds, while one or two AV types can only address others. SDG 1 (No Poverty), SDG 3 (Good Health and Wellbeing), and SDG 7 (Affordable and Clean Energy) are among the 11 SDGs that any of the three AV types may achieve.

4.4. Weakness (Internal, Negative Factor)

(a) **Cost:** Dual-purpose solar panels are suspended many feet above the ground, allowing crops to flourish and cattle to graze beneath. However, the main downside of agrivoltaics systems is the high cost of installation and infrastructure. Agrivoltaic systems have higher installation and maintenance costs than conventional PV systems but may generate additional income from crop sales. The installation cost of an agrivoltaic system will be higher because of the additional requirements of plant cultivation, irrigation, pumping, harvesting, and regular maintenance, which increase the operating costs. The ROI depends on the local energy prices, government incentives, tax credits, specific conditions, and requirements of each project.

(b) **Lack of awareness of agrivoltaics**: The agrivoltaic system is very new for farmers. Proof of concept is needed to show the potential of agrivoltaic plants.

(c) **Shade-intolerant plants**: Plants that require more intense sunlight for their growth are prohibited in this spatial arrangement. Mostly leafy greens such as spinach, chard, and kale are sensitive to irradiance [70,71].

(d) **Weak regulatory and policy instruments**: The lack of appropriate legislation and support and prohibitive amounts of initial financial commitment were the fundamental causes of the sluggish start. This initial phase led to a modest market penetration [72].

(e) **Land use conflicts:** Agrivoltaic systems may require significant land for agriculture and solar energy production. This could lead to conflicts with other land uses, such as urban development or natural habitats [73].

(f) **Reduced solar energy output:** When solar panels are installed over crops, they may receive less direct sunlight [74], which can reduce the per unit electricity generated by the solar panels. Additionally, shading from crops may cause variations in the panel temperature, which can decrease the efficiency of the solar cells [75].

4.5. Threat (External, Negative Factors)

(a) **Extreme weather events:** Agrivoltaic systems may be vulnerable to extreme weather events such as hail, heavy rain, high winds, and snow [76]. These events can cause damage to solar panels and/or crops, leading to lower energy production and crop yield.

(b) **Pest and disease infestations:** Introducing solar panels into an agricultural system may create new microclimates that could attract pests and diseases that can harm crops. This could increase the need for chemical pesticides, which can have negative environmental and health impacts [77].

(c) **Land use conflicts:** As mentioned earlier, agrivoltaic systems require significant land for agriculture and solar energy production. This could lead to conflicts with other land uses, such as urban development, natural habitats, or other agricultural activities [78].

(d) **Maintenance and repair costs:** Agrivoltaic systems require ongoing maintenance and repair to ensure the solar panels and crops function correctly. This can be expensive and time-consuming [79].
(e) **Economic viability:** The economic viability of agrivoltaic systems may be limited by the cost of installation, maintenance, and repair, as well as the fluctuating price of electricity and crops. Additionally, the regulatory and policy framework may not always support the development of agrivoltaics [80].

4.6. TOWS Matrix Results

TOWS Matrix Analysis

Based on the SWOT analysis, the TOWS matrix analysis in Table 2 can provide strategic recommendations to maximize the potential of the agrivoltaic system while mitigating its weaknesses and threats. The following are the strategic recommendations for each quadrant of the TOWS matrix:

Strengths-Opportunities:

Table 2. Summary of TOWS matrix.

TOWS Matrix	Internal Strength (S)	Internal Weakness (W)
External opportunities (O)	**Strategy SO** GHG Emission Employment Risk-free farming Less water-footprint	**Strategy WO** Bureaucracy Upfront costs Aesthetics
External threats (T)	**Strategy ST** Lack of awareness Crop rotation is required Operation and maintenance	**Strategy WT** Land acquisition New policies Financial constraint

Adopt a flexible pricing strategy to attract potential customers and create new business opportunities.

Promote research and development of innovative technologies to increase energy efficiency and reduce costs.

Provide incentives to farmers and energy companies to encourage the adoption of Agrivoltaic s systems.

Strengths-Threats:

Conduct extensive research on the environmental impact of the agrivoltaic system to identify potential risks and develop mitigation strategies.

Promote collaboration between government agencies, farmers, and energy companies to overcome regulatory challenges and promote the development of agrivoltaic systems.

Explore opportunities to expand the use of agrivoltaic systems in other sectors, such as urban agriculture and horticulture.

Weaknesses-Opportunities:

Conduct cost–benefit analyses to identify the economic viability of the agrivoltaic system and explore alternative financing options.

Develop land use plans to minimize conflicts and optimize agricultural land use for crop production and energy generation.

Promote public awareness and education on the benefits and challenges of agrivoltaic systems.

Weaknesses-Threats:

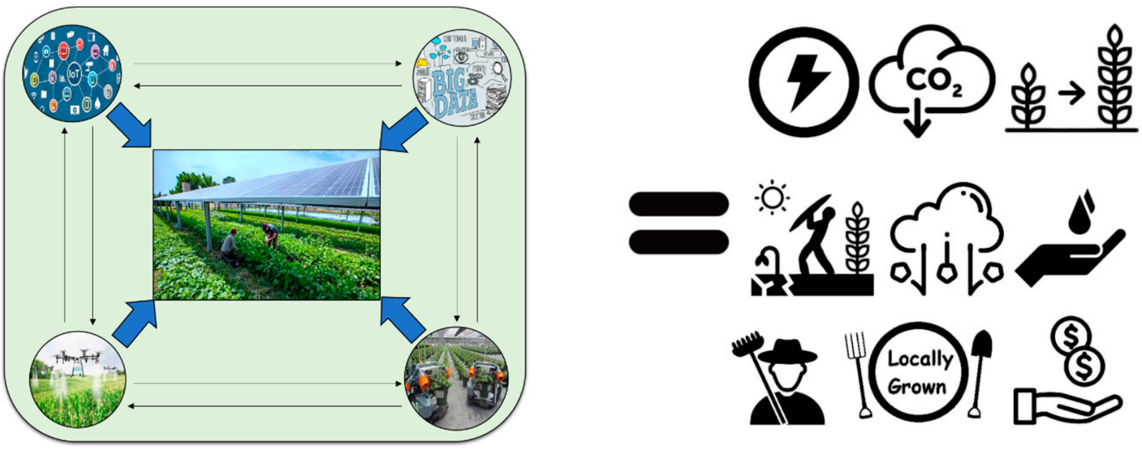
Develop maintenance and repair plans to minimize costs and increase the system's economic viability.

Conduct extensive research on the agrivoltaic system's potential risks and negative impacts to identify ways to mitigate these impacts.

Explore opportunities to integrate the agrivoltaic system with other renewable energy technologies.

5. Discussion, Recommendation, and Future Perspectives

Agrivoltaics is a term that refers to the use of advanced technologies, such as precision agriculture, big data analytics, and automation, to improve the efficiency and sustainability of agricultural systems (Figure 4).



(**A**) IOT,data analytics,Smart machines and surveillance (**B**) Benefits

Figure 4. Smart agrivolatics concept.

The key advanced elements of agrivoltaic systems can include the following features such as the use of hybrid PVT systems, concentrator PVT systems, MPPT trackers, cooling, cleaning, energy storage, and remote monitoring system. Integrating intelligent technologies, such as unmanned aircraft systems (UAS), sensors, and data analytics tools, into agrivoltaic systems can enhance their design by optimizing crop yields, improving energy yield and resource allocation (water/fertilizer), and boosting performance.

5.1. Benefits of Implementing Smart Agrivolatics System

The implementation of agrivolatic systems can lead to several benefits, including:

Land use efficiency: Agri-PV systems can be installed on land unsuitable for agriculture, such as land with poor soil quality or steep slopes. This allows for the efficient use of land that would otherwise not be productive, leading to increased crop yields and reduced costs due to the more efficient use of resources.

Multiple revenue streams: Agri-PV systems generate revenue from both the sale of electricity and agricultural products. They have improved food safety and traceability due to the ability to track and monitor crop growth and harvest conditions.

Environmental benefits: Agri-PV systems provide shade for crops, which can improve crop yields and reduce water usage. The PV panels can also help reduce the urban heat island effect and enhance air quality.

Community engagement: Agri-PV systems can be integrated into local communities and provide education, research, and training opportunities. This can lead to reduced environmental impact through more precise use of inputs such as water and fertilizer.

Overall, Agri-PV systems offer a more sustainable and efficient way of generating renewable energy while providing additional benefits such as food production and environmental and social benefits. Overall, agrivolatic systems have the potential to significantly improve the efficiency and sustainability of agricultural systems [36].

5.2. Challenges of Smart Agrivolatics System

However, agrivoltaic systems also have certain limitations and challenges, such as:

1. High initial investment costs for the technology [81].
2. Potential lack of technical expertise among farmers to effectively use the technology.
3. Dependence on data connectivity and availability may not be consistent in some rural areas.
4. Possible negative impact on the rural labor force.

It is important to note that SWOT analysis should involve a team effort where different perspectives and experiences can be shared. This will ensure that the analysis is comprehensive and robust. Overall, a SWOT analysis is a powerful tool for identifying key factors that can impact the success of a project or organization and for developing a strategy to leverage strengths, address weaknesses, take advantage of opportunities, and mitigate threats.

However, carefully considering the costs, benefits, and potential challenges is necessary to ensure successful implementation. In the context of the agrivoltaic system, it could be used to evaluate the impact of the technology on the farm's technical efficiency, economic viability, social acceptance, and environmental sustainability. The combined TOWS matrix and SWOT analysis provide valuable insights and relevant information on making informed decisions about the strategic direction of the agrivolatic system. Using these tools, researchers, policymakers, and farmers can make informed decisions about adopting and implementing agrivoltaic systems.

6. Conclusions

In this paper, we conducted a SWOT and TOWS matrix analysis to evaluate the potential of the agrivoltaic system. Our research identified several system strengths, weaknesses, opportunities, and threats, and we provided strategic recommendations to maximize its potential.

Our analysis identified that the agrivoltaic system has several strengths, including its potential to increase land use efficiency, provide clean and renewable energy, and reduce carbon emissions. However, the system has several weaknesses, including its high initial capital cost, land use conflicts, and potential reduction in crop yields.

Adopting agrivoltaics may face challenges in areas with limited availability of suitable land, inadequate technical capacity, harsh climatic conditions, and unfavorable policies. Therefore, it is essential to develop context-specific strategies for promoting the adoption of agrivoltaics and to address the specific barriers and challenges faced in different regions.

Despite these weaknesses, our analysis identified several opportunities for the agrivoltaic system, including government incentives and subsidies and increased demand for renewable energy. We also identified several threats to the system, including competition from other renewable energy sources, climate change, and potential land conflict among the local communities.

To maximize the potential of the agrivoltaic system, we provided several strategic recommendations, including increasing public awareness and support, developing innovative financing mechanisms, and conducting further research to address the potential negative impacts of the system. Overall, our analysis demonstrates that the agrivoltaic system has the potential to provide a sustainable solution for both energy and food production. However, to fully realize this potential, policymakers, farmers, and energy companies must work together to address the challenges and opportunities presented by the system. Yet, the future appears bright for agrivoltaics, which are both technically and commercially practical. This study suggests that agrivoltaics has excellent potential to enhance agriculture's sustainability and productivity while contributing to the development of renewable energy.

6.1. Limitations of the Study

SWOT analysis and TOWS matrix focus primarily on a system's internal factors (strengths and weaknesses) and external factors (opportunities and threats). They do not consider other important factors, such as historical trends or cultural and political considerations. The analysis is highly subjective and may vary according to the authors' perspective. It does not quantify the impact or compare different options. It can only provide an overview of the current technology status and not a clear action plan for addressing the identified issues. Additionally, the recommendations provided in this analysis are based on the current state of knowledge and may require further validation through empirical research. The inter-relationships between various factors and the complexity of particular situations are ignored. This analysis has several limitations, including the reliance on secondary data sources and potential biases in the data collected.

6.2. Practical and Policy Implications of the Study

Despite these limitations, SWOT analysis and TOWS matrices are still valuable tools for identifying key factors that can affect the success of the agrivolatic system. We hope the strategic recommendations in this analysis can guide and inform the development and implementation of agrivoltaic systems. To enable the diffusion of this technology, policymakers should consider conducting feasibility studies, providing financial incentives, developing appropriate regulations, and promoting awareness and education programs. Based on the SWOT analysis, policymakers should consider the following steps while enabling the diffusion of 'Agrivoltaics' technology:

- Conducting technical due diligence to identify potential areas for implementation.
- Providing financial incentives and subsidies for farmers to adopt the technology.
- Developing appropriate regulations and standards for the installation and operation of agrivoltaic systems.
- Promoting awareness and education programs for farmers and other stakeholders on the benefits and best practices of agrivoltaics.

6.3. Future Scope and Directions

SWOT analysis is based on the current state of the agrivolatic system and its implementation. The SWOT analysis may change and adapt as technology and research progress. To revolutionize Agri-PV, threats detected must be adequately tracked. The future direction of this study could include conducting further research to:

- Identify the most effective strategies for promoting the adoption of agrivoltaics in different contexts.
- Assess the potential for scaling up and replicating agrivoltaic systems in different regions and countries.
- Based on SWOT indices, evaluate the economic and social benefits and costs of agrivoltaics for farmers and other stakeholders.
- Assess the long-term impacts of agrivoltaics based on crop yields, soil health, microclimatic environment, and biodiversity.
- Develop appropriate policy frameworks and standards for their installation and operation.

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