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A study on the recommended policies and regulations pertaining to Agrivoltaics in Thailand

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The project "Clean, Affordable and Secure Energy for Southeast Asia" (CASE) implemented by GIZ with the funding from the Ministry of Economic Affairs and Climate Change of Germany (BMWK) to drive change in the energy sector across Southeast Asia, aiming to mitigate the climate change. This project focuses on the four most populous countries in the region: Indonesia, Vietnam, Thailand and the Philippines. The objective of the project is to propose evidence-based solutions to the challenges that decision-makers are facing and to build societal support around those solutions in the region by applying a joint fact-finding approach to narrow areas of disagreement through the involvement of expert analysis and dialogue. CASE furthermore aims at supporting coordination in the SEA power sector by providing technical and policy support and facilitating dialogue concerning energy issues.

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1

Introduction

1.1 Background of Agrivoltaics in Thailand

Agrivoltaics is the integration of agriculture[1] [1] practices with solar power generation by installing solar panels over or between crop (interspace panel) and livestock areas. This innovative approach could be a key component in driving Thailand towards sustainable development. As an agricultural nation [2], Thailand has significant potential of solar energy [3], making agrivoltaics an ideal solution to promote both agricultural productivity and renewable energy. Furthermore, agrivoltaics can help address many challenges the country faces, including the unpredictability of agricultural yields, limited access to necessary infrastructure and resources, land use efficiency, the need for renewable energy, and various risks associated with climate change which is explained in the following chapter.

Implementing agrivoltaics offers economic benefits to farmers by enhancing productivity, reducing electricity costs, optimizing land use, and increasing the share of solar energy use. Therefore, **this innovation deserves focused attention as a key strategy for Thailand's future**. However, the significant gap for Thailand is the need to develop knowledge and understanding for the public who are interested in agrivoltaics practices, especially farmers or those who are mainly engaged in agriculture [3] since the research team recognizes that this method not only reduces carbon dioxide emissions by transforming the use of electricity from the distribution power transmission line or fossil fuel generators to solar energy in agricultural practices, it can also lead to long-term cost savings. Solar power generation, as a renewable source, allows farmers to produce energy independently. This integration is also a key strategy for enhancing electricity accessibility and supporting farmers in their cultivation efforts. Notably, shade-tolerant plants can improve growth under these conditions, potentially reducing water usage as well [4].

[1] Agriculture: using land to cultivate various crops, including animal farming, fishing, and forestry (integrated agriculture)

Mutual Land Use: Managing Land Use for Efficiency

While Thailand does not face a critical land scarcity, research from other countries indicates that agrivoltaics can help address the problem of inefficient land use [5], such as dedicating land exclusively to agricultural activities. Agrivoltaics provides a dual-use solution, enabling the simultaneous production of food and solar power generation on the same parcel of land. Optimizing land use in this manner is essential, allowing Thailand to maximize the use of available lands without choosing either food production or energy demand.

Renewable Energy Development: Supporting the Energy Transition

Thailand has set a target to increase the proportion of electricity generation from renewable energy by at least 50% [6], leveraging the country’s significant potential to solar power generation. Agrivoltaics aligns with these objectives by focusing on transitioning energy use in the agricultural sector from reliance on fossil fuels in generators or electricity from the grid to utilizing electricity generated from solar cells in a parallel system on agricultural land. Additionally, implementing the Agrivoltaics project can help reduce greenhouse gas emissions in the country. This innovative approach not only provides a means to produce and use solar energy, but also contributes to Thailand's energy transition by reducing GHG emissions.

Mitigating Climate Change: Reducing Environmental Impacts

Agrivoltaics plays a key role in Thailand's efforts to mitigate climate change, by reducing greenhouse gas emissions through solar power generation which reduces the dependence on fossil fuels in which have a high carbon dioxide emission. Additionally, installing solar panels overhead or between crops or livestock can also help reduce evaporation from the soil, and it reduces the intensity of direct sunlight reaching the soil surface [7]. Additionally, water traps can be installed at the edges of solar panels for storing dew or rainwater, which is particularly beneficial in drought-prone regions such as the northeast or part of the northern region in Thailand [8]. Thus, the two benefits of reducing carbon dioxide emissions and ability to store water or maintain soil moisture makes Agrivoltaics an environmentally sustainable option for Thailand's agricultural sector.

Economic Benefits for Farmers: Improving Livelihoods

For Thai farmers, Agrivoltaics presents an opportunity to enhance their income by allowing them to manage their land to the highest efficiency, for example, leasing land or joint investment with the private or public sector to install solar panels on their properties. This approach enables them to generate clean electricity for personal use, resulting in reduced electricity costs compared to purchasing power from distributors or relying on diesel for irrigation. Additionally, farmers may benefit from selling electricity back to the national grid. Such initiatives underscore the advantage of implementing the agrivoltaics project.

The research team suggests that the initiative shall commence in areas where agricultural production is below the national average per unit of land. The data can be referred to the Office of Agricultural Economics [9]. The factors contributing to lower agricultural yield may include fluctuating market prices or adverse weather conditions. Reducing farmers' energy costs or providing additional income through electricity sales by agrivoltaics, has the potential to enhance the long-term economic resilience of farmers.

Improved Agricultural Productivity: Being Beneficial to Agricultural Production

Selecting appropriate agricultural activities, particularly the type of crop, can enhance the positive impact of Agrivoltaics on agricultural production, especially in Thailand's hot and sunny climate. Partial shading provided by solar panels can help protect crops or livestock from excessive heat, reduce water stress, and create an optimal environment for growth. This approach is particularly advantageous for crops that do not thrive in high temperatures or intense sunlight. Implementing agrivoltaics can lead to improved agricultural yields for these crops.

Rural Development: Promoting Infrastructure and Quality of Life

Agrivoltaics is one of the promising innovations that can lead to the improvement of infrastructure through the development of solar power generation, thereby expanding access to electricity across various areas. This improvement in electrical infrastructure can significantly elevate the quality of life within the communities. In addition, the adoption of technologies and practices can stimulate economic development and foster innovation, such as transforming agrivoltaics sites into a tourist attraction.

Policy Support and Research Opportunities

Agrivoltaics can foster opportunities for research and development across various innovations, especially within Thailand's agricultural sector. The collaboration among farmers, academia, industry, and the government can drive progress in agricultural productivity and advancing solar energy technology. This synergy has the potential to position Thailand as a leader in sustainable agriculture and the use of renewable energy.

Therefore, Thai government shall recognize the potential of agrivoltaics and support it through various policies and incentives aimed at promoting the increase of agricultural production and renewable energy generation. Supporting these policies will be crucial for widespread adoption of agrivoltaics across the country.

To conclude, agrivoltaics presents a comprehensive solution to many of Thailand's pressing challenges. By integrating agriculture with renewable energy production, it can support the country's goals in sustainable development, climate change mitigation, land management, land use efficiency, renewable energy development, increased agricultural productivity and economic benefits for farmers, as well as rural economic growth. As Thailand continues its journey toward energy transition and sustainable development, agrivoltaics can play a crucial role in shaping the future of the agriculture and energy sectors. However, the country currently lacks necessary policies and regulatory frameworks to effectively promote the development of agrivoltaics.

For this study, the Clean Affordable and Secure Energy for Southeast Asia (CASE) project under the operation of the German Company for International Cooperation (GIZ), along with the research team recognize that Thailand has the opportunity to develop policies and regulations that promote the integration of agriculture with solar power generation. This research report is focus on providing relevant policy and regulatory recommendations to support agrivoltaics.

1.2 Purpose of the study

To analyze international practices and existing national laws and provide recommendations for effective policies and regulations to promote agrivoltaics in Thailand.

1.3 Definition and Scope

For Thailand, there is no definition and scope of agrivoltaics. The researchers draw the international definitions [3] and adapt them to be appropriate for the context of Thailand, with a particular emphasis on agricultural activities.

Definition of Agrivoltaics for Thailand

Agrivoltaics is the joint use of land between agriculture activities and solar power generation

Agriculture: using land to cultivate various crops, including animal farming, fishing, and forestry (integrated agriculture)

Scope of Agrivoltaics

Brownfield – promoting the electricity production from **existing** Photovoltaic Power Plants while selecting agriculture practices suitable for the area. This approach aims to avoid negative impacts, or disruptions, and does not require additional investment in the existing solar power generation system.

Greenfield – promoting the **new** Agrivoltaics system in areas where agriculture practices are already taking place or in previously unused areas.

The ratio of agricultural land use shall be designed to be more than energy production. For instance, the Federal Republic of Germany sets the land use ratio of 66% for agriculture to 34% for energy, while the Republic of Italy set the ratio at 70% for agriculture to 30% for energy. Further research will be required in Thailand to establish a suitable ratio for the country. Note that this report cannot yet identify the appropriate ratio for Thailand, as further research is necessary.

1.4 Overview of the report structure

This report consists of an introduction that demonstrates the importance and readiness to promote agrivoltaics in Thailand. Chapter 2 outlines the current policies and measures related to agriculture, electricity generation from solar power, and land use. Chapter 3 highlights international practices, projects and studies and lessons learned. Chapter 4 offers guidelines for promoting agrivoltaics by addressing gaps. The report concludes with Chapter 5, which provides recommendations for policies and regulations tailored to Thailand.

2

Current Policies and Regulations Overview: Agrivoltaics in Thailand

Promoting and supporting agrivoltaics in Thailand has policies, regulations, and measures across three key sectors; agriculture, energy, and land use. This report presents an overview of the current situations related to agrivoltaics as follows:

Countries worldwide are actively working to reduce the greenhouse gas (GHG) emissions, a major contributor to climate change. Thailand itself has set targets, aiming for Carbon Neutrality by 2050 and Net Zero GHG Emission by 2065. These commitments are outlined in the Nationally Determined Contributions (NDCs) which provide a framework for guiding country's emission reduction efforts. The NDCs are integral to the United Nations Framework Convention on Climate Change (UNFCCC) process, as they represent each country's pledges to combat climate change and are assessed during the periodic reviews conducted by the UNFCCC. Moreover, the targets set in the NDCs are closely linked to the 17 Sustainable Development Goals (SDGs), as they promote efforts to ensure sustainable development while addressing climate change. To ensure accountability, each country is required to submit a progress report on its emission reduction effort to the Secretariat of the UNFCCC every two years [10]. Several of these SDGs are relevant to Thailand's initiatives in agrivoltaics. The relevant SDGs includes Goal 2 which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. Within this goal, target 2.4 focus on ensuring a sustainable production system thaht can be applied in agricultural practices to increase productivity while preserving ecosystems. This approach is crucial for strengthen the fight against climate change, extreme weather, drought, floods, and other disasters that can degrade land and soil quality by 2030 [11]. Goal 7 is to ensure that everyone has access to affordable, reliable and sustainable energy. Specifically, target 7.2 aims to increase the share of renewable energy in the global energy mix by 2030. Meanwhile, Goal 13 emphasizes the need for urgent action to combat climate change and its impacts, with target 13.2 integrating climate change measures into national policies, and strategies.

In 2019, Thailand emitted 373 million ton Carbon Dioxide equivalent (tCO_2e) of greenhouse gases with the energy and transport sectors accounting for largest share at 70%, followed by the agricultural sector (15%) [10,12]. Thailand is actively working to reduce GHG emission, particularly in energy and agricultural sectors. Agrivoltaics present a promising solution to address these challenges, particular in its role in GHG mitigation within energy sector. The research team identified a promoting plan for agrivoltaics as a part of Alternative Energy Development Plan (AEDP) and Thailand solar policy [13].

For agricultural sector, the Thai Rice Nama project, which is a collaboration between the Ministry of Agriculture and Cooperatives and the German International Cooperation (GIZ) in Thailand and Thailand Development Research Institute (TDRI) [14] proposes measures to reduce GHG emissions to support the Thai economy. Effective emission reduction strategies should align with efforts to enhance resource efficiency. Emission reduction measures can be divided into three phases based on technological readiness and cost, 1) Short-term measure: These can be implemented immediately with quick returns on investment, Examples include using animal manure to produce biogas, utilizing renewable energy for electricity generation in the industrial sector, optimizing energy consumption, and installing solar PV for buildings, 2) Medium-term measure: While cost may be high, these options are expected to become more economically viable as technology advances. One example is adjusting the animal feed formula to reduce methane gas in the agricultural sector, and 3) Long-term measure: These require advancement in technology, such as the developing animal breeds or vaccines to further reduce methane emissions in the agricultural sector. Given these considerations, the **researchers considered that agrivoltaics can effectively contribute to the short measures,** which will be discussed in greater detail in Chapter 5.

Agrivoltaics can play an important role in reducing GHG emissions and mitigating climate change. Therefore, it is necessary to review the current policies, rules, regulations, and measures, in order to find ways to support and promote the use of agrivoltaics in Thailand. The following policies from each sector, in effect during the report preparation period, that promote agrivoltaics include:

2.1 Agriculture

The current agricultural policies support the agrivoltaics projects, are listed as follow;

Important agricultural policies of the Ministry of Agriculture and Cooperatives in 2023 [15] which include:

Policy: Emphasizing the creation of working methods for implementation including:

1) Establishment of the Agricultural Public Service Center, which is a joint service center serves as a comprehensive resource for farmers and public across all provinces. The joint service center aims to facilitate communication, address complaints, and alleviate the challenges faced by farmers, providing them with dedicated support in one accessible location.

Recommendations on this policy are to collect the information or contact of the experts, technicians or relevant personnel responsible for monitoring agrivoltaics after their installation. This information should be provided at the service center.

2) Building a strong agricultural family and integrating strong work, which focuses on strong collaboration among various agencies under the Ministry of Agriculture and Cooperatives. It is essential for all agencies to work as cohesive team, demonstrating determination and unity to achieve common goals.

Recommendations on this policy are that agencies within the Ministry of Agriculture and Cooperatives adopt collaborative projects, in which one of the topics may include but not limited to knowledge exchange, research information sharing, and best practices. Additionally, there is potential to organize these initiatives in the form of a cooperative in the future.

3) Driving the mission of agricultural product supervision by upgrading "MR. Agricultural products" ensuring all agricultural products must have designated responsible agencies who can work proactively to identify and address issues at every stage – from production to distribution.

Recommendations on this policy are that the agricultural products produced from the project shall have the main responsible agencies responsible for oversight. This will ensure that the agricultural products meet the safety standards and regulatory requirements, while also addressing farmers' concerns, such as the use of chemicals for cleaning solar panels.

Policy: Coping with natural disaster

When facing drought or any natural disaster, clear measures must be planned to address all phases, from prevention to resolution and recovery.

The current policy promotes the implementation of the projects that mitigate the impact of natural disasters on agricultural operations, similar to the benefits offered by the agrivoltaics. The benefits include preserving soil moisture during droughts or reduce the intensity of direct solar radiation on plants and animals.

Policy: Upgrading agricultural products and empowering farmers includes

1) Promoting high-value agricultural products and services by creating "One Locality, One High-Value Agricultural Product" and branding for the products, tying it to the story of the province or district. By doing so, tihis measure will add value to agricultural products, fostering greater market appeal and differentiation.

Suggestions for current policies are increasing the agricultural products obtained from the agrivoltaics project to be high-value agricultural products or focusing on implementing projects with high-value agricultural products.

2) Promoting farmer(s) or farmer institutions to be a comprehensive agricultural service provider equip farmer(s) or institutions with the necessary tools and machinery. This would enable them to deliver modern agricultural service, offering advance technology and innovation to meet the needs of the modern agricultural population.

Suggestions for current policies are to promote the farmer(s) or institutions with access to solar power generation technology and enable them to develop and sustain agrivoltaics business model independently.

Policy : Agricultural Facilitation

The development of the agricultural insurance system, which is another important risk management policy for the sustainable agriculture. The policy will enable farmers to have a stable income and aims to develop and create an insurance system for Thai farmers.

The suggestion for current policies is that an agricultural insurance system should include the products from agrivoltaics project. This inclusion will help reduce farmers' financial risks and create incentivized environment to start the project.

Standard for Agricultural Product: Mor Kor Sor 9000-2564 Organic Agriculture: The National Agricultural and Food Standards Agency under the Ministry of Agriculture and Cooperatives [16], has established **Mor Kor Sor 9000-2564** the standard for organic agriculture. This standard strictly limits the use of synthetic inputs at all stages of organic production and supply chain. It covers production, processing, labeling, distribution of organic product(s). Additionally, it restricts exposure to persistent chemicals that may be harmful to people and the environment, thereby reducing pollution and degradation of production and processing units, including the surrounding environment. Furthermore, the organic production system excludes certain technologies that have not been proven to be unnatural and harmful.

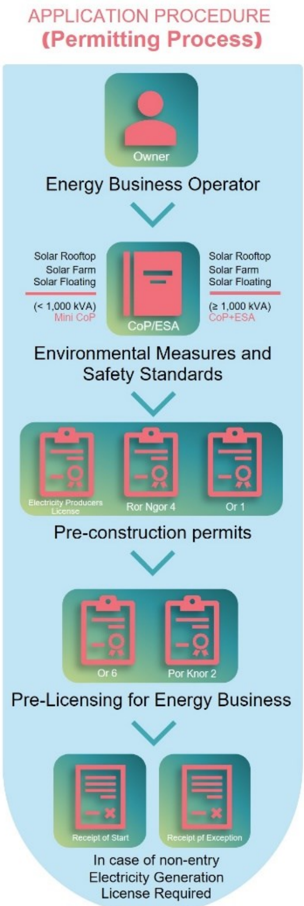
The suggestion for the current measure is to establish and implement a waste management aimed to prevent waste leakage, and pollution emission, while in corporating recycling as one of the procedures. For non-recyclable wastes such as batteries, plastic foils, and so on, proper disposal is essential to avoid contamination in organic farms. Measures to prevent contamination during use of equipment, and cleaning of equipment must be taken, including cleaning equipment and facilities and recording of the cleaning process [16]. Therefore, it is necessary to manage organic farming effectively, particular when developing it as an agrivoltaics site, where solar panels are installed to generate power alongside agricultural production.

Low-carbon agriculture to sustainable agriculture (Sustainable Agricultural Products): The sustainable agricultural system refers to the agricultural production, processing, distribution of agricultural products, as well as the lifestyle of farmers ensuring preservation of the ecosystem, environment, and biodiversity to contribute to food security and safety. This aim is to create a balance of economic, social, environmental and ecological fairness, while enhancing the quality of life both farmers and consumers.

This aligns with the implementation of the agrivoltaics project, which requires supervision and monitoring to ensure it is carried out without long-term impacts.

Therefore, it can be seen that the agricultural sector can **support and promote agrivoltaics**. Agricultural support policies can be improved to incorporate agrivoltaics as part **of sustainable agricultural practices.** This may involve providing technical assistance, conducting research, offering training, and extending financial support to farmers who adopt agrivoltaics technologies. Further detail can be found in Chapter 5.

2.2 Energy related to the Photovoltaic Power Plant



The current energy policies already provides the supportive environment for promoting agrivoltaics project. The Ministry of Energy's urgent policy [17] aims to reduce the burden of energy costs for the people, which is crucial for living standard and economic growth. The government will manage energy prices, including electricity, LPG, and fuel, to maintain them at appropriate level. Additionally, the government plans to adjust the country's energy consumption structure by implementing demand response and ensuring the reliable supply of energy sources.

The government will also promote the production and use of clean and renewable energy in line with the sustainable economic and environmental development guidelines. This includes accelerating negotiations on energy consumption in disputes area with neighboring countries [17], and explore additional energy sources. Furthermore, the government will support the procurement of new energy sources under the market mechanism to ensure Thailand's energy security, which will continue to drive the country forward.

Therefore, energy policy will consistently promote joint land use projects between agriculture and photovoltaic power generation, both within the scope of existing and new agrivoltaics projects. This policy will provide farmers with increased access to electricity from renewable energy. Regarding the generation of electricity from photovoltaic power plants, it is necessary to obtain a license to operate a power generation, distribution system, and electricity distribution business. For new projects, the implementation is possible; however, with a policy to promote the production and use of electricity from the agrivoltaics project, the electricity produced can be connected to the electricity distribution system. If the policy allows grid connection, selling back electricity would be one of the financial mechanisms promoting the adoption of agrivoltaics. The Office of the Energy Regulatory Commission (ERC) has prepared a detailed manual [18-19] for applying for an electrical business license for photovoltaics electricity production as Type 3 factory operation No. 88. This requires a factory business license (Ror Ngor 4), a land use permit, a permit for construction, modification, or demolition of a building (Or 1), and a controlled energy production license (Por Kor 2). **Figures 1 and 2** detail the required permission for photovoltaic power plant project with installed capacity of less than 1,000 kVA and more than 1,000 kVA.

Installed capacity < 1,000 kVA

1 Section 47 (according to Inverter) — In case of requesting an exemption — **ERC** Issued to electricity producers both for their own use and for sale

2 Section 48	In case of being outside the industrial estate area			outside the industrial estate area	
	ERC	**PIO/PIW**	**Local Government**	**ERC**	**IEAT**
Self-consumption — 2.1 Rooftop / Farm / Floating					
• License Or.1 • License Kor Nor Or 02/2	X	X	issued to building owner (electricity consumers)	X	issued to building owner (electricity consumers)
• License Ror Ngnor 4 • Letter Knor Nor Or 01/2	X	• Expand on the sequence plant (Farm / Floating) • Not eligible for panel expansion (only Rooftop ≤ 1000 kVA)	X	X	issued to electricity producers
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X
For Sale — 2.2 Rooftop					
• License Or.1 • License Kor Nor Or 02/2	X	X	issued to building owner (electricity consumers)	X	issued to building owner (electricity consumers)
• License Ror Ngnor 4, No.88 (1) • Letter Knor Nor Or 01/2 (PV panel ≤ 1000 kVA)	X	X (ได้รับการยกเว้นตามกฎหมายโรงงาน)	X	X	X (ได้รับการยกเว้นตามกฎหมายโรงงาน)
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X
For Sale — Farm / Floating					
• License Or.1 • License Kor Nor Or 02/2	issued to electricity producers	X	X	X	issued to* building owner (consumers or producers)
• License Ror Ngnor 4, No.88 (1) • Letter Knor Nor Or 01/2	issued to electricity producers	X	X	X	issued to electricity producers
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X

Note

* Kor Nor Or issued to electricity producers in the event that being the building owners (electricity consumers) Transfer of the right to the top of the building (Rooftop) / Land (Farm / Floating) to the power producer

X is not an authorizer / a notifier

License Or 1	: Building Permit, Modification or Demolition
License Kor Nor Or 02/2	: Building Permit, Modification or Demolition
License Ror Ngor 4 No. 88(1)	: License to operate an electric power plant
Letter Kor Nor Or 01/2	: Land Use and Business License in Industrial Enterprises
License Por Knor 2	: License to produce controlled energy (according to the specific inverter 200 - < 1000 kVA))

ERC.	: Office of Energy Regulatory Commission
Sor Or Jor.	: Provincial Industry Office (PIO)
Kor Ror Or.	: Department of Industrial Works (PIW)
Kor Nor Or.	: Industrial Estate Authority of Thailand (IEAT)

Search : https://www.erc.or.th/th/infographics/2990

Figure 1 permission for photovoltaic power plant project that installed capacity < 1,000 kVA

Installed capacity ≥ 1,000 kVA

1	In case of requesting a permission	
Section 47 (according to Inverter)		**ERC** Issued to electricity producers both for their own use and for sale

2 **Section 48**	In case of being outside the industrial estate area			outside the industrial estate area	
	ERC	**PIO/PIW**	**Local Government**	**ERC**	**IEAT**
Self-consumption — 2.1 Rooftop / Farm / Floating					
• License Or.1 • License Kor Nor Or 02/2	X	X	issued to building owner (electricity consumers)	X	issued to building owner (electricity consumers)
• License Ror Ngnor 4 • Letter Knor Nor Or 01/2	X	• Expand on the sequence plant (Farm / Floating) • Not eligible for panel expansion (Rooftop)	X	X	issued to electricity producers
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X
For Sale — 2.2 Rooftop					
• License Or.1 • License Kor Nor Or 02/2	X	X	issued to building owner (electricity consumers)	X	issued to building owner (consumers or producers)
• License Ror Ngnor 4, No.88 (1) • Letter Knor Nor Or 01/2 (PV panel ≤ 1000 kVA)	issued to electricity producers	X	X	X	issued to electricity producers
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X
For Sale — Farm / Floating					
• License Or.1 • License Kor Nor Or 02/2	issued to electricity producers	X	X	X	issued to* building owner (consumers or producers)
• License Ror Ngnor 4, No.88 (1) • Letter Knor Nor Or 01/2	issued to electricity producers	X	X	X	issued to electricity producers
• License Por Kor 2	issued to electricity producers	X	X	issued to electricity producers	X

Note * Kor Nor Or issued to electricity producers in the event that being the building owners (electricity consumers) Transfer of the right to the top of the building (Rooftop) / Land (Farm / Floating) to the power producer

X is not an authorizer / a notifier

License Or 1 : Building Permit, Modification or Demolition

License Kor Nor Or 02/2 : Building Permit, Modification or Demolition

License Ror Ngor 4 No. 88(1) : License to operate an electric power plant

Letter Kor Nor Or 01/2 : Land Use and Business License in Industrial Enterprises

License Por Knor 2 : License to produce controlled energy (according to the specific inverter 200 - < 1000 kVA))

ERC. : Office of Energy Regulatory Commission

Sor Or Jor. : Provincial Industry Office (PIO)

Kor Ror Or. : Department of Industrial Works (PIW)

Kor Nor Or. : Industrial Estate Authority of Thailand (IEAT)

Search : https://www.erc.or.th/th/infographics/2990

Figure 2 permission for photovoltaic power plant project that installed capacity of more than 1,000 kVA.

Reference to the Factory Act B.E. 2535 in Section 1 regarding factory business operations [20-21]

In Section 7, factory operations are classified based on the need to control and prevent nuisances, damage, and danger according to the severity of the impact on people or the environment. The classification are as follows:

1) Category 1 factories include factories of the type and size where factory business can be started immediately at the discretion of the factory business operator.

2) Category 2 factories include factories of the type and size that require notification to the officials before commencing the factory business.

3) Category 3 factories include factories of the type and size that require a license before setting up a factory can be set up and operated.

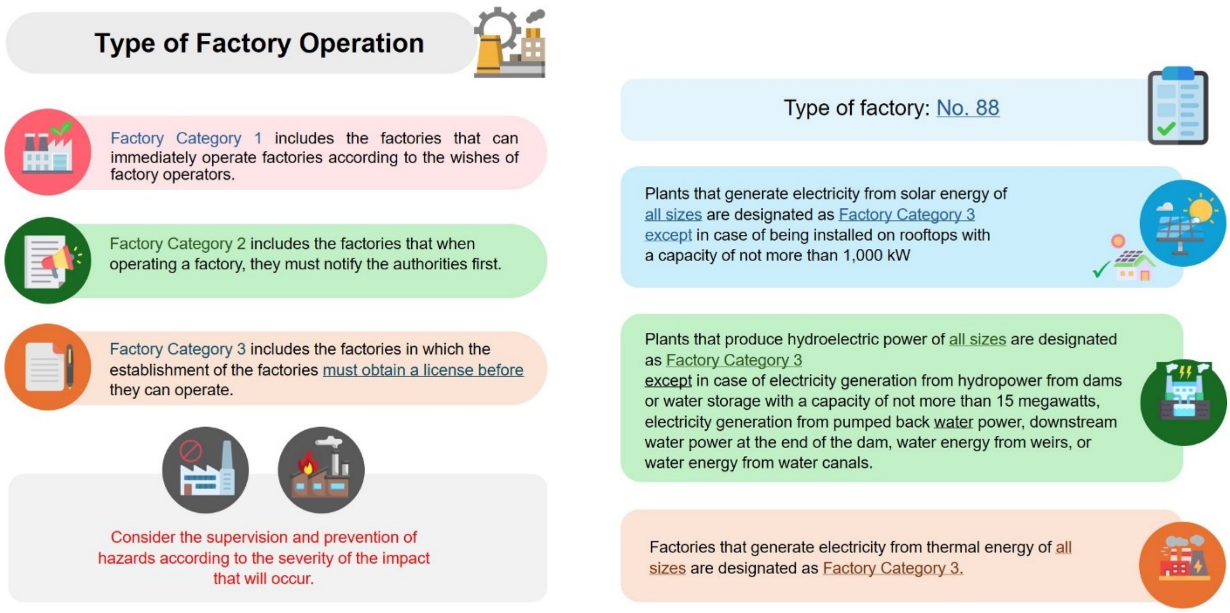


Figure 3 Type of Factory Operation

Reference to the Ministerial Regulations on specifying types and sizes of factories, B.E. 2020, and the list appended to the Ministerial Regulations specifying types and sizes of factories, B.E. 2020 [22]

According to the list attached to the Ministerial Regulations specifying the types and sizes of factories, B.E. 2020, there is the designation type of factories No. 88 [23], specifying the following types of electric power production plants as follows:

1) Factories that produce electrical energy from solar energy, except those installed on the roof, rooftop, or any part of the building where people may enter or use it, with the combined maximum installed capacity of solar panels not exceeding 1,000 kilowatts.

2) Factories that produce electrical energy from thermal energy

3) Factories that produce electricity from hydropower, except for the production of electrical energy from hydropower from dams or water storage with a capacity not exceeding 15 megawatts, the production of electrical energy from pumped hydropower, the production of electrical energy from

hydropower behind the dam, the production of electrical energy from hydropower from weirs, or the production of electrical energy from hydropower from canals.

Considering the size and type of factory, the factories that produce electricity from solar energy with an installed capacity of all sizes are set as Category 3 factories. If there is no revision of the regulation, the agrivoltaics shall also be set as the Category 3 factories.

Reference: Ministerial Regulation No. 2, B.E. 2535, issued in accordance with the Factory Act, B.E. 2535, Section 1, regarding location, environment, building characteristics, and internal characteristics of factories [24]

The regulation specifies the prohibition of setting Category 3 factories in the following areas:

1) Housing development for living, residential condominiums, and row houses for living

2) Within 100 meters from the public contact zone, including school or educational institution, temples or religious places, hospitals, historical sites, and government offices. This does not include the location used specifically to control, supervise, facilitate, or provide services to the operation of that factory.

In addition to the prohibitions, Category 3 factories must still be located in an appropriate location and environment. There must be sufficient area for industrial operations according to size and type of factories without causing danger, nuisance, or damage to the person or property.

Therefore, it should be prioritized to promote solar power generation and support the integration of agrivoltaics systems as a way to increase the proportion of clean energy consumption and production that can be connected to the power distribution network. Guidelines should be established for monitoring and measuring the amount of electricity produced specifically for agrivoltaics power producers, and the process should be streamlined for requesting permission to produce electricity, connecting to the grid, and other related steps. Further suggestions can be found in Chapter 5.

2.3 Land use and zoning

From the past to the present, policies, and plans related framing the direction of national development and land management have only defined and classified certain types of land use. The area where the land classification target has been specified clearly is the country's forest area, with target proportion of the country's forest area differently according to the policy and plan objectives, in the range of 40 to 50% of the country's area. In the future, these proportions should be aligned across policies and plans to guide national development consistently. Meanwhile, other types of land use, such as agricultural, urban and community, public, industrial areas, have not yet been clearly defined in terms of the land use proportions.

The management under the National Land and Soil Resources Management Policy and Plan (2023 - 2037) of the National Land Policy Committee (NLPC) [25] aims to prioritize the classification of state land and private land to achieve clarity of land boundaries. Once the boundaries of public and private land are clearly defined, it will be easier to manage for economic and social benefits. This aims to identify which areas should be designated as state-restricted areas for the various state affairs, which areas should be designated as forest areas for the conservation and protection of natural resources and the environment, and to determine how the remaining areas should be used effectively. It is essential to develop tools and mechanisms to determine target proportions for land use classification that are clear and aligned with the direction of national development. This would ensure that Thailand has a systematic and coordinated land use plan in each field of production, serving as a framework and practice guidelines for relevant agencies and sectors for further implementation.

However, the country's land use planning that has been defined through clear land use proportions and classifications to control land use and economic activities per the national development direction, should be flexible and adaptable to changes in the direction and trend of economic and social utilization in a highly dynamic future. This requires the arrangement of important mechanisms or government tools to signal that landowners can adjust the land use pattern correctly and appropriately. This will positively impact driving Thailand's long-term economic and social development [25]. Such policies will play an important role in changing land use patterns to allow for a combination of agriculture and producing electricity from photovoltaics.

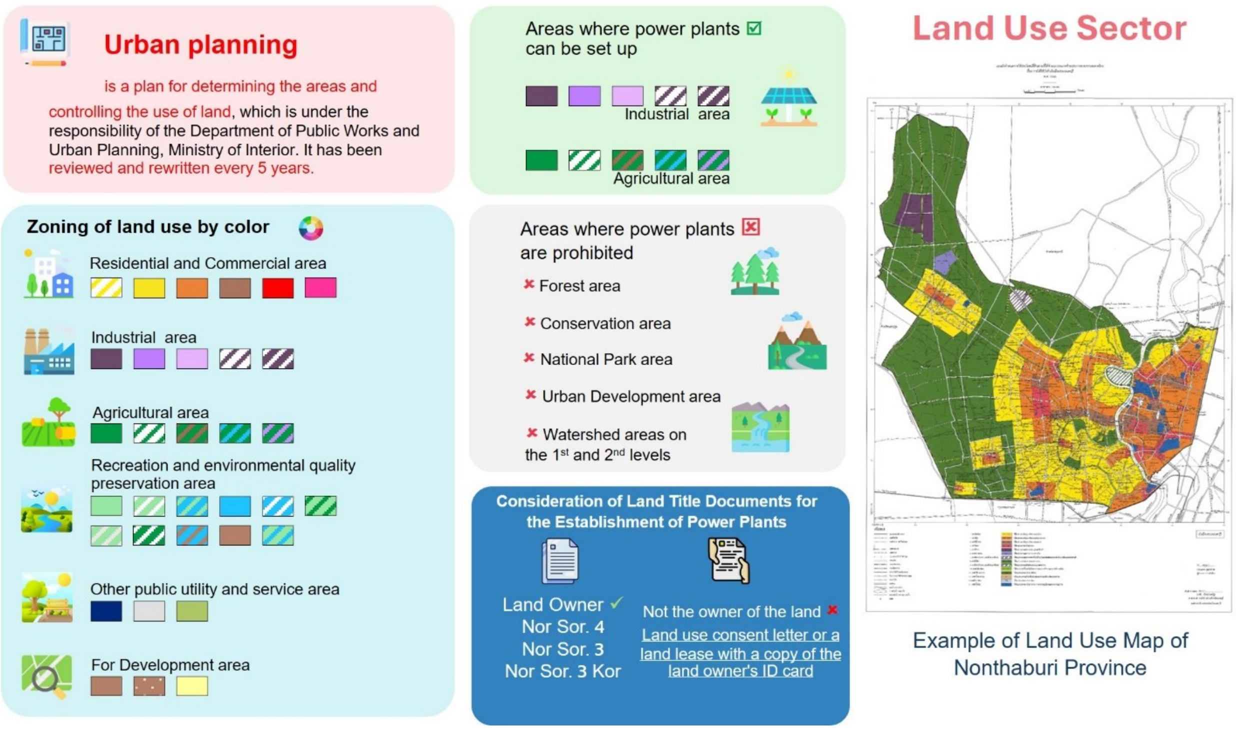


Figure 4 Urban planning and zoning of land use

The Town Planning Act [26] is a law, or policy related to planning, classification of areas, and allocation of land use for the sake of urban order and maximum benefits without affecting the environment and people's livelihood. The Department of Public Works and Urban Planning under the Ministry of Home Affairs, is assigned to prepare policy maps and land use schedules for each province in Thailand, in collaboration with relevant agencies in each sector, such as local government organizations. Additionally, the land use schedule is updated every 5 years. The latest and currently effective Town Planning Act is the Town Planning Act of 2019 (B.E.2562) [27].

Laws related to urban planning include Ministerial Regulations for the Enforcement of Provincial City plans, Ministerial Regulations for the Enforcement of City Planning, Ministerial Regulations for the Enforcement of Community Planning and Specific City Planning, including Announcements of the Ministry of Interior or Local Regulations.

Town planning according to the Town Planning Act is divided into 2 parts:

1. The Land Use Policy Map is the determination of the policy framework and strategy of national development in the field of land use for government agencies to implement, and it is divided into 3 levels:
   1) National Policy Map
   2) Regional Policy Map
   3) Provincial Policy Map

2. Land use plan is to determine the framework of guidelines and plans for land use in any area for urban development and urban and rural areas maintenance. It is divided into 2 types:
   1) Integrated Town Planning
   2) Specific Town Planning

Details of the determination of land use areas for each province are specified in terms of the land use requirements of the area. Also, the summary table of the use of the area for any activity or the setting up of each type of factory in the area is determined according to the requirements of each province. For example, Nonthaburi Province has designated a solar power generation plant as a Category 3 factory and can apply for permission to set up a factory in the areas Or 2, Or 3 (industrial land) and Kor 2, Kor 3 (agricultural land).

Energy Regulatory Commission (ERC) [29] will consider the location and suitable environment of the solar power plant type, except for those installed on the roof, rooftop, or any part of the building that individuals can occupy or use with a capacity of not more than 1,000 kW according to the criteria set forth in the relevant laws for consideration for the issuance of power generation licenses as follows

1. **The Law on Urban Planning** includes the Ministerial Regulations for the Enforcement of Provincial City plans, Ministerial Regulations for the Enforcement of City Planning, Ministerial Regulations for the Enforcement of Community Planning and Specific City Planning, including Announcements of the Ministry of Interior or Local Regulations that stipulate the criteria for classification of land use according to activities on the site, which are divided into main land use and other land uses as follows:

(Kor) The main land use is the basic land use, which is divided into 4 types: residential, commercial, industrial, and agricultural as follows:

1) Residential and commercial types are sub-classified as follows:

Kor) Land of the residential conservation type (yellow with a white diagonal).

Khor) Land of the low-density residential type (yellow)

Kal) Land of medium-density residential type (orange)

Ngor) Land of the high-density residential type (brown).

Jor) Land of high-density commercial and residential type (red)

Chor) Land of community type (pink)

2) Industry Type: The subcategories are as follows.

Kor) Land of industrial and warehouse type (purple)

Khor) Land of specific industrial type (light purple)

Kal) Land of warehouse type (plum mango seed purple)

Ngor) Land of general industrial type that is not toxic to the community or the environment and warehouses (white with purple frame and diagonals)

Jor) Land of industrial and warehouse and agricultural type (purple with white diagonal).

3) Agricultural categories are classified as follows:

Kor) Land of rural and agricultural type (green)

Khor) Land of the rural and agricultural conservation type (white with a green frame and diagonal).

Kal) Land of the agricultural land reform type (green with a brown frame and diagonal).

Ngor) Land of the agricultural land restructuring type (green with a blue frame and diagonal).

Jor) Land of the rural and livestock type (green with a light purple frame and diagonal).

(Khor) Other land uses are defined as symbolic colors in the map as follows.

1) Recreation and environmental quality preservation category is divided into sub-categories as follows:

Kor) Open land for recreation and environmental quality preservation (light green)

Khor) Open land for recreation, animal husbandry, and preserving environmental quality (light green with a frame and white diagonals)

Kal) Open land for recreation and preservation of coastal environmental quality (blue with light green diagonal)

Ngor) Open land for preserving environmental quality (blue)

Jor) Open land for preserving environmental quality and wetlands (blue with white diagonal)

Chor) Land reserved for recreation and environmental protection (light green with green frame and diagonal)

Shore) Land reserved for the preservation of mangrove forest conditions (light green with gray diagonal)

Zor) Land for forest conservation (light green with white diagonal)

Shal) Land for environmental conservation for tourism purposes (green with white frame and diagonal)

Yor) Land for natural resource conservation and coastal environmental quality conservation (blue with light brown diagonal)

Dor) Land of conservation to promote Thai cultural identity Thai artistic and cultural identity (light brown)

Tor) Land at risk of flooding (light green with blue diagonal)

2) The categories of public utilities, public utilities and other public services are subdivided as follows:

Kor) Land for Government Institutions, Public Utilities and Public Utilities (Blue)

Khor) Land of religious institution type (light gray)

Kal) Land for Educational Institutions (Olive Green)

3) Types for development are subdivided into subcategories:

Kor) Land for urban development land (dark brown)

Khor) Land for supporting urban development (light brown with white spots)

Kal) Land for agricultural development and settlement (light yellow)

An applicant for a power generation license is prohibited from setting up a power plant on land on Type 1 (Kor) 1) land which includes main land use, residential and commercial land, as well as (Khor) other land uses, except where other regulations on land use for various activities as specified in the Town Planning Act.

In case of an applicant who wishes to set up a power plant on Type 1 (Kor) 2) and 1. (Kor) 3) land, the requirements of land use for various activities specified in the final account of the Ministerial Regulation on Town Planning shall be applied. This includes city planning area maps, land use zoning plans, and land use zoning plans that are normally in effect, to be used for consideration of permission under the Energy Business Act.

2) Factory Law includes other rules that stipulate criteria regarding the location and environment of the factory, the number, size, and type of plants to be set up or expanded.

3) The Law on Building Control includes other rules that stipulate the criteria regarding areas prohibited from construction, modification, demolition, and removal.

4) Other laws that stipulate the criteria regarding the location and environment of the establishment.

5) Law on the Promotion and Preservation of Environmental Quality

6) Relevant Laws or Cabinet Resolutions

In the case of the Law on Urban Planning, the details are different from this regulation, so the Energy Regulatory Commission (ERC) will consider according to the criteria specified in the Town Planning Act.

In case there is reasonable suspicion that the location of a power plant may violate laws or other criteria other than those specified in this regulation, the ERC will consider granting permission only when the agency with authority under the law or other criteria has approved, authorized, permitted, or has an opinion that the power plant can be established in such an area.

An applicant for a power generation license **cannot** set up a power plant in an area where there are terms or conditions prohibiting the establishment of a power plant of that type in the area as follows:

1) National parks, parks, botanical gardens, Arboretum according to the Law on National Park
2) Wildlife sanctuaries, and no-hunting zones in accordance with the Law on Wildlife Conservation and Protection.
3) Community forests under the Law on Community Forests
4) Mangrove conservation areas or marine and coastal resource protection areas in accordance with the Law on Promotion of Marine and Coastal Resources Management as well as mangrove forest conservation areas according to the Cabinet Resolution.
5) 1st and 2nd levels watershed areas according to the Cabinet Resolution
6) Wetlands of international and national importance according to the Cabinet Resolution.
7) Raw Water Conservation Zone for Water Supply according to the Cabinet Resolution
8) Legally protected forest areas or additional protected forest areas according to the Cabinet Resolution.
9) Other areas where relevant Laws or Cabinet Resolutions are additionally prescribed.

In case of the use of the area as the location of the power plant, it is necessary to obtain approval or permission to use the area under other laws. Applicants for a power generation license to operate a power generation business must strictly comply with the rules and conditions stipulated in the relevant laws.

In case that it becomes apparent after the issuance of the power generation licenses that the action has not been taken in accordance with the provisions of paragraph one, the Office of the Energy Regulatory Commission (ERC) shall implement the notification of the ERC related to the rules, procedures, and conditions for suspension and revocation of energy business license.

The criteria for determining the location of power plants for the issuance of power generation licenses under this regulation shall apply to the consideration of permits in the case of expansion of power plants, whether it is done on the original land or the new plot of land.

This regulation does not apply to applicants for electricity generation licenses who have previously used land under the Town Planning Act on the date this regulation comes into force and must have received permission, approval, or acted in accordance with the law from the agency or organization with legal authority.

In summary, the establishment of a power plant can be in the area of Type 1, (Kor) 2) and 1, (Kor) 3), the main land use in the industrial category and in the agricultural category, but it must be accompanied by land use regulations specified in the list attached to the Ministerial Regulation on Town Planning and a list of accompanying land use plans that are used for consideration of permission. In the case where there is a desire to establish a power plant in land 1. (Kor) 1) and 1. (Khor), the land use regulations in accordance with the Town Planning Act must be considered.

ERC has the power to adjudicate on issues concerning compliance with these regulations, and the ERC's decision is final.

Consideration of land use: In terms of considering and inspecting land use or land use in accordance with the Law on Urban Planning, it is in the order of responsibility of the Ministry of Industry. After the Provincial Industrial Office receives the application from the applicant for the factory license No. 88 and attaches the land use right document [31-34], the relevant land use right documents will include the followings.

1. In case the applicant is a land owner, the certificate must be attached, which is a copy of the land deed (Nor Sor 4), Land Use Certificate (Nor Sor 3 or Nor Sor 3 Kor)
2. In case the applicant is not the owner of the land or has a joint owner, the applicant shall attach a letter of consent to use the land, a land lease agreement, or a contract to purchase and sell the land to obtain permission to set up or expand an electric power plant from the land owner together with a copy of the identity card of the land owner.
3. In the case of state land, permission to use the land for the establishment of an electric power plant must be obtained from a government agency that supervises the land according to the law.
4. In the case of multiple plots of land, when applying for permission, it needs to attach a land title deed map with a certification from the local land office where the factory will be located.

Current policies that encourage landowners to adjust land use patterns in a correct and appropriate manner reveal certain limitations. One key challenge is that farmers are required to own the land to implement projects, and there is a lack of clear land classification specific to agrivoltaics.

To address these challenges, land use and allocation for agrivoltaics, should include a well-defined zoning regulations that **clearly permit and support the integration of agrivoltaics systems**. These policies should establish land classifications that allow agricultural activities alongside energy production. Further recommendations can be found in Chapter 5.

3

International Best Practices

Agrivoltaic technology, which combines agricultural production with solar energy generation, is gaining popularity worldwide. This approach not only increases land use efficiency but also enhances the sustainability of both the agricultural and energy sectors. This chapter reviews significant documents and research from various countries, including Germany, the United States, China, India, Japan, Korea, and several European examples. It aims to present key technical and policy issues related to agrivoltaics that can serve as guidelines for adapting this technology to the context of Thailand for future use.

3.1 Asia

Asia, the largest continent, is home to a diverse array of countries, including Thailand. In recent years, several Asian nations have initiated innovative agrivoltaic projects, each with varying scopes and objectives depending on their specific contexts. These projects range from research initiatives focused on improving technologies to commercial-scale endeavors producing both food and clean energy. For example, the People's Republic of China has more than 500 agrivoltaic projects covering a wide range of agricultural activities [35], such as crop production, livestock farming, and aquaculture. Japan has also made significant progress in solar sharing, including the installation of a 200 MW agrivoltaic system funded by the government. Other countries, such as India and South Korea, are exploring similar projects, focusing on community participation and technological innovation to maximize land-use efficiency and promote sustainable energy practices. This trend highlights the increasing importance of agrivoltaics in addressing both energy and food security issues in Asia. Key issues that are likely to be applicable to Thailand are summarized in case studies from these Asian countries.

People's Republic of China

Human-caused greenhouse gas emissions, particularly carbon dioxide from fossil fuel use and industrial operations, account for 65% of global greenhouse gas emissions, with China being the largest emitter [36]. This poses significant challenges, such as air and water pollution, extreme weather events, and health impacts, particularly for the agricultural sector. To address these issues, China has been increasing its use of clean energy, with a growing share of solar power. Although solar power is non-polluting, it can conflict with agricultural land use. Therefore, an agrivoltaic system, which integrates solar power generation with agriculture, is a promising land-use solution to achieve dual-use. However, further research is needed to assess its feasibility in different regions of China, taking into account environmental, market, and policy factors.

Agrivoltaic technology has rapidly developed in China, as illustrated in Figure 5. The exploration of solar-powered agricultural systems began around 2011, initially focusing on integrating photovoltaic (PV) panels into various agricultural applications, such as crop production, livestock farming, aquaculture, greenhouse farming, and tea plantations. The Chinese government has played a key role in promoting agrivoltaics through policies that support the development of energy projects. These policies emphasize the importance of renewable energy and target solar power generation capacity, especially in central and eastern China, where land is limited and land use efficiency is maximized. By 2024, China has implemented more than 500 agrivoltaic projects [35], demonstrating significant potential for increasing both food and energy production, resolving land-use conflicts, and promoting sustainable agricultural practices.

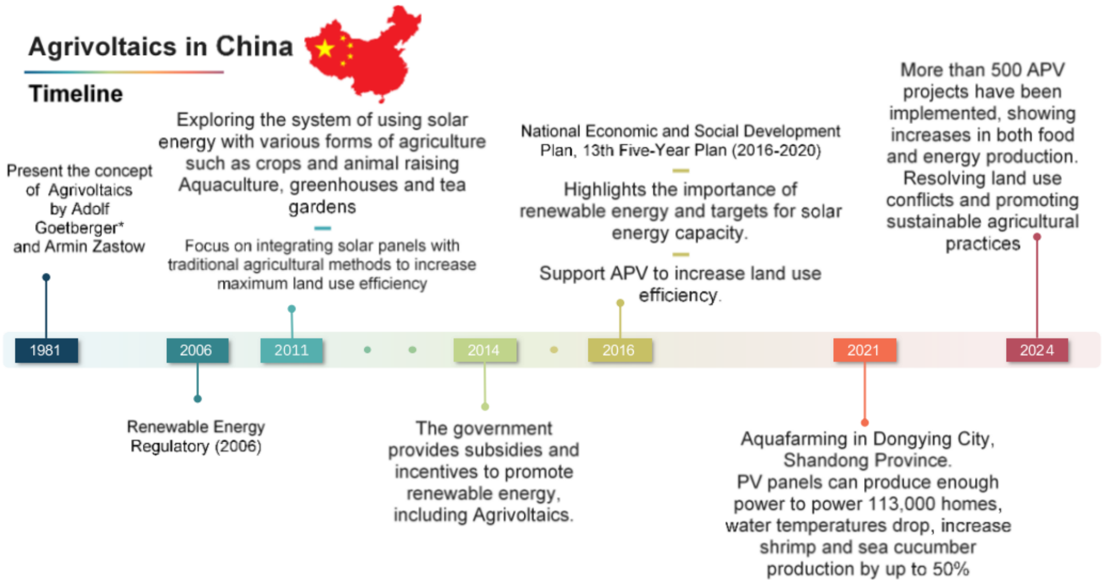


Figure 5 Timeline of agrivoltaic development in China

Case study in China

The 200MW Agrivoltaic Park in Jiangshan

The 200MW agrivoltaic park project in Jiangshan, developed by CHINT Solar Co. Ltd., is the largest solar park in East China. This 200MW solar power plant is located on degraded land with soil erosion problems, covering an area of 4.2 square kilometers. The site features hilly topography and experiences an average annual temperature between 16.3 and 17.3 degrees Celsius. Jiangshan receives an average annual precipitation of about 1,843 mm and an average evaporation of about 1,658 mm. The area has a relatively high solar radiation potential as shown in Figure 6, with annual solar radiation of approximately 1,357.8 kWh/m², making it suitable for large-scale solar power plants. The project aims to address land degradation and meet electricity demand as shown in Figure 7, while also increasing agricultural profits, developing the solar power industry, and establishing a business model to improve land use efficiency. Although agricultural operations may be hindered by the shading caused by solar panel structures, resulting in some reduction in agricultural productivity, the project has provided additional economic and social benefits. These include clean energy production, creating ecological balance, maximizing land use, increased value of previously degraded land, eco-tourism opportunities, and job and income generation for farmers. Additionally, it has produced environmental by-products that benefit the system as a whole [37].

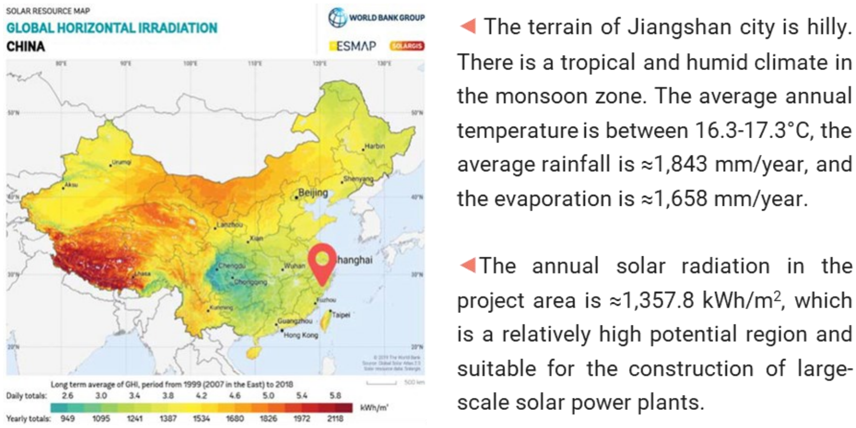


Figure 6 Solar energy potential and location of agrivoltaic park projects in Jiangshan [37]

Figure 7 Landscape of the agrivoltaic Park project area in Jiangshan before (left) and after (right) restoration with agrivoltaic system. [37]

CHINT Solar has planned the landscape to restore the ecological diversity of the land. In terms of technical design, CHINT Solar established Jiangshan Longtai Agricultural Development Co., Ltd. to develop the project's agrivoltaic system by hiring professional technicians to manage the land. The layout, height, and spacing of the PV modules are designed to suit various crops, as shown in Figure 8. This creates an area suitable for shade-loving plants and Chinese herbs, which are grown in bamboo troughs, as shown in Figure 9. For example, Dendrobium and Bletilla are planted under the PV panels, while sun-loving plants, such as vegetables, are planted in the areas between the PV panels. The agrivoltaic activity area of the project is divided into five zones: vegetable zone, Chinese herbal zone, tea zone, kiwi zone, and livestock zone. Additionally, the solar radiation from the PV panels can reduce heat and increase the water retention capacity of the soil, resulting in a vegetation cover of more than 90%, which can reduce erosion and improve soil fertility.

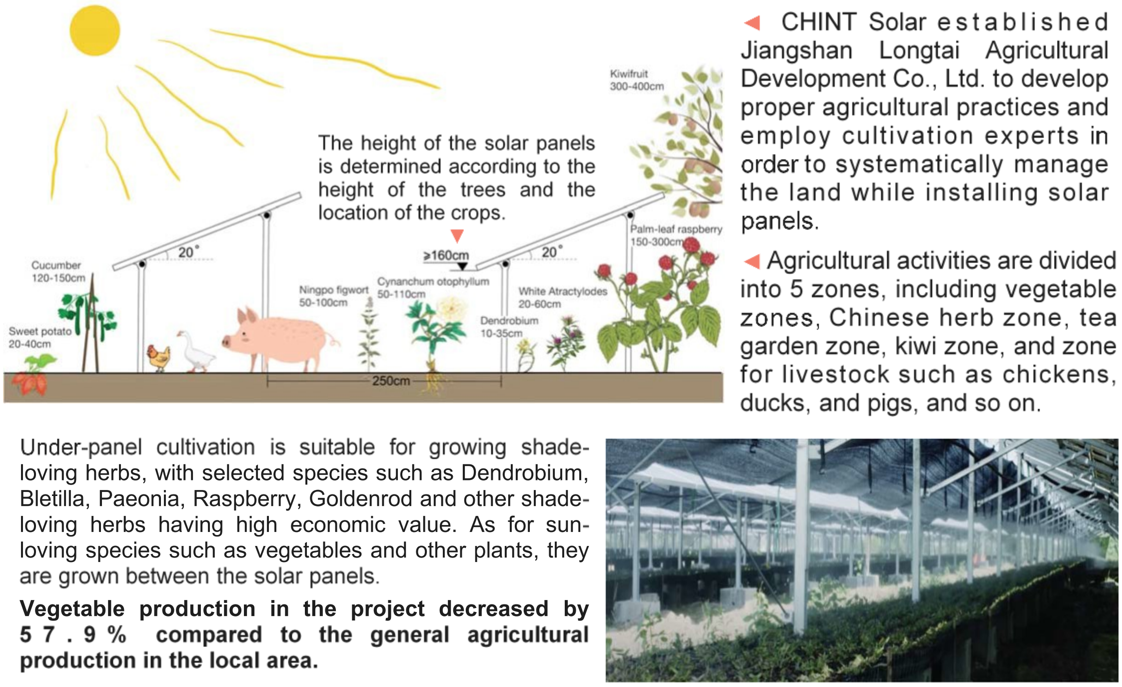


Figure 8 Design of agrivoltaic system and agricultural activities within the agrivoltaic Park project [37]

Figure 9 Orchid seedlings growing in bamboo containers with bark as a growing medium [37]

The conclusions on the application of agrivoltaic technology from the case study of the 200 MW Agrivoltaic Park project in Jiangshan, developed by CHINT Solar Co. Ltd., are as follows:

- The project aims to create a business model that increases land use efficiency on degraded land due to soil erosion. It seeks to establish a sustainable model that balances agricultural production with renewable energy generation, thereby benefiting the local economy, social well-being, and ecological restoration.
- The height of the solar panels is designed by considering the height of the trees and the specific positions of the crops to ensure optimal sunlight and agricultural production. The park is divided into five different agricultural zones: a vegetable zone, a Chinese herbal zone, a tea zone, a kiwi zone, and a livestock zone, which includes chickens, ducks, and pigs.
- Despite the innovative approach, vegetable production in the project is still lower than local agricultural production. However, the project is supported by a feed-in tariff (FIT) rate of 0.17 USD/kWh, which helps to offset some of the economic challenges.

- The project aims to create a sustainable model that balances agricultural production with renewable energy generation, thereby benefiting the local economy, social well-being, and ecological restoration.

Adaptation to the Thai context

Adapting China's agrivoltaic concept to the Thai context could involve several key steps. Leveraging Thailand's abundant sunlight and diverse agricultural practices may help maximize the synergies between solar power and agriculture. Tailoring solar farm systems to local crops and farming practices, such as rice paddies and tropical orchards, would be highly beneficial. Government support through policies and incentives similar to China's approach can drive adoption. Additionally, collaboration with local universities and research institutes may also be valuable in optimize system design and address specific issues, such as monsoon weather patterns and the restoration of degraded land. By focusing on these areas, Thailand could effectively promote agrivoltaics, enhancing both agricultural productivity and renewable energy production.

Republic of India

Agrivoltaics in India is still in its infancy, evolving from initial pilot projects in 2016 to more structured implementations as shown in Figure 10. Initially, solar agriculture was limited to a few experimental models aimed at understanding the feasibility of combining agriculture with photovoltaic (PV) generation. These early projects demonstrated potential benefits, such as increased land-use efficiency and improved crop yields, as solar panels partially blocked sunlight. Despite this progress, the commercialization of solar agriculture in India still faces several challenges, including the need for standardized guidelines, financial incentives, and technical support for farmers. However, ongoing research and pilot projects continue to provide valuable data, paving the way for the wider adoption of solar agriculture in India's renewable energy and agricultural sectors.

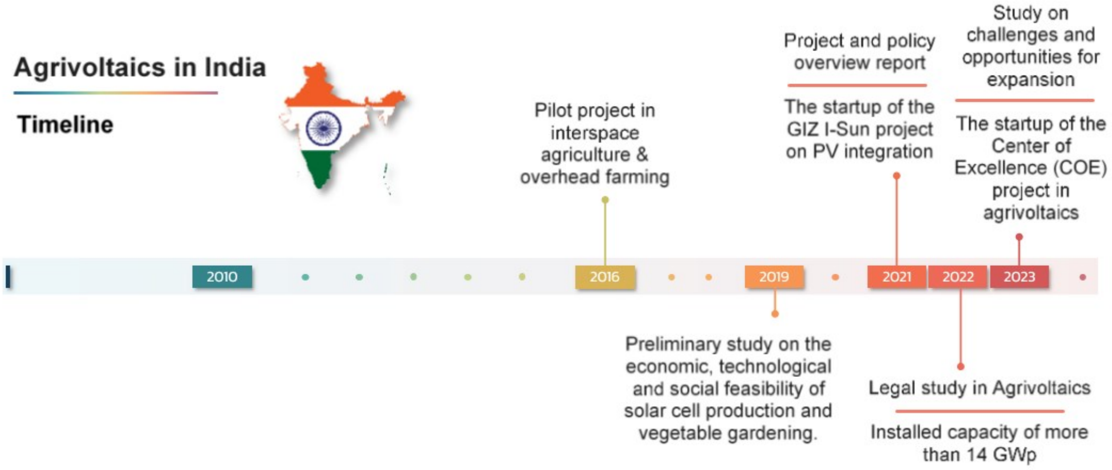


Figure 10 Timeline of agrivoltaic development in India

In response to international efforts to decarbonize the economy, the Indian government has set a target of 500 GW of renewable energy capacity by 2030, with around 300 GW coming from solar power. To achieve this target, the Indian government has introduced the Kisan Urja Suraksha evam Uthaan Mahabhiyaan (KUSUM), or Farmer Energy Security and Warranty Scheme. The scheme consists of three components, as shown in Figure 11, aiming to increase distributed solar power capacity. In particular, the PM-KUSUM Component-A involves the development of grid-connected, ground-mounted solar power plants, with a target of 10 GW of total capacity. These plants range in size from 500 kW to 2 MW and can be installed on both agricultural and dry land, which together account for approximately 60% of the country's land area and over 50% of the country's workforce [38]. However, land use in India remains strict and regulated, with nine types of land use, some of which are eligible for agrivoltaic development. Generally, any solar or renewable energy development is considered a non-agricultural activity. Each state prescribes different land use procedures, which need to be requested from the district administration. Engaging non-agricultural activity on agricultural land without proper land conversion is subject to penalties for the landowner or lessee. In other words, agricultural land must be converted to non-agricultural land for an agrivoltaic project to be established. Therefore, the selection of agricultural land for solar power plant development must be primarily driven by infrastructure and demand, along with the availability of government incentives and the willingness of farmers to set up projects on their land. However, it is important to note that this approach may create challenges in land use between energy generation and crop cultivation. As a result, the co-use of agricultural land and solar power generation is facing challenges in the academic, industrial, and political sectors in India.

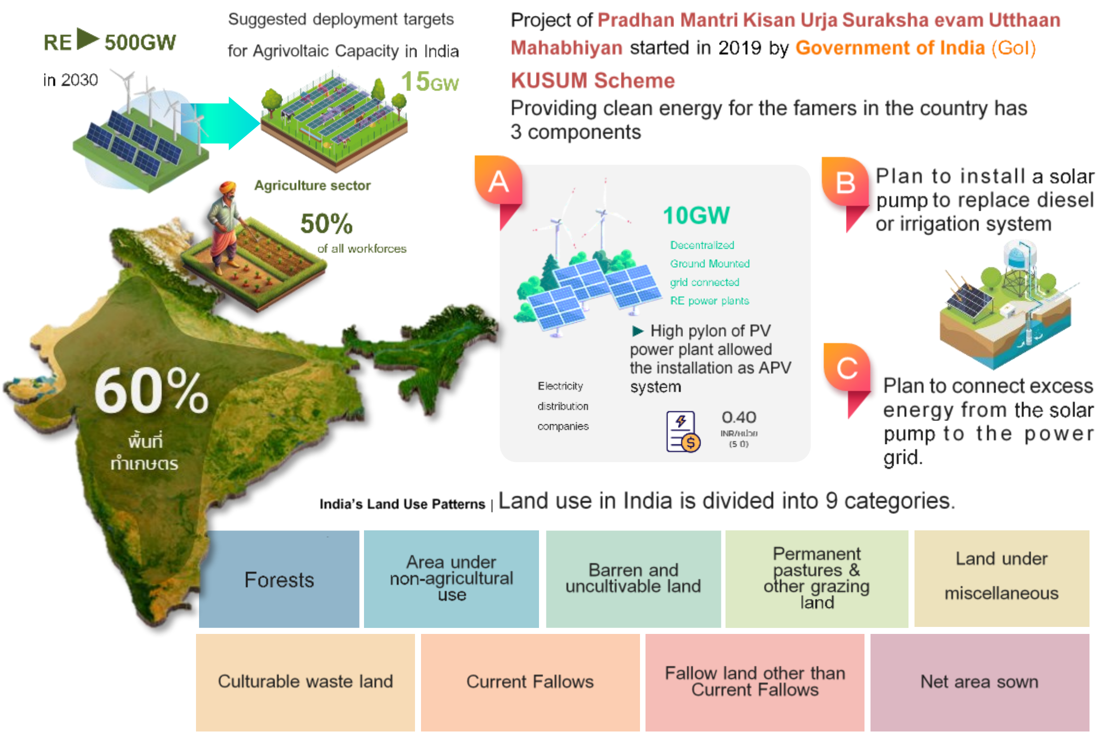


Figure 11 Setting renewable energy targets and supporting agrivoltaic in India

The PM-KUSUM project promotes the use of solar power in agriculture, among other strategies. It encourages the installation of small-scale, decentralized, grid-connected solar power plants on farmers' land. Although the project primarily targets arid and non-arable areas, it also permits the installation of power plants on agricultural land, provided that the solar panels are mounted on elevated poles and spaced appropriately to allow for continued cultivation. This provision facilitates the adoption of agrivoltaics under the project. In the past, agrivoltaic projects in India have been in the technology demonstration phase across various states as shown in Figure 12. Currently, the development of agrivoltaics is still in its infancy, with ongoing advancements in relevant technologies, appropriate design, and regulatory standards for implementation. At present, it is limited to a few pilot projects and has not yet reached commercial scale. However, existing schemes can be leveraged as a broader approach.

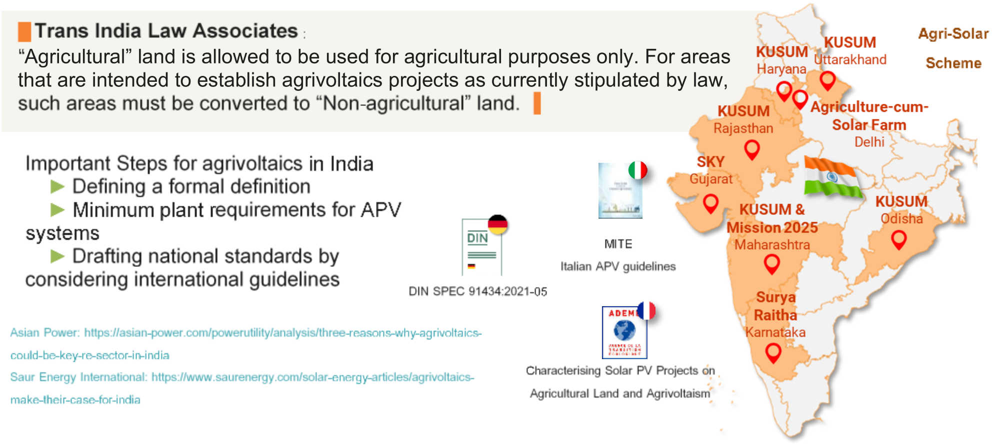


Figure 12 Government support for agrivoltaic spread across states in India

Case study in India

All pilot projects in India are open-field farming systems with cropping, differentiated mainly by three types of structures: ground-mounted panels or interspace panels, slightly elevated panels, and fully elevated panels. Ground-mounted panels are installed directly on the ground, while slightly elevated panels are mounted higher to allow some crops to grow under and between the panels, making the space suitable for shade-loving crops and slightly increasing land utilization. Fully elevated panels enable small-scale farming and mechanization across the entire field. Depending on the number of panels installed and the additional irrigation system, new aeration systems can be developed, allowing farmers to grow new or higher-value crops, thereby increasing their income.

To understand the implementation and best practices for agrivoltaics in India, a study and review of agrivoltaic projects across the country were conducted. Experts from the National Solar Energy Federation of India (NSEFI) and the Indo-German Energy Forum Support Office (IGEF-SO) collected data on power plant capacities, crops grown, operating principles, and technological and economic aspects, as shown in **Figure 13**. Overall, agrivoltaics in India encompass 23 ongoing projects and as of 3 upcoming projects in 2024, providing technical, financial, and agricultural insights. The study also assesses India's agrivoltaic policies, which serve as a foundation for discussions on project potential, highlighting the importance of agrivoltaics in the country's ongoing energy transformation.

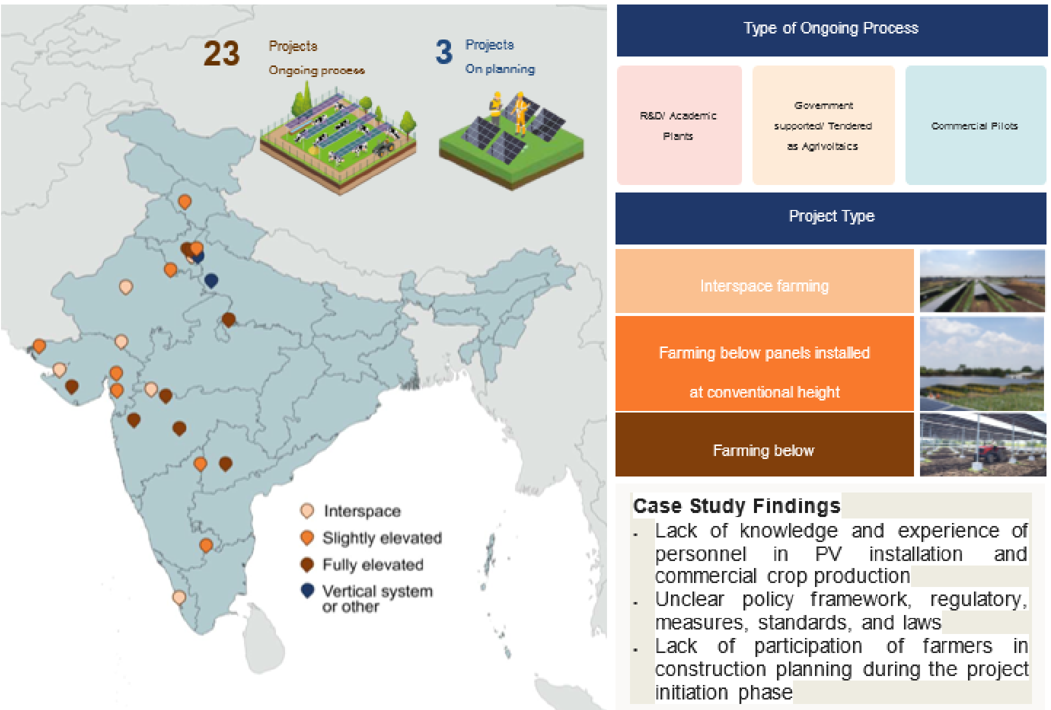


Figure 13 Overview of agrivoltaic projects in India

India has been testing the concept of agrivoltaics on a large scale, with almost half of the projects located in Gujarat. These projects have been implemented since 2012 by Abellon Energy and Jain Irrigation Systems Limited (JISL) from Maharashtra, both of which are leaders in the agricultural sector in India. Since then, agrivoltaics in India has evolved, involving several entrepreneurs. Currently, there are three distinct types of projects underway in the country: R&D-intensive projects, government-sponsored projects, and commercial projects developed by private entities.

To drive the adoption of agrivoltaics in India, a policy framework is necessary to create the right conditions. Drawing on the experiences of existing pilot projects, inputs from discussions within sub-committees on agriculture and energy sectors, and exchanges with local R&D institutions, appropriate policy recommendations have been identified. These recommendations are illustrated in Figure 14, with detailed descriptions provided in Table 1 [39].

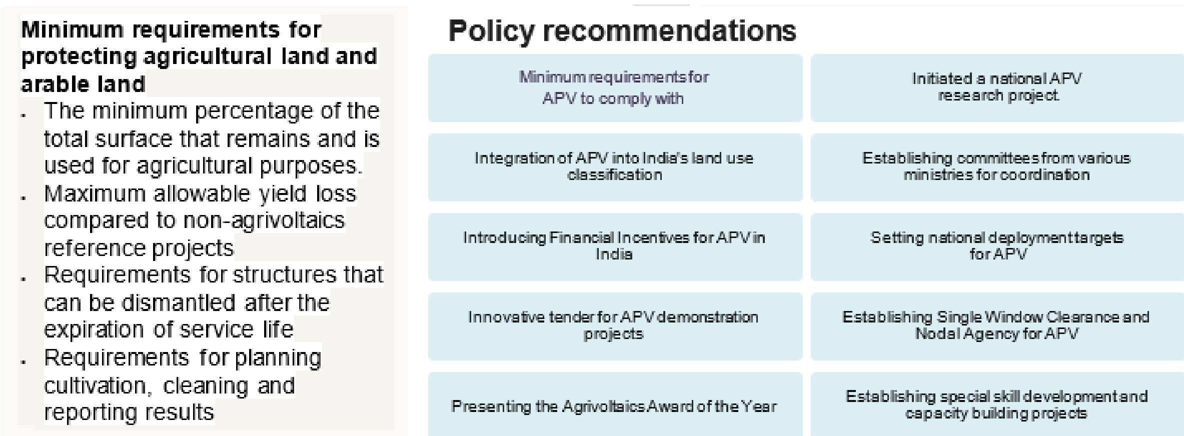


Figure 14 Policy recommendations on various topics [39]

Table 1 Policy recommendations for agrivoltaics in India [39]

Suggestions	Guidelines
1. Define Agriphotovoltaics[1]	- India may propose additional standards or requirements by assessing and analyzing international standards, such as DIN SPEC 91434:2021-05 [40] from Germany, ADEME's guidelines for characterizing solar PV projects on agricultural land and agrivoltaism from France, or the guidelines for the design, construction, and operation of agrivoltaic plants from Italy. - Allow the development of projects on agricultural land. - Ensure that at least 80% of the total surface area remains available for agriculture. - Enforce cropping plans, cleaning protocols, and periodic reporting. - Anticipate further modifications based on continuous feedback from farmers and project developers to improve the design. - Consult with the Ministry of Agriculture & Farmers Welfare to ensure that the ownership structure is clear from the outset.
2. Define deployment targets for Agriphotovoltaics for the next 10 years	- Start annual usage targets from MW to GW by 2030 - State sector requests to submit clear targets in ownership rights - Ministry of Agriculture & Farmers Welfare should be involved in improving cooperation between agriculture and energy sectors
3. Initiate special "innovation tenders" for Agriphotovoltaic projects	- The government should draft tender guidelines to facilitate states in adapting to regional conditions more easily. - Consider the cost structure of different types of agrivoltaic concepts by defining sub-groups within the tender guidelines (e.g., separate bidders for vertical and horizontal agrivoltaics). - Explore agrivoltaic farms with capacities greater than 10 MWp at the utility scale. - Consider providing a 25% viability gap funding for a predetermined initial capacity. - Facilitate bank financing for AgriPV projects specifically through institutions like IREDA and NABARD. - Engage with the Ministry of Agriculture & Farmers Welfare to explore opportunities for collaboration in the horticultural sector,

[1] In India, agrivoltaics is referred to as agriphotovoltaics.

Suggestions	Guidelines
	such as grapevines or other fruits and vegetables that require protection from the sun or other extreme weather conditions.
4. Introduce the 10th category of "agriphotovoltaic land" to the current classification of land in India	- Based on a report from the Ministry of Statistics and Programme Implementation [41] - Provide legal certainty to farmers by certifying specific land tenures, specifically on agricultural land yields and clearly defining lease rights - Categorize to ensure that developers receive all building permits if they comply with Agriphotovoltaics requirements - Develop guidelines to support states to expand common approval procedures in their regions
5. Establish a multi ministerial committee to coordinate action	- Establish a working group with members from MNRE, Ministry of Agriculture & Farmers Welfare and Ministry of Science and Technology - Engage stakeholders from industry and agriculture and the government
6. Introduce Agriphotovoltaics Award of the Year	- Collaborate with NISE at the national level
7. Establish a dedicated national research program on Agriphotovoltaics	- Create a summary of suitable agricultural and horticultural crops, the scope of productivity increase according to the climatic zone, which will help in designing and developing projects. - Involve Ministry of Agriculture & Farmers Welfare
8. Establish dedicated skill development and capacity building programs	- For example, cooperation with the Skill Council for Green Jobs.

From the case study on agrivoltaics in India, the following conclusions can be drawn:

- Agrivoltaics is a beneficial concept for India, with the potential to generate clean energy, help rural farmers contribute to the country's growth and progress, and preserve valuable and fertile agricultural land from increasing land pressure.
- Currently, the pilot agrivoltaic projects in operation range from kilowatt to several megawatt scales. These projects mostly focus on exploration, experience gathering, and research. There are no utility-scale pilot projects, resulting in a lack of technical, economic, and agricultural experiences.
- The case study of India shows a tendency to develop agrivoltaic project plans in three types of installation patterns:

    - Ground-mounted panels or interspace: An example is the project at Cochin Airport, which is the most modern and largest system in India.
    - Slightly elevated panels: These panels are installed slightly elevated to allow some crops to be grown under the panels and in the gaps between them. This space is suitable for growing shade-loving crops, resulting in slightly higher land utilization. Examples of projects include the CAZRI research projects in Jodhpur and the Gujarat Industries Power Company Ltd. (GIPCL) near Amrol.
    - Fully elevated panels: This type can be used for small-scale farming and mechanized cultivation in all parts of the area. It can be developed for complete climate adjustment depending on the number of panels installed and additional irrigation. This enables farmers to grow new or higher-value crops and thus diversify their income. An example of this system is a project near Parbhani. This type of farming has also been successfully implemented in the Amrol area on a large scale. The Junagadh and Amity projects stand out for their scientific data, and the Jain Irrigation project has the longest experience in this field.
- Although the cost of the panels is slightly higher due to the elevated installation structure of the agrivoltaic system, the reflection at the back of the panels is also increased, leading to a tendency for the use of bifacial panels.
- Promoting collaboration and good communication with all relevant parties will reduce the chances of miscommunication between stakeholders, leading to increased productivity and operational efficiency.
- Establishments across the country are consistently assessing the balance between the increased costs associated with supporting agrivoltaics and the income generated from cultivation. Key considerations for this analysis include identifying the increased infrastructure costs and the efficient maintenance and cleaning of solar panels, both of which are important for enhancing the efficiency and positive impact of agrivoltaic systems.

Adaptation to the Thai context

Adapting the Indian's agrivoltaic use case to the Thai context involves leveraging Thailand's abundant sunlight and agricultural land, similar to India's approach, to maximize the dual benefits of solar power generation. It is important to implement a policy framework that supports the integration of solar power into agricultural activities. This includes providing incentives for farmers, ensuring flexibility in land use regulations, and offering technical support for the optimal combination of crops and solar power. Furthermore, addressing local issues such as power system reliability and water management can enhance the efficiency of solar power generation systems. This can be achieved by fostering collaboration between government agencies, research institutions, and local communities. Thailand can adapt India's successful strategy to suit its unique environment and socio-economic conditions.

Japan

In Japan, agrivoltaic farming, also known as solar sharing, is a system of installing photovoltaic (PV) panels on agricultural land, enabling both energy production and crop cultivation by sharing sunlight. This practice was initiated in 2004 in Chiba Prefecture by Akira Nakashima, with the aim of utilizing agricultural land for both crop cultivation and solar power generation to address the problem of land shortage. Nakashima studied the light saturation of plant photosynthesis to develop the basic concept of agrivoltaics, which he named "solar sharing." This concept involves allocating sunlight to plants according to their needs and directing the excess light to solar panels, thereby enabling simultaneous crop production and energy generation. The development of agrivoltaics technology in Japan is illustrated in Figure 15. The benefits of this technology extend beyond renewable energy production; it also serves as a strategy for rehabilitating abandoned and underutilized agricultural land, positively impacting both energy and food security.

Solar Sharing: agricultural production in agrivoltaics relies on direct solar insulation

The Japanese government has set an ambitious target to increase the country's share of renewable energy in the power sector to 36–38% by 2030, according to its Sixth Strategic Energy Plan released in October 2021. Increasing the share of solar power is a challenge for Japan, as only 34% of its land area is flat, and much of it was already developed by the time the Feed-In Tariff was introduced in 2012 [42]. Solar PV projects on hillsides and in forest areas face increasing resistance from local stakeholders due to their impacts on deforestation and landslides [43]. Therefore, it is important to find alternative areas for solar power development.

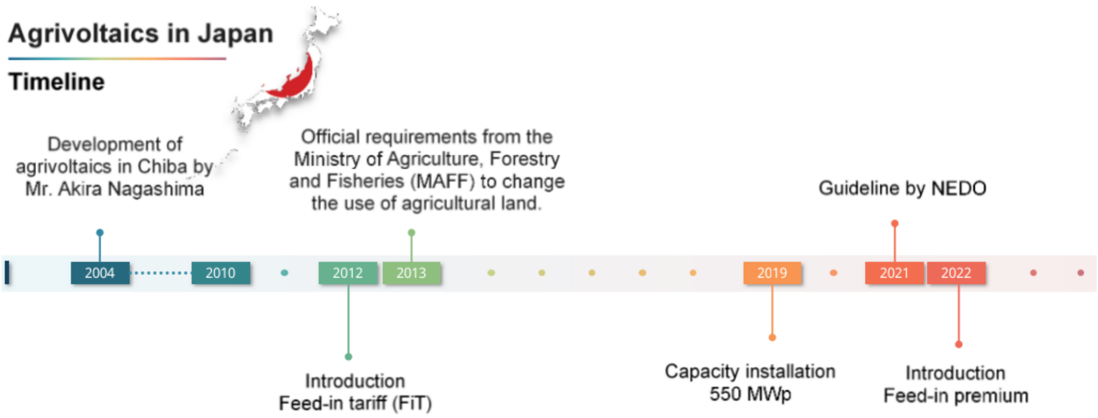


Figure 15 Timeline of agrivoltaic development in Japan

To achieve this goal, solar photovoltaic power (also known as solar power) plays an important role in the development of the Regional Circular and Ecological Sphere (R-CES) [44], which is used as a guiding principle for domestic environmental policies. This makes renewable energy projects implemented in rural areas particularly important. Agrivoltaic systems (AVSs) can not only improve farmers' incomes but also create opportunities to revive declining population growth and economic activity in rural areas [45]. Agrivoltaics is a concept that is expected to help reduce land use conflicts and increase the area of abandoned farmland in Japan [46]. The extra income from agrivoltaic systems can help sustain agricultural businesses [47]. Although Japan has been a pioneer in agrivoltaics, it still accounts for less than 1% of the non-residential solar PV systems in the country.

With approximately two-thirds of Japan's terrain being mountainous and limited flat land available, there is a significant demand for rooftop and unused land. The Solar Sharing community aims to make better use of agricultural land, utilizing home-grown technology to increase self-sufficiency on various types of agricultural land, including abandoned land as shown in **Figure 16**. If Solar Sharing were expanded to cover an additional 10% of Japan's approximately 4.77 million hectares of agricultural land (with abandoned land accounting for 9% of the total), it could potentially meet around 37% of the country's electricity needs [48].

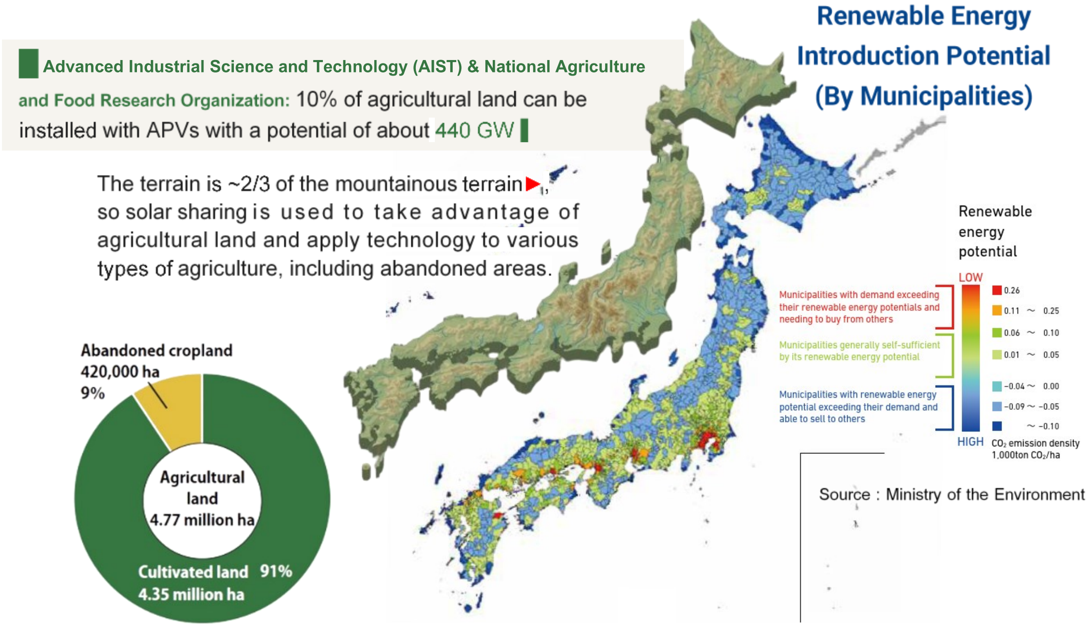


Figure 16 Overview of the driving forces behind agrivoltaic development in Japan

Based on the case study of Japan, the benefits of solar sharing can help address several challenges the country is facing, including coping with climate change, improving energy self-sufficiency, enhancing food self-sufficiency, and revitalizing local communities [48]. The details are as follows.

Figure 17 Using of solar sharing to solve four of Japan's problems

Fighting Climate Change: the Japanese government has set a goal to reduce greenhouse gas emissions by 2030 and achieve net-zero GHG emissions by the fiscal year 2050. To accomplish this, they aim to use renewable energy to lower CO2 emissions and convert abandoned or unused land into arable land to create carbon sinks [48].

Improving energy self-sufficiency: Japan's self-sufficiency rate for primary energy is very low for an industrialized country, as it still relies heavily on imported fossil fuels such as oil, coal, and natural gas (LNG). Renewable energy can help increase energy self-sufficiency, and agrivoltaics can contribute by boosting the share of solar power generation from the community sector [48].

Improving Food Self-Sufficiency: Considering the calorie intake data, Japan's food self-sufficiency rate in 2021 was only 38%, which is quite low. Therefore, converting abandoned or unused land into agricultural land can help improve food self-sufficiency. This initiative can also increase farmers' incomes and support the next generation of farmers [48].

Revitalizing Local Communities: Japan is facing a population densification issue as a significant portion of the population continues to migrate to large cities. Currently, 35.4% of the population resides in the Tokyo metropolitan area, and 52.5% live in the surrounding regions of Tokyo, Osaka, and Nagoya. This migration trend has led to population decline in other areas. Utilizing distributed energy within communities and promoting active agriculture can enhance local food self-sufficiency and help revitalize these communities [48].

Case study in Japan

There are currently approximately 1,992 agrivoltaic projects spread across Japan, as shown in Figure 18. These projects cover an area of 560 hectares, with most being small-scale systems, typically less than 0.1 hectare. In Japan, more than 120 types of crops are grown under agrivoltaic systems. However, the installation of these systems often results in changes to the types of crops grown, which can affect local markets. Shading rates in agrivoltaic systems vary greatly, generally depending on the light requirements of the crops. Typically, higher shading rates are selected to maximize electricity production [49].

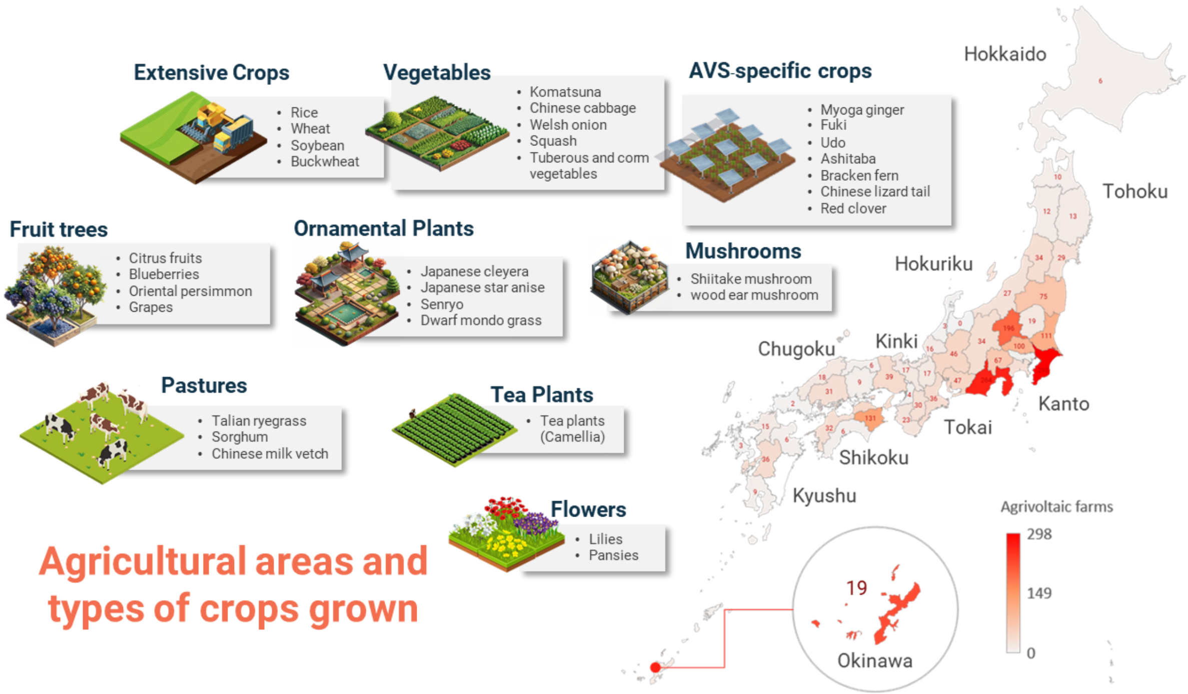


Figure 18 Agrivoltaic projects spread across the country and the types of crops that can be grown in Japan

Policy and Legal Framework

Laws and regulations play a crucial role in the diffusion of technologies, including simplifying local implementations to enable rapid expansion. Common barriers to the spread of renewable energy include unclear energy policies, inadequate legal frameworks, complex bureaucratic approval processes, conflicting interests among stakeholders, and a lack of research and institutional capacity [50]. These factors can undermine stakeholder confidence in investing in renewable energy technologies. Therefore, well-designed laws and regulations are essential to creating a safe, predictable, and resilient environment for this innovation.

The case of agrivoltaics is more complex than other renewable energy technologies, as it directly affects both the energy and agriculture sectors. Furthermore, the involvement of all levels of government is essential for its effective implementation. Therefore, multi-sectoral and multi-level regulatory interactions are required. It is crucial to achieve policy integration that transcends defined policy sectors, enabling information sharing, transparency, and the reinforcement of policies towards a common goal [51]. Effective collaborative policies can create a win-win situation for all sectors, which should be the goal for agrivoltaics. Capacity building and awareness-raising at the local level are also crucial for its successful implementation[52].

The introduction of the Feed-in Tariff (FIT) scheme in 2012 significantly promoted the development of solar farms by providing financial incentives for renewable energy projects, making them more cost-effective. In 2021, Japan’s New Energy and Industrial Technology Development Organization (NEDO) issued new guidelines on the development and construction of ground-mounted agrivoltaic facilities, as shown in Figure 19. Developed under the supervision of the Ministry of Economy, Trade and Industry (METI), these guidelines provide comprehensive instructions for ground-mounted solar PV systems on agricultural land. They emphasize the importance of planning these projects from the design stage to optimize both agricultural and energy production. The guidelines also include height restrictions and other regulations to ensure the efficient integration of agrivoltaics into the agricultural landscape. This approach not only supports renewable energy generation but also serves as a strategy to rehabilitate abandoned and underutilized agricultural land, positively impacting both energy and food security.

Table 2 Policy and regulation supporting agrivoltaic in Japan

	Policy/Regulation	Function
Japan	• 6th Basic Plan for Energy • Basic Plan for Food, Agriculture, and Rural Areas • Design and construction guidelines for farming solar power generation systems	agrivoltaics Planning Development, Authorisation, and Incentivisation

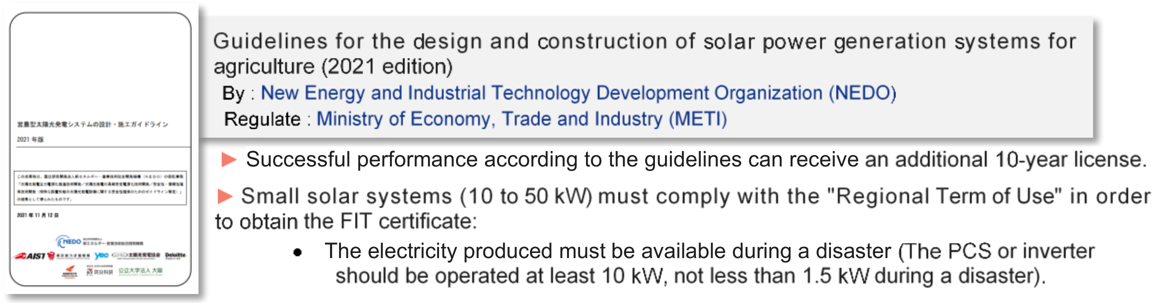


Figure 19 Guidelines for implementing solar power generation systems for agriculture in Japan

Since the issuance of an order by the Agricultural Promotion Bureau of the Ministry of Agriculture, Forestry, and Fisheries (MAFF) in March 2013 [53], agrivoltaic systems have been permitted on all types of agricultural land in Japan. This is in contrast to traditional ground-mounted PV systems, as illustrated in Figure 20.

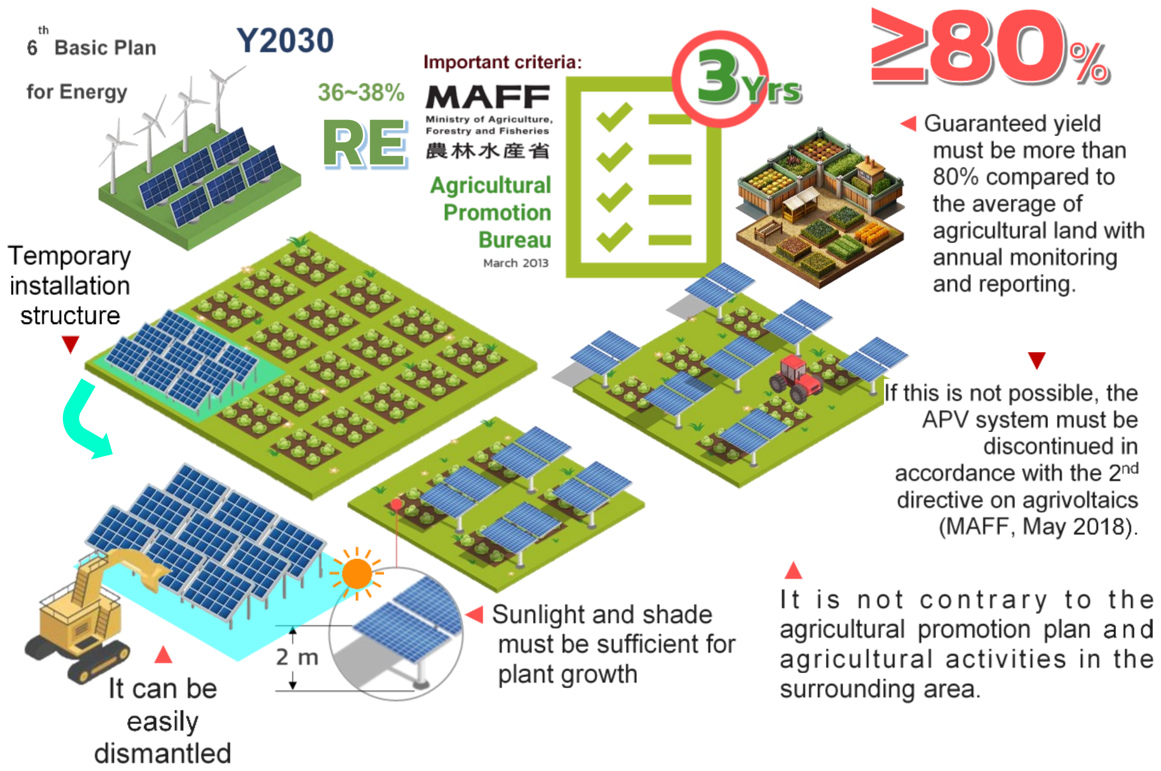


Figure 20 Agricultural Promotion Bureau conditions for agrivoltaic systems issued by the Ministry of Agriculture, Forestry and Fisheries (MAFF)

Regulations from both the agriculture and energy sectors are crucial for the implementation of agrivoltaic projects. Initial permits are only available for three years, after which a new permit must be obtained. The requirements for approval are as follows:

- The installation structure must be temporary and easily removable.
- The shading rate must allow sufficient sunlight for plant growth.
- The minimum panel height is 2 meters.
- The system should not interfere with agricultural practices in the surrounding area or adversely affect the implementation of the Agricultural Promotion Plan.
- The yield must not decrease by more than 20% compared to the average level of the surrounding agricultural area, as monitored by annual reporting.

In cases where agricultural production is not possible, the agrivoltaic system must be discontinued, according to the second directive on agrivoltaics issued by MAFF in May 2018. The conditions for obtaining a license have been extended to 10 years if:

- Farmers can demonstrate competence in agricultural practices and management, or
- The system is installed on devastated farmland, or
- The system is installed on second- or third-class farmland.

The latest, third directive issued by MAFF in March 2021 allows exceptions to the established rules by:

- Waiving the 2-meter height requirement for vertically installed agrivoltaic systems, and
- Removing the need for temporary land conversion and yield requirements for agrivoltaics on devastated land

However, agrivoltaic projects require approval for certain land use conversions to non-agricultural purposes by the responsible local agricultural councils. Key guidelines and regulations include height restrictions for installations (not exceeding 9 meters) [54], exemptions for projects using trackers or facilities in barns and greenhouses, and the classification of land used for agrivoltaics as agricultural land, which provides tax benefits. Development incentives include the Feed-in Tariff (FIT) scheme, a 50% rebate on project costs, and incentives for self-consumption production or projects with a Power Purchase Agreement (PPA). Policy support is available through orders from the Ministry of Agriculture, Forestry and Fisheries (MAFF) and amendments to the FIT Act. Key regulations cover planning and design to optimize agricultural production, land conversion requirements, and shading and crop selection to balance the benefits of agricultural and solar power generation.

Adaptation to the Thai context

To adapt Japanese renewable energy power generation systems to the Thai context, we should consider Thailand's unique agricultural practices, climate, and crop types. Elevated solar panels should be installed to ensure they do not obstruct agricultural activities and provide sufficient sunlight to crops. It is also important to select crops that can grow under partial shade. Furthermore, the integration of Thai renewable energy power generation systems should align with Thailand's renewable energy goals, which aim to increase farmers' income while maintaining agricultural yields. Regular monitoring and reporting of agricultural and energy yields are important to ensure compliance and assess system performance. Adapting these practices to local conditions will help promote sustainable agriculture and renewable energy in Thailand.

Republic of Korea

The development of agrivoltaics in South Korea began in 2016, as illustrated in Figure 21. Solar Farm installed a 15 kW agrivoltaic system in Ochang City for rice cultivation and another 15 kW system for cabbage and potatoes. These installations were based on the Solar Sharing farm design from Japan and were part of a research project by the Ministry of Agriculture, Food & Rural Affairs (MAFRA). Currently, the installed agrivoltaic systems in South Korea total approximately 3.2 MW [55]. From 2016 to 2019, most of these systems were research and testing projects, as shown in Table 3. The main project developers include:

- Power companies: South-East Power Company, Water-Nuclear Power Company, East-West Power Company
- Private companies: Solar Farm, Paru, GS Construction, HS Solar, Haereum, Nonghyup
- Research institutes and universities: Green Energy Institute, Yeungnam University

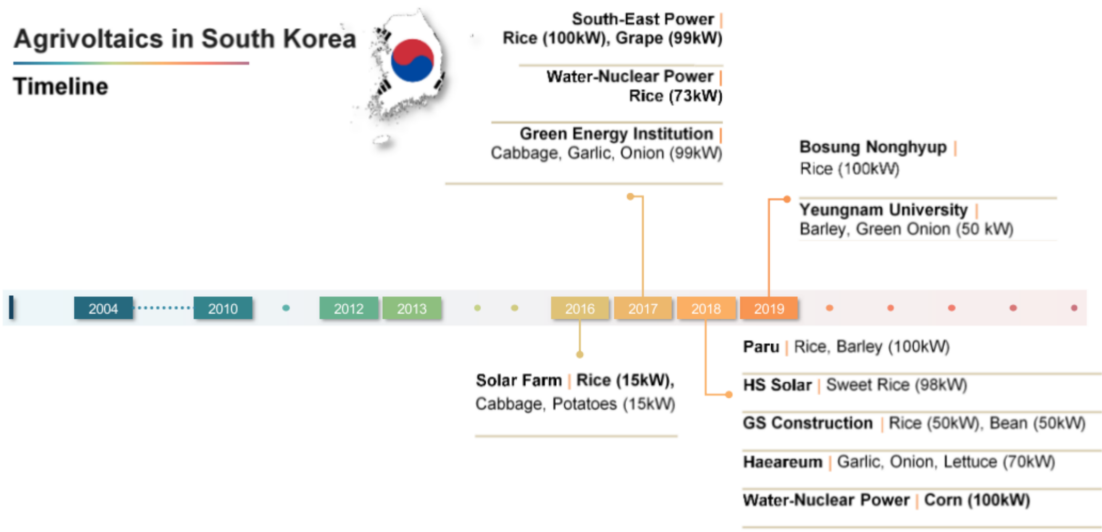


Figure 21 Timeline of agrivoltaic development in South Korea

Table 3 Installation of Korean agrivoltaic solar power systems from 2016 to 2019 [55]

Year	Organization	Crop	Capacity (KW)	Cover Ratio (%)
2016	Solar Farm	Rice	15	29
	Solar Farm	Cabbage, Potatoes	15	29
2017	South-East Power	Rice	100	28, 32
	Water-Nuclear Power	Rice	73	-
	Green Energy Institution	Cabbage, Garlic, Onion	99	28, 30
	South-East Power	Grape	99	30
2018	Paru	Rice, Barley	100	-
	HS Solar	Sweet Rice	98	25, 30
	GS Construction	Rice	50	31.5

Year	Organization	Crop	Capacity (KW)	Cover Ratio (%)
	GS Construction	Bean	50	31.5
	Haeareum	Garlic, Onion, Lettuce	70	31.5
	Water-Nuclear Power	Corn	100	-
2019	Bosung Nonghyup	Rice	100	31.6
	Yeungnam University	Barley, Green Onion	50	30

The motivation for agrivoltaics in South Korea stems from the fact that the country imports 97% of its energy, primarily from fossil fuels such as coal and oil as shown in Figure 22 [56], which poses a significant energy security risk. Additionally, to achieve carbon neutrality by 2050 and address global warming and the energy crisis, there is a need to shift energy use patterns from fossil fuels to renewable energy. South Korea has ample renewable energy sources, most notably solar power.

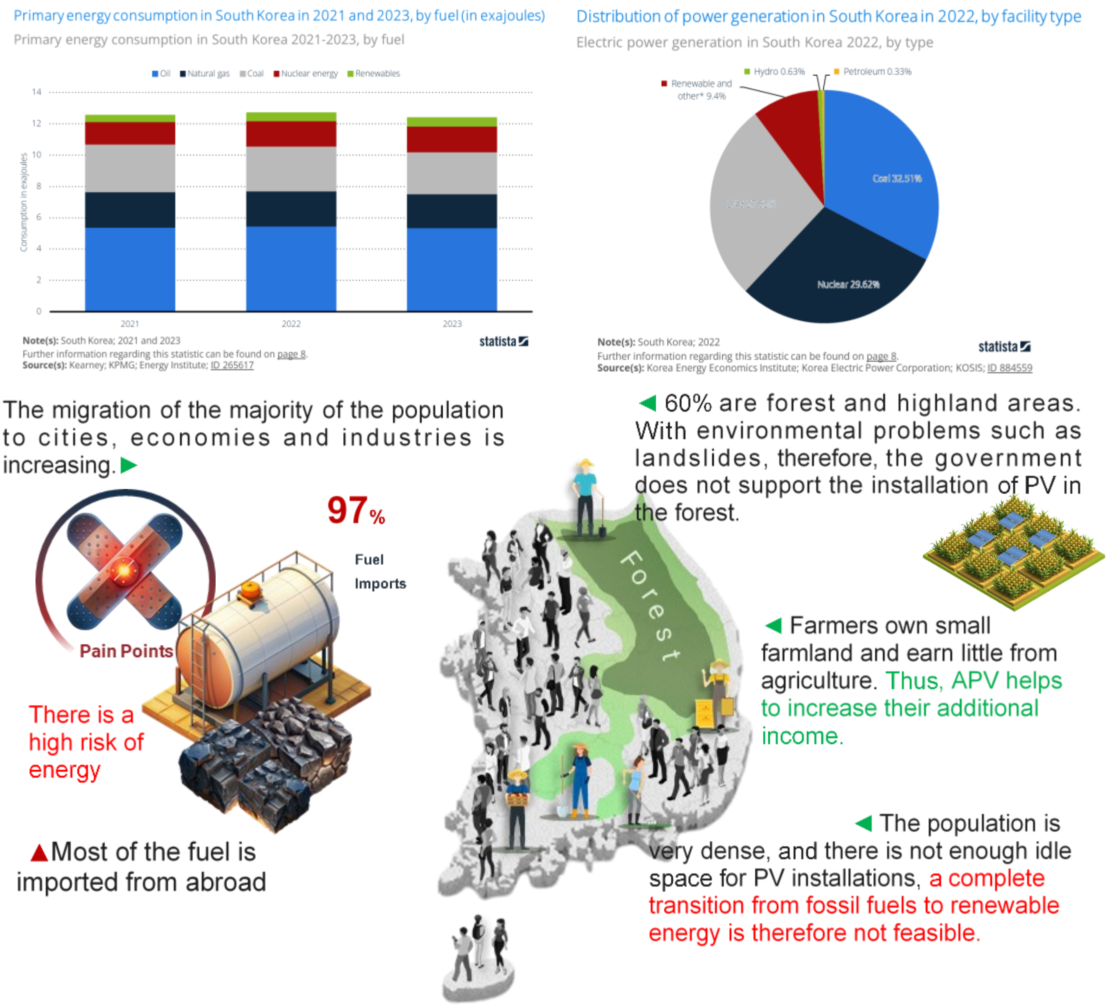


Figure 22 Energy consumption and incentives for agrivoltaic in South Korea

Since South Korea is a densely populated country, most of the land is allocated for residential purposes. As a result, there is limited available land for solar PV installations, which hinders the complete transition from fossil fuels to renewable energy. In 2019, the total PV installations in Korea amounted to 3.7 GW [55], with 61 % located in forests, as shown in Figure 23. Agricultural land accounted for 20 percent, while the remaining 7.2 percent and 11.8 percent were installed in salt farms and other types of farms, respectively. However, due to environmental concerns, the Korean government does not support the installation of PV systems in forests. Therefore, to meet the country's energy transition needs, utilizing agrivoltaic land in agricultural areas is another solution that can provide sufficient space for solar PV generation.

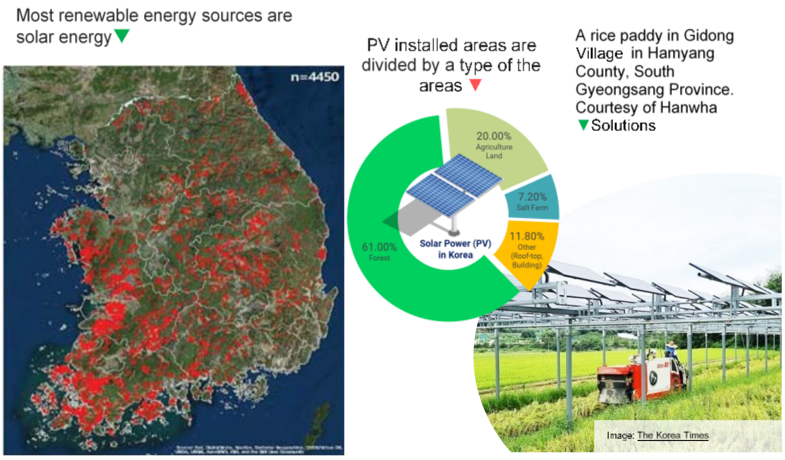


Figure 23 Current solar power (PV) installations in Korea [55]

Case study in South Korea

Another reason for the demand for agrivoltaics in South Korea is that farmers are looking to increase their income. Korean farmers typically own only small plots of arable land, making the agricultural economy less prosperous compared to the booming manufacturing industries in cities. As a result, many young people from rural areas are moving to urban centers. Agrivoltaics can offer a solution to the challenge of land allocation for solar power generation, facilitating the energy transition and generating additional income for farmers.

To revive the agricultural economy, it is necessary to generate income from farmland through agrivoltaic systems. However, the Korean Agricultural Land Act prohibits the use of farmland for activities other than farming. Additionally, Korean farmers, who mostly own small plots of land, face significant obstacles, making the agricultural economy less robust compared to the manufacturing industry. As a result, most of the working-age population has moved from rural agricultural areas to cities where economic growth is more prominent.

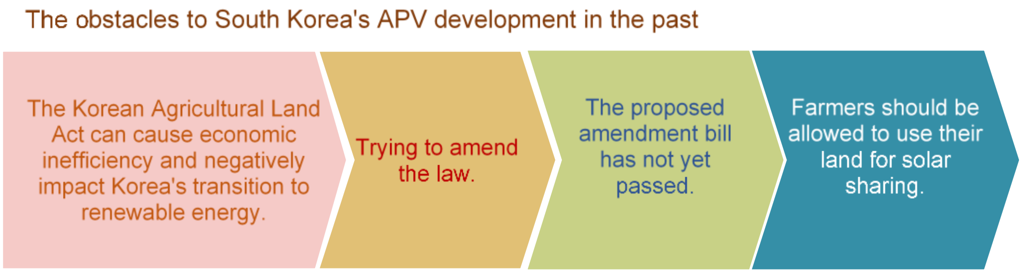


Figure 24 The challenge of South Korea's agrivoltaic development

However, the Agricultural Land Act imposes significant restrictions on solar power generation. South Korea's agricultural land is categorized into absolute agricultural land and relative agricultural land as shown in Figure 25. On absolute agricultural land, no activity other than farming is permitted. Land conversion to other types is also prohibited, except for reclaimed agricultural land with salinity levels exceeding 3,200 ppm, which can be temporarily used for solar power generation for up to 20 years. On relative agricultural land, temporary use for solar power generation is allowed for up to 8 years (5 years plus an additional 3 years), and such land can be converted to non-agricultural use. Despite the higher income from energy production compared to agriculture, the government and farmers remain concerned about the potential loss of agricultural land, which could reduce food production and pose food security risks.

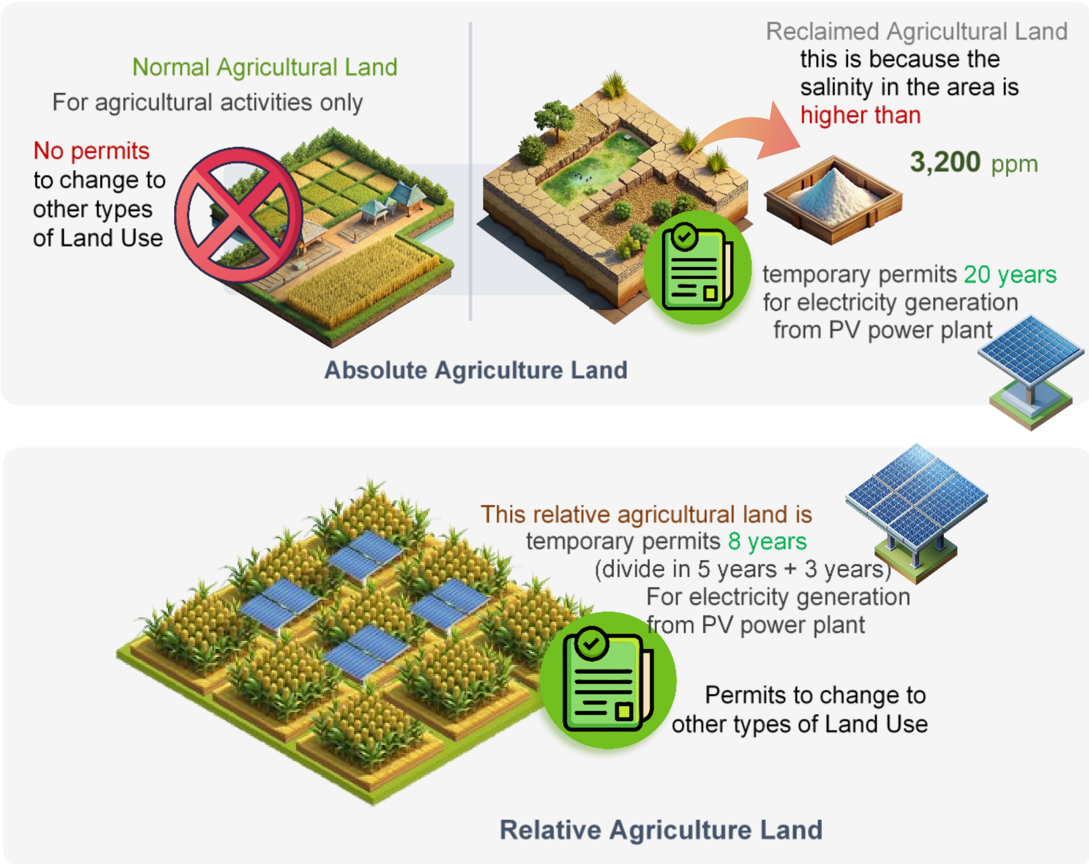


Figure 25 Types of agricultural land in South Korea

Policy and Legal Framework

Regarding the current status of South Korea's agrivoltaic policy, the government has made efforts to promote agrivoltaics. The parliament has proposed several amendments to the Agricultural Land Act. In June 2020, members of the Korean parliament proposed an amendment to the Agricultural Land Act, which would define agrivoltaics as a power generation system under the new Renewable Energy Act. This amendment also proposed that all agricultural land (including both absolute and relative agricultural land) be used for a minimum period of 10 years. However, MAFRA did not support the amendment due to concerns about food security. Environmentalists also raised concerns about potential damage to the landscape. A compromise amendment was proposed in March 2021, suggesting that agrivoltaics be used only on relative agricultural land. This amendment would allow each farmer to generate up to 100 KW of electricity for temporary use over 23 years, with government financial support and special rights to purchase agrivoltaic power. Ultimately, MAFRA agreed to this amendment, and it is expected to pass the amendment process in the Korean parliament in the future [55].

Table 4 Policy and regulation supporting agrivoltaic in South Korea

	Policy/Regulation	Function
Korea	• Korea's Farmland Act	• Under Korea's Agricultural Land Act, farmers are permitted to use their farmland for non-agricultural purposes for up to 8 years.
	• The Measures of South Korea's Ministry of Agriculture, Food and Rural Affairs	• The permit period for using non-agricultural land for power generation has been extended from 8 years to 23 years

From the case study of agrivoltaics in South Korea, two main needs can be summarized:

- Expansion of solar power generation areas to support the policy of transitioning from fossil fuels to renewable energy, addressing the energy crisis, global warming, and energy security. The Ministry of Trade, Industry, and Energy (MOTIE) plans to produce 10 GW of agricultural PV by 2030.
- Promotion of agrivoltaics to increase farmers' income. However, the Ministry of Agriculture, Food and Rural Affairs (MAFRA) is concerned about the potential decline in agricultural yield, which may affect the country's food security. The use of agricultural land is of great importance, and the sudden introduction of agrivoltaics may face resistance.

Therefore, it is crucial to demonstrate that the reduction in agricultural yield due to agrivoltaics is acceptable and does not compromise the country's food security. This should be based on research and data from tested projects. This approach will guide the agricultural sector and environmentalists to ensure that any impact on food security and the landscape is within acceptable limits. It will also lead to the improvement of agricultural land laws, allowing for the gradual introduction of agrivoltaics and ensuring the confidence of all stakeholders, including the government, farmers, and environmentalists [55].

Adaptation to the Thai context

The adaptation of the South Korean solar farm concept to the Thai context involves leveraging Thailand's abundant sunlight to install solar panels at optimal heights and angles to shade crops. This approach, similar to the Korean model, will protect crops from excessive heat and reduce evaporation. Additionally, policy support is crucial. Thailand can offer incentives and training programs for farmers, akin to the Korean initiative, to encourage the adoption of solar farms. Integrating solar farms with local crops that thrive in partial shade, such as certain vegetables and herbs, can also boost agricultural productivity. Regular monitoring and community engagement will ensure these projects are sustainable and effective.

3.2 Europe

Agrivoltaics in Europe is particularly relevant to policies focused on energy transition, sustainable agriculture, and environmental protection, aligning with the objectives of the European Green Deal [57]. This technology offers numerous benefits, such as improved land productivity, water conservation, and economic advantages for farmers. Europe is a key player in driving a sustainable energy future and continues to explore and expand the agrivoltaic sector, showing a positive development trend. This section presents case studies of agrivoltaics technologies in various European countries that have made significant progress in this area, detailed below.

French Republics

France has made significant progress in solar agriculture in recent years. The concept initially began with small greenhouse projects in the early 2000s, as shown in Figure 26, which aimed to integrate solar energy production into agricultural activities. Over the past 15 years, the government of France has supported large-scale solar installations, particularly in degraded areas, through incentives such as guaranteed electricity feed-in tariffs. Additionally, new regulations and laws, such as Decree No. 2024-318, have been introduced to promote the combined use of solar and agricultural land. These regulations ensure that solar farm installations do not negatively impact soil potential and agricultural productivity, while supporting the country’s energy transition and agri-economics.

Although solar agriculture offers many opportunities, such as increasing the agricultural potential of unused farmland and contributing to the decarbonization of the energy sector, regulating solar agriculture involves complex and diverse policymaking at both national and local levels.

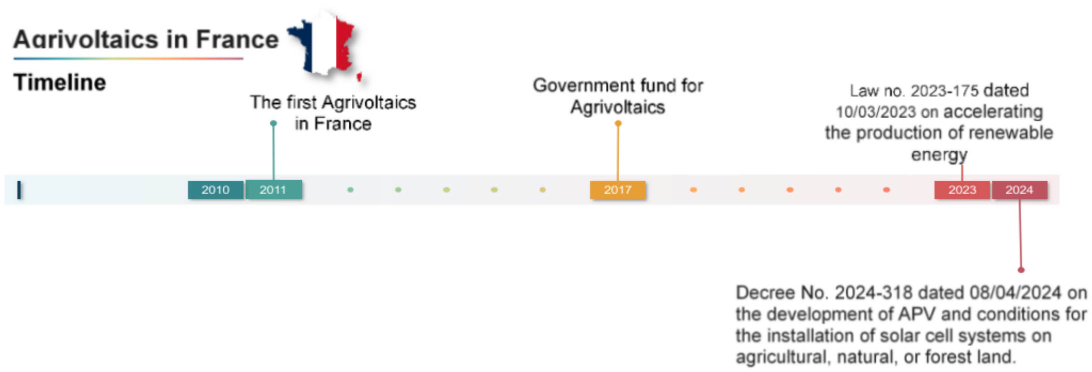


Figure 26 Timeline of agrivoltaic development in France

France: electricity production facility using the sun's radiative energy, whose modules are located on an agricultural plot where they make a sustainable contribution to the establishment, maintenance or development of agricultural production

Case study in France

Pilot and research projects, such as those conducted by Sun'Agri, Ombrea, Reden Solar, and Akuo Energy, play a key role in monitoring the performance of solar power generation systems, as shown in Figure 27. These projects collect data on parameters including plant growth, energy yield, and environmental impact to inform best practices and policy decisions [58].

Figure 27 Example images of agrivoltaic projects in France

Policy and Legal Framework

The French government has been proactive in integrating solar power generation into agricultural activities, recognizing the dual benefits of using land for both energy production and agriculture. This approach addresses land shortages while promoting renewable energy. In April 2024, France issued a new regulation, Royal Decree No. 2024-318, which sets clear guidelines for the installation of photovoltaic (PV) panels on agricultural land, as shown in Table 5. The provisions emphasize that PV installations should not negatively impact soil potential and ensure that no more than 10% of agricultural yield is lost. Furthermore, PV installations are limited to no more than 40% of agricultural land. These measures aim to balance energy production with agricultural yield, ensuring that the primary function of the land remains agriculture [59]. Additionally, the target of 100 GW of solar power generation capacity by 2050 significantly increases the role and potential of agrivoltaics in the energy transition within both the French energy and agricultural sectors [60].

Table 5 Policy and regulation supporting agrivoltaics in France

	Policy/Regulation	Description
France	• Décret no° 2024-318 by the Ministère De L'économie (08 April 2024), Development of agricultural systems and conditions for the installation of photovoltaic power systems on natural agricultural or forest land.	• The new provisions state that agrivoltaic systems should not adversely affect soil potential and must ensure that the loss of agricultural yield is less than 10%. • Establishments installing agrivoltaic systems, except for those involved in livestock farming, must ensure that agricultural yield is not less than 90% per hectare compared to the specified control zone. The installation of PV systems can cover an area not exceeding 40% of the agricultural plot.
	• Law no. 2023-175	**Criteria**: Agrivoltaics must provide at least one of the following services to ensure essential agricultural production and sustainable income for farmers: • Climate change adaptation • Natural hazard protection • Animal welfare • Improvement of agricultural potential The above services define essential agricultural production and sustainable income for farmers. They also outline the conditions for implementation and supervision, and provide for the inspection and control of operations, which may be specified by a future Royal Decree.

France has established several key mechanisms to monitor and support the development of agrivoltaic projects, ensuring their effectiveness and sustainability in the following areas:

In terms of regulatory framework and monitoring and inspection

In addition to Decree No. 2024-318, agrivoltaic projects are subject to regulatory controls at both local and national levels. The technologies for installing agrivoltaic systems must comply with the requirements set by the Ministerial Decree responsible for Energy and Agriculture. Data obtained from agrivoltaic activities are compiled based on the latest developments and statistics collected by the Environmental and Energy Management Office, serving as a reference for evaluating agricultural productivity.

For new farmer installations, income is considered sustainable when compared to the results observed in other farms of the same type in the locality. Therefore, agrivoltaic projects must undergo performance monitoring to ensure they meet regulatory requirements and achieve the desired outcomes. This includes monitoring agricultural productivity, soil health, and energy production to assess the overall impact of the installation [59].

In terms of support mechanisms

In France, the adoption of agrivoltaic systems is supported through various mechanisms. The government offers financial incentives, such as feed-in tariffs for solar PV installations with a power output of 500 kW or less, and special tenders to make these projects more cost-effective for farmers and energy producers. Research and development efforts are bolstered by organizations like the French Environment and Energy Management Agency (ADEME), which publishes standards and guidelines to ensure agrivoltaic systems meet specific criteria for both energy production and agricultural output. Additionally, the French Agro-Photovoltaic Association unites stakeholders from various sectors to promote and develop agrivoltaic solar power, focusing on certification, regulation, and international affairs to enhance industry standards and support growth. Details are as follows:

- The French government offers various incentives to support the adoption of agrivoltaic systems. For example, solar PV installations with a power output of 500 kW or less are eligible for feed-in tariffs. Special tenders are also called for. These financial incentives help make agrivoltaic projects more cost-effective for farmers and energy producers [61].
- Research and Development: Organizations such as the French Environment and Energy Management Agency (ADEME) support agrivoltaic research and development. ADEME publishes standards and guidelines to help define and classify agrivoltaic systems, ensuring they meet specific criteria for both energy production and agricultural output [62].
- French Agro-Photovoltaic Association: This association brings together stakeholders from the agricultural, energy, research, finance, and technology sectors to promote and develop agrivoltaic solar power. It has established a committee focused on certification, regulation, and international affairs to raise industry standards and support the growth of agrivoltaic solar power in France [58].

Environmental restrictions and restrictions on land use

Environmental Restrictions for Agrivoltaic Systems in France, once installed, agrivoltaic systems should not negatively impact the soil's potential. They must also allow for the demolition and restoration of the local area without causing environmental damage [62]. Regarding land use restrictions, agrivoltaic systems can be operated on agricultural land, except in protected areas, areas designated for agricultural and forest land development under the Rural and Marine Fisheries Act, conservation and landscape areas, natural protection areas, and forests of the Highlands.

Together, these mechanisms ensure that solar power projects in France are well-regulated, supported, and monitored, helping to achieve the country's goals for sustainable agriculture and renewable energy production, as shown in Figure 28.

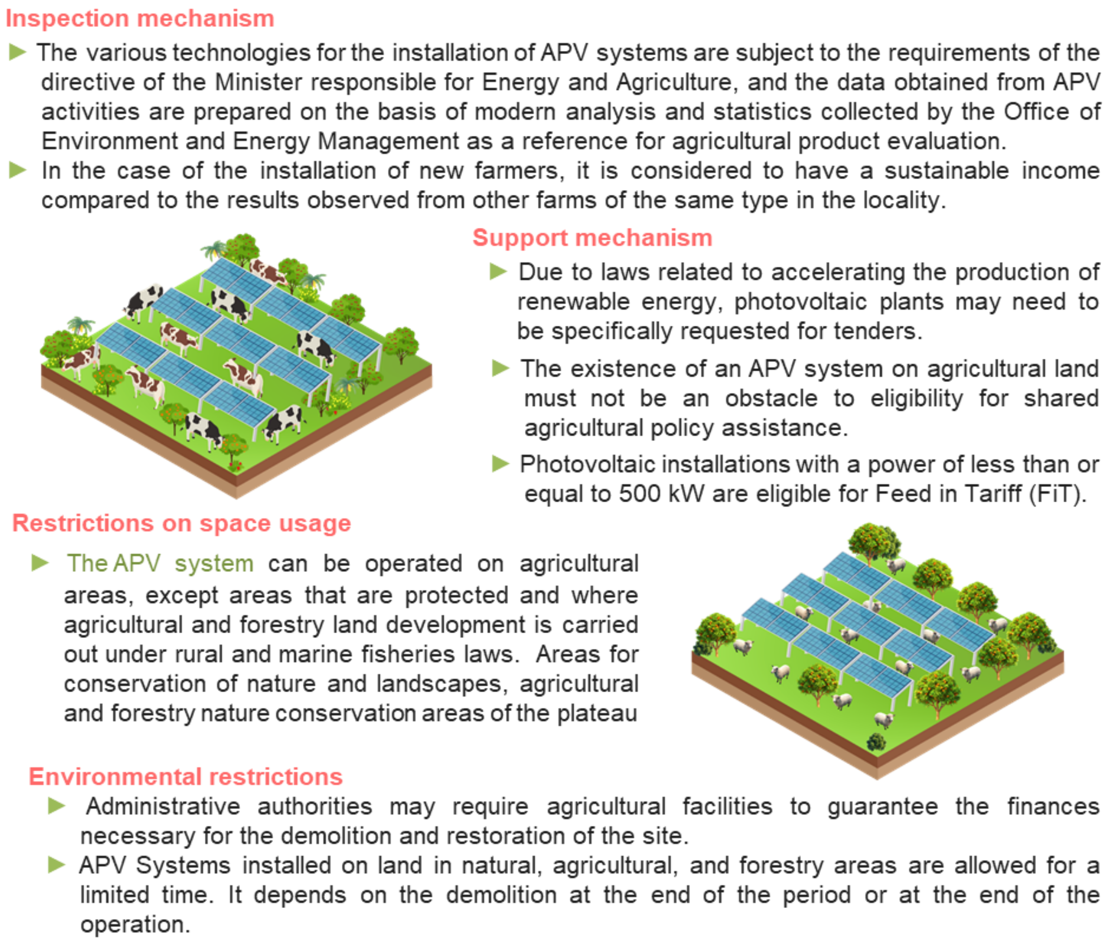


Figure 28 The Key mechanisms to monitor and support the development of agrivoltaic in France

Adaptation to the Thai context

To adapt the French solar use case to the Thai context, we can focus on integrating solar panels with agricultural practices in a way that maximizes both energy yield and crop production. The French approach emphasizes minimizing the impact on agricultural production, with regulations ensuring that the installation of solar systems does not reduce crop yields by more than 10% and covers no more than 40% of the agricultural area. For Thailand, a similar approach can be developed to protect agricultural production while promoting renewable energy. Furthermore, given Thailand's tropical climate, selecting crops that thrive in partial shade and designing adaptive solar systems to optimize light distribution can help maximize the synergy between solar power and agriculture. Collaboration with local farmers and researchers to tailor these systems to the specific needs and crops of each region will be essential for successful implementation.

Federal Republic of Germany

Agrivoltaic technology in Germany has been continuously developed since its inception in 1981, as shown in Figure 29, through a combination of technological and policy advances. The EEG 2023 Act has significantly supported this progress by improving the auction process, ensuring grid access rights, and establishing feed-in tariffs to encourage more renewable energy generation [63]. Additionally, land used for agrivoltaic systems remains eligible for a direct payment of 85% under the EU's Common Agricultural Policy (CAP) [64], provided that at least 80% of the land is used for agriculture. To ensure the quality and reliability of agrivoltaic systems, the DIN SPEC 91434 standard has been introduced as a framework for their supervision and certification.

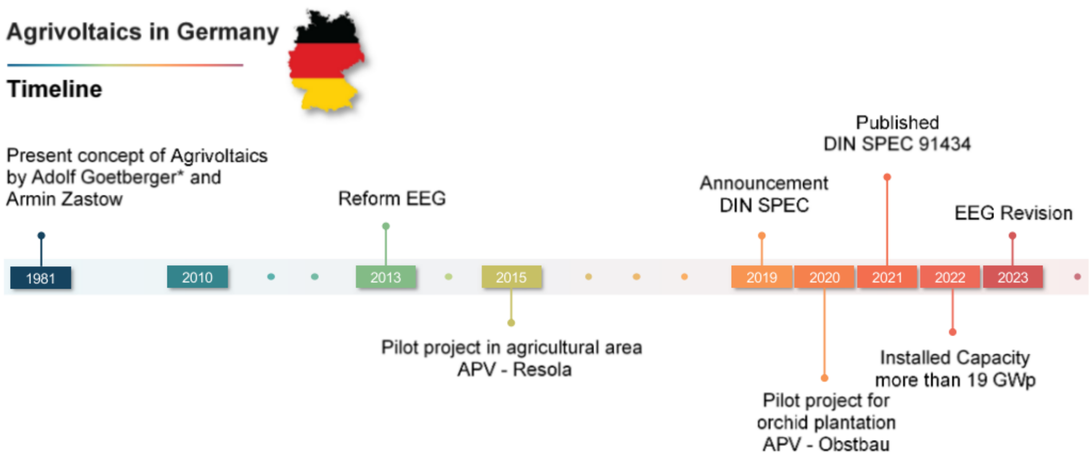


Figure 29 Timeline of agrivoltaic development in Germany

As of 2021, Germany has approximately 59 GWp of installed solar PV capacity, with 75% coming from rooftop systems and the remainder from ground-based systems [65]. However, this is not sufficient. The Fraunhofer ISE estimates that Germany will need between 300 and 450 GWp of installed capacity by 2045 [66]. Integrating solar PV technologies into buildings, vehicles, and transport routes, as well as deploying them in agricultural, aquatic, and urban areas, will unlock significant electricity generation potential.

Germany has established several research projects focused on agrivoltaics. These projects explore the integration of solar panels with crops such as berries, apples, cereals, and vegetables, as well as with animal husbandry. The APV-RESOLA (Agrophotovoltaic - A Contribution to Resource-

Efficient Land Use) project, led by Fraunhofer ISE, aims to develop and study new photovoltaic (PV) systems that can use agricultural land to generate solar energy and grow crops. The project, which ran from March 2015 to January 2021, was funded by the German Federal Ministry of Education and Research (BMBF) and involved partners such as the University of Hohenheim, KIT's Institute for Technology Assessment and Systems Analysis (ITAS), Hofgemeinschaft Heggelbach, BayWa r.e. renewable energy GmbH, and EWS Vertriebs GmbH. The project focuses on coordinating agricultural land use with electricity production on the same land, addressing the issue of land use competition. The project demonstrates that agri-photovoltaic systems can reduce water consumption, protect crops from adverse weather conditions, and increase farmers' income through solar power generation, emphasizing that solar power systems are a sustainable solution for efficient land use.

Fraunhofer ISE:

" Agrivoltaics is a combined use of an area for agricultural crop production (photosynthesis) and PV electricity production (photovoltaics)."

Figure 30 The APV-RESOLA project is led by Fraunhofer ISE and relevant partners.

Case study in Germany

For agrivoltaic applications in Germany, the Fraunhofer ISE estimates that the country could generate around 1,700 GWp of solar power using only 4% of its agricultural land, as shown in Figure 31. This capacity is achieved through the use of shade-tolerant crops and crop rotations. Utilizing just 10% of this capacity would nearly triple Germany's current solar power generation capacity. Solar power systems with intercropping solar modules allow crops to be grown between the rows of panels, and one hectare can generate 0.25 MW of electricity. Additionally, growing fodder on permanent pasture has the potential to support another 1,200 GWp of capacity. From an electricity generation perspective, solar power systems are significantly more efficient than energy crops, producing 32 times more electricity per hectare than corn used for biofuel. Currently, energy crops occupy 14% of Germany's agricultural land [65].

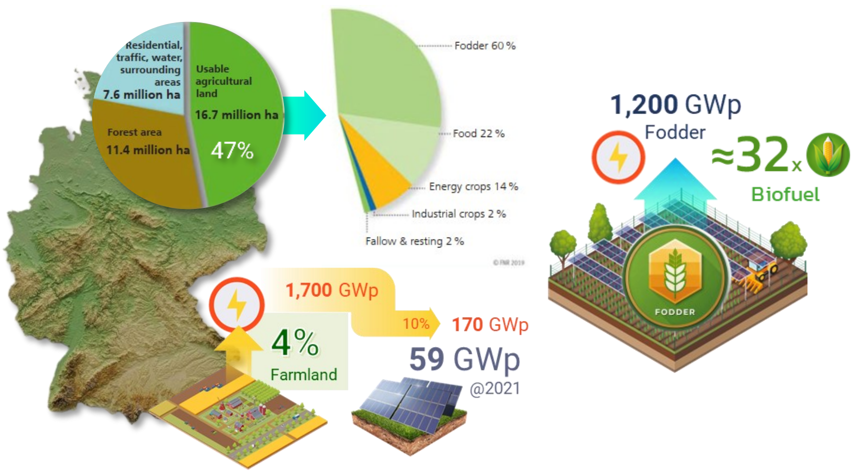


Figure 31 Land use in Germany and the power generation capacity of agrivoltaic technologies [65]

Germany is a leader in researching solar power generation systems integrated with agricultural production. Several notable projects, as shown in Figure 32, are primarily operating in the southern and western regions of Germany, covering seven states: Bavaria, Baden-Württemberg, Rhineland-Palatinate, North Rhine-Westphalia, Saarland, and Saxony. The types of crops and livestock produced are selected based on the suitability of each area, with a total installed capacity of no less than 9,492 kWp [67]. Each project contributes to the understanding and optimization of agrivoltaic systems in various agricultural contexts.

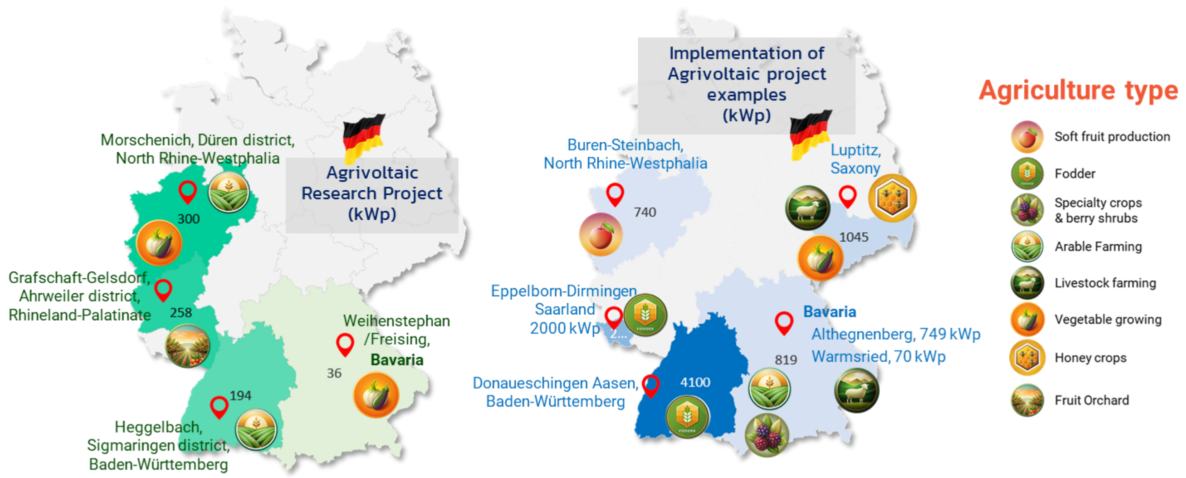


Figure 32 Agrivoltaic projects in research and implementation form in Germany, which are applied appropriately to the agriculture of each area.

Policy and Legal Framework

The agrivoltaic support policy in Germany aligns with the German Renewable Energy Sources Act (EEG). It aims to increase the share of renewable energy and prevent overcompensation by producers. This is achieved through competitive bidding to set feed-in tariffs specifically for agrivoltaic systems [67]. The details of the support are shown in Table 6.

Table 6 Policy and regulation supporting agrivoltaics in Germany

	Policy/Regulation	Description
Germany	• Renewable Energy Act (EEG 2023) • Determination of Federal Network Agency	Ground-mounted PV systems are considered building code structures and require a building permit as follows: 1. **Location in the Federal Building Code (BauGB):** They must not overlap with the development plan. 2. **Absence of a Development Plan:** If there is no development plan, the permit will depend on whether the project is located in an urban or non-urban area. A building permit can be issued only if there is no conflict with other public laws.

To utilize solar power plants in agricultural areas, it is essential to assess the potential of the area based on the criteria set by the Federal Network Agency as shown in Figure 33 The focus should primarily be on cultivated areas, while also considering the agricultural potential of other areas, such as peatlands for various crops. Additionally, the use of these areas should be monitored every three years to ensure that the proportion of production meets the specified criteria. This approach emphasizes creating a balance between renewable energy development and sustainable agricultural practices.

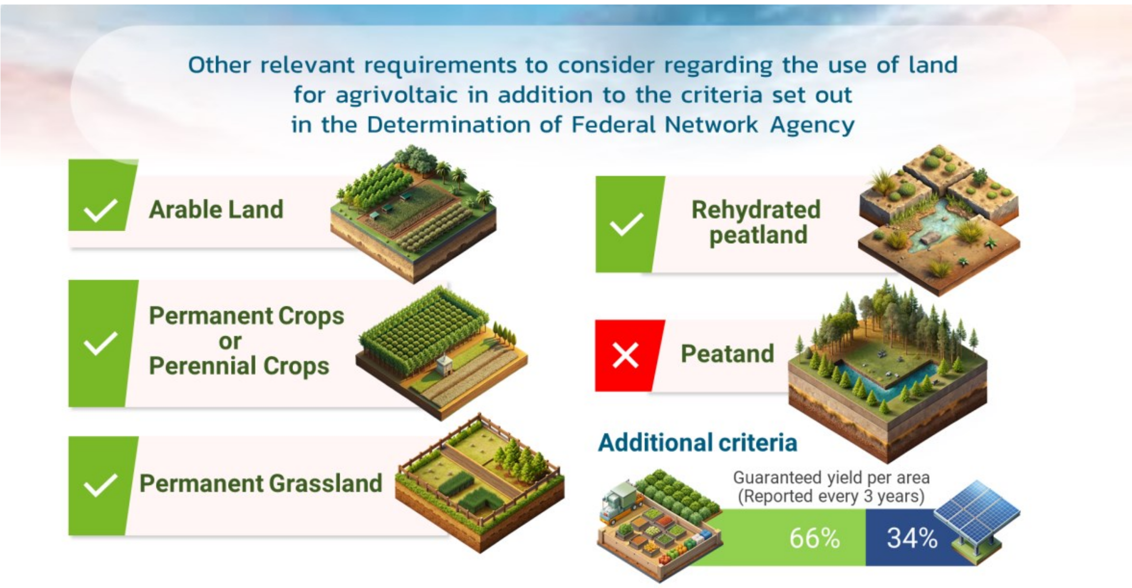


Figure 33 Requirements for the use of land for agrivoltaics in addition to the criteria set forth in the Determination of Federal Network Agency

For the structure and design of PV systems in agriculture, there are technical variations, much like in agriculture itself. Agricultural PV systems can be broadly classified based on agricultural production activities into open and closed systems, as shown in Figure 34. Closed systems primarily include PV greenhouses, while open agricultural systems can be further subdivided into ground-level PV, inter-area PV, and overhead PV. In overhead systems, PV modules are installed at least 2.1 meters above the ground, according to DIN SPEC 91434, as shown in Figure 35. This standard specifically applies to open systems, excluding aquaculture. The DIN SPEC 91434 standard includes the following criteria and requirements:

- Agricultural yield must be at least 66% of the reference yield.
- Agricultural land must be preserved.
- Land loss after PV system installation must not exceed 10% (Category I) or 15% (Category II).
- Measures must be taken to prevent erosion and soil degradation (including construction, anchoring, and water management).
- Demolition must be possible without causing significant damage to the soil or leaving construction debris.

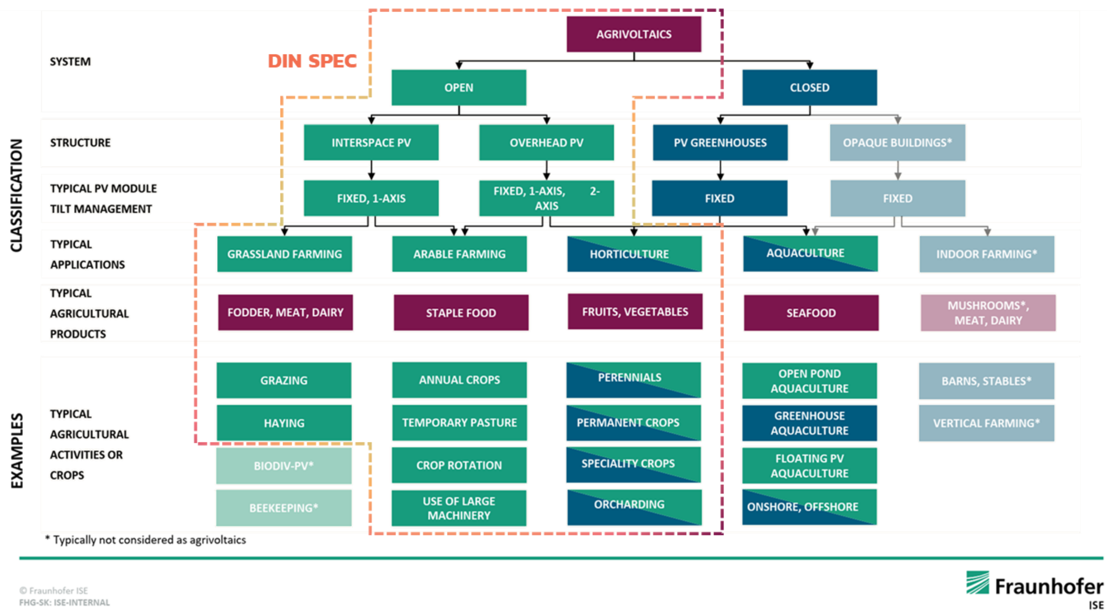


Figure 34 Classification of agro-voltaic systems Scope of DIN SPEC **91434**

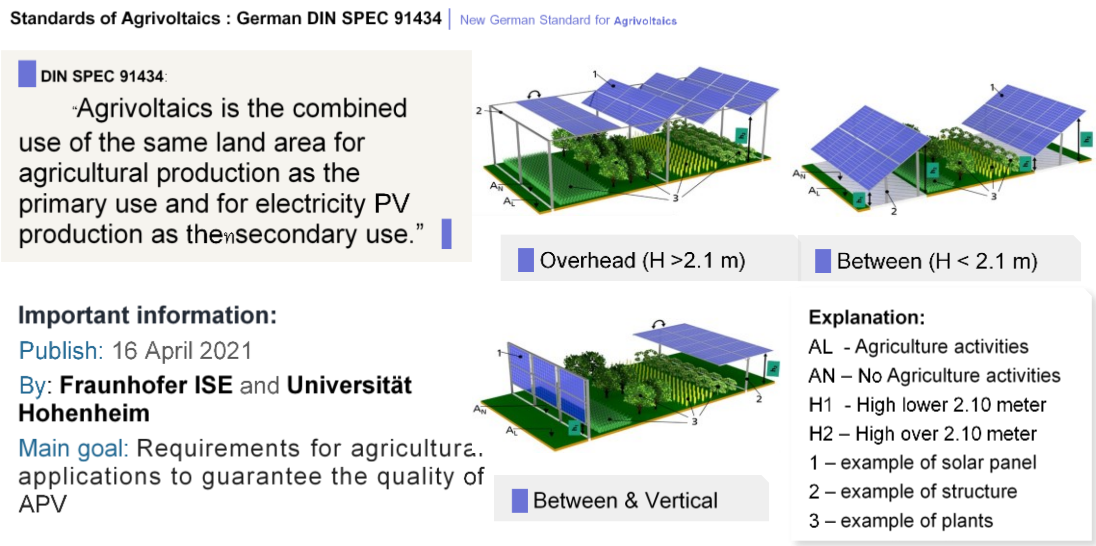


Figure 35 DIN SPEC 91434 standard for agrivoltaics

DIN SPEC 91434:

"Agrivoltaics is the combined use of the same land area for agricultural production as the primary use and for electricity PV production as the secondary use."

The DIN SPEC 91434 standard certifies the quality of agrivoltaic systems, marking an important step towards enhancing policy support for integrating agricultural production with renewable energy generation. These measures collectively support and incentivize the development of agrivoltaic systems in Germany.

Adaptation to the Thai context

To adapt the German agrivoltaic use case to the Thai context, we can highlight several key points. Germany's success in implementing agrivoltaics lies in its efficient land use, water conservation, and additional income for farmers through solar power generation. Similar benefits can be achieved in Thailand by promoting both agricultural and solar land use, which can help reduce water consumption and provide farmers with stable incomes. Furthermore, early involvement of local communities in the planning process and government support through subsidies and incentives can facilitate the adoption of agrivoltaics. Tailoring the technology to Thailand's specific crops and climate, as well as providing farmers with appropriate training and financial support, is essential for successful implementation.

Italian Republic

Agrivoltaic systems in Italy have been developed since the early 2000s and continue to evolve, similar to other European countries, supported by regulatory and technological advances as shown in Figure 36. Initially, the focus was on integrating photovoltaic (PV) systems into agricultural activities to maximize land use efficiency, especially with the enactment of various decrees supporting the installation of PV systems on agricultural land. This approach allows for the simultaneous generation of electricity and cultivation of crops, enhancing the sustainability of rural areas and highlighting the important role of the country's renewable energy strategy.

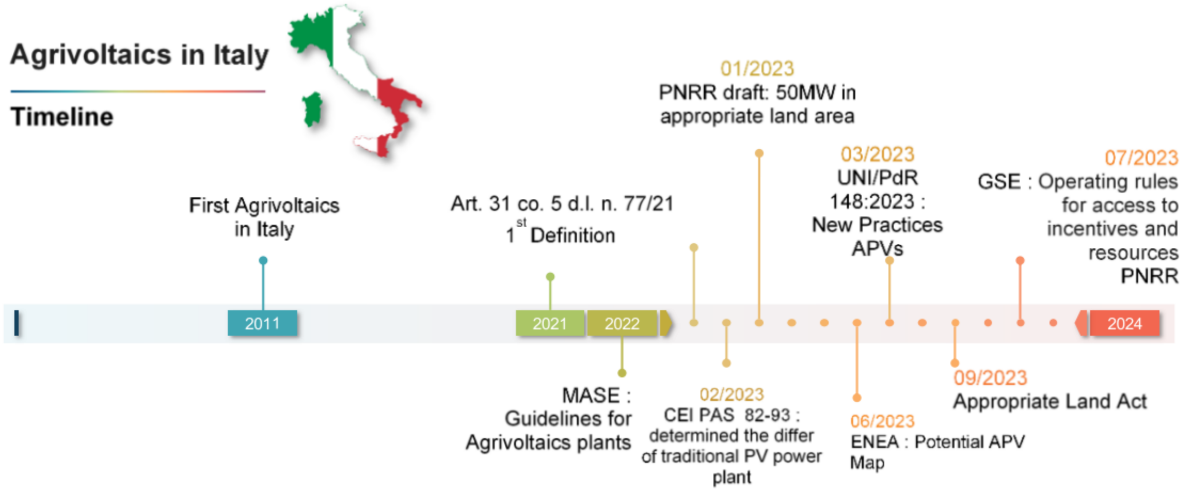


Figure 36 Timeline of agrivoltaic development in Italy

Case study in Italy

The development of solar power generation systems in Italy involves integrating solar PV systems into agricultural and livestock activities. This integration enables efficient land use and promotes the regeneration of wastelands. The installation of solar PV systems in Italy requires only a small area and can increase the yield of various crops. Italy has large agrivoltaic projects under development, with a capacity of more than 250 MW [68], as shown in Figure 37. According to Enel Green Power, the total installed capacity of solar PV plants in Italy is currently around 25 GW. The National Integrated Energy and Climate Plan (NIPEC) expects this capacity to increase by at least 52 GW by 2030. An additional 1 GW of solar PV capacity can provide clean energy for 550,000 households [69], as shown in Figure 38. This supports the participation of agricultural development in Italy to ensure the energy supply meets its needs.

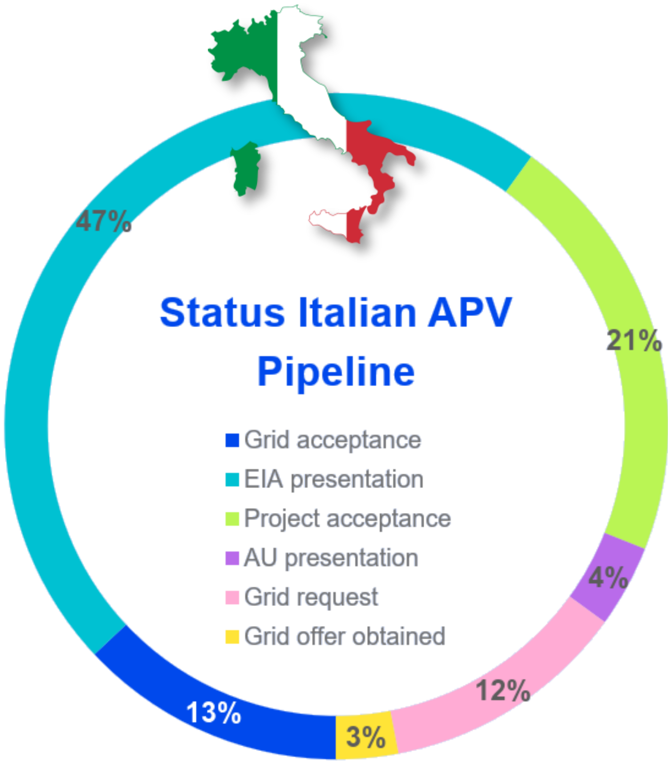


Figure 37 Large agrivoltaic projects under development in Italy

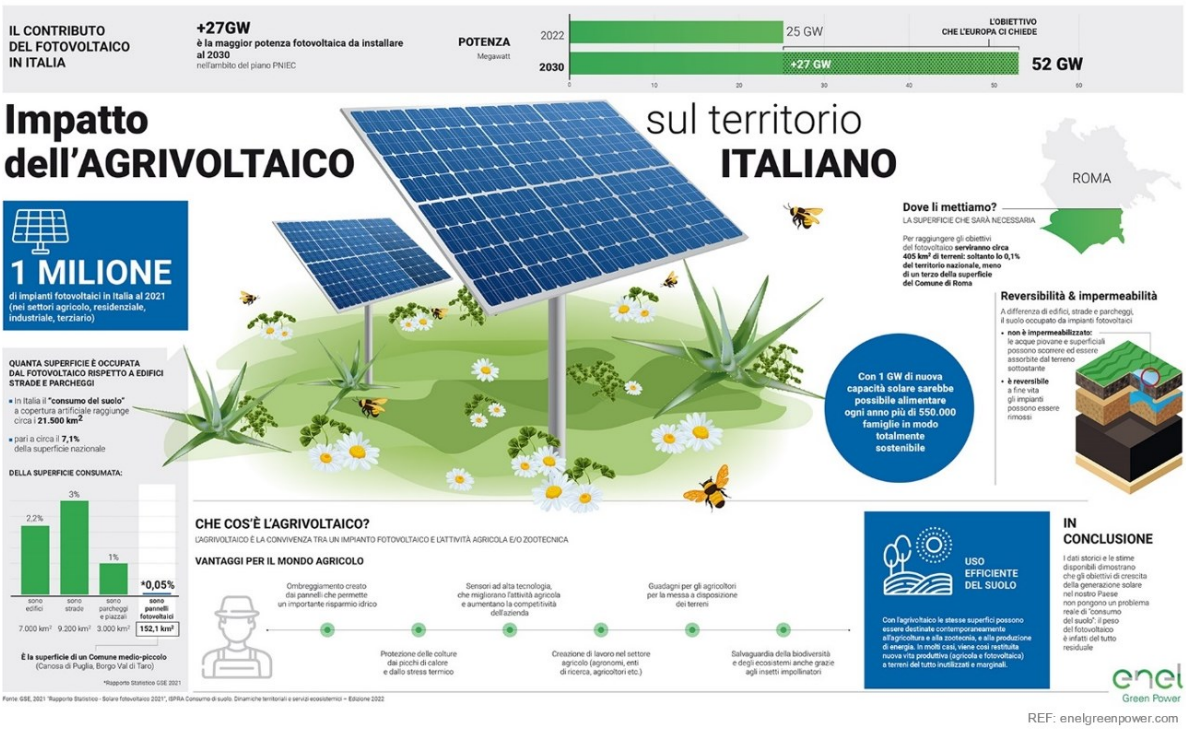


Figure 38 Argivoltaic agriculture in Italy and efficient land use

In addition, the construction of the largest photovoltaic power plant in Italy, located in Tarquinia and shown in Figure 39, will be built on land owned by a local company in collaboration with Enel Green Power. This project demonstrates the integration of agricultural activities, particularly the cultivation of fodder crops and borage in the spaces between the rows of solar panels, which significantly reduces carbon dioxide emissions [70].

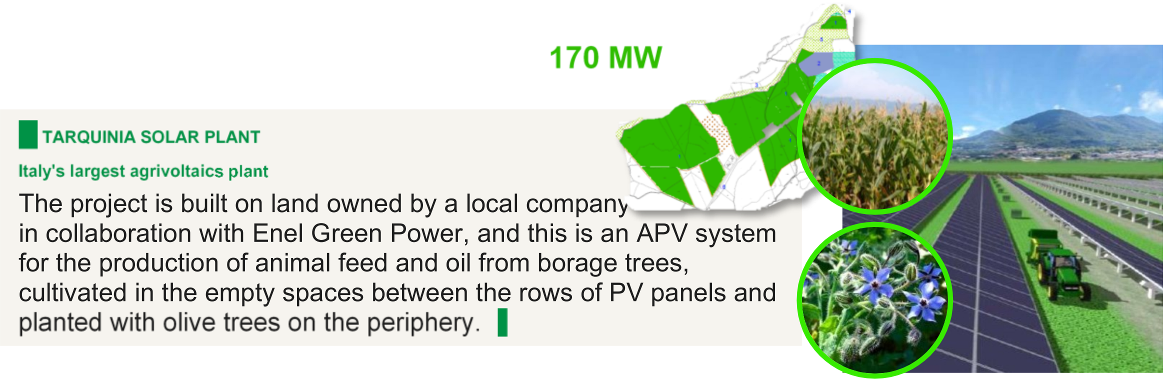


Figure 39 The largest integrated agricultural solar power plant in Tarquinia

Another example of a large-scale project is Cero Generation's 70 MW solar PV project with agricultural operations in Lazio, as shown in Figure 40. Known as the Pontinia project, it utilizes advanced technologies such as single-axis trackers, dual-sided PV modules, and string inverters to maximize efficiency. The project is expected to generate enough renewable electricity to power 47,000 homes and reduce carbon dioxide emissions by approximately 40,000 tons per year. Additionally, 65% of the site will be used for agricultural production, promoting dual land use.

Figure 40 Cero Generation's 70 MW Pontinia project in Lazio

Policy and Legal Framework

Italy has been using the agrivoltaic guidelines and policies published by the Ministry of Ecological Transition (MITE), as shown in Figure 41, to drive agrivoltaic projects in the country. These guidelines were developed in collaboration with several key organizations, including the Council for Agricultural Research and Analysis of Agricultural Economics (CREA), the Energy Services Manager (GSE), the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and the Research on the Energy System S.p.A. (RSE). The aim was to create a comprehensive guideline that addresses both agricultural and energy production needs.

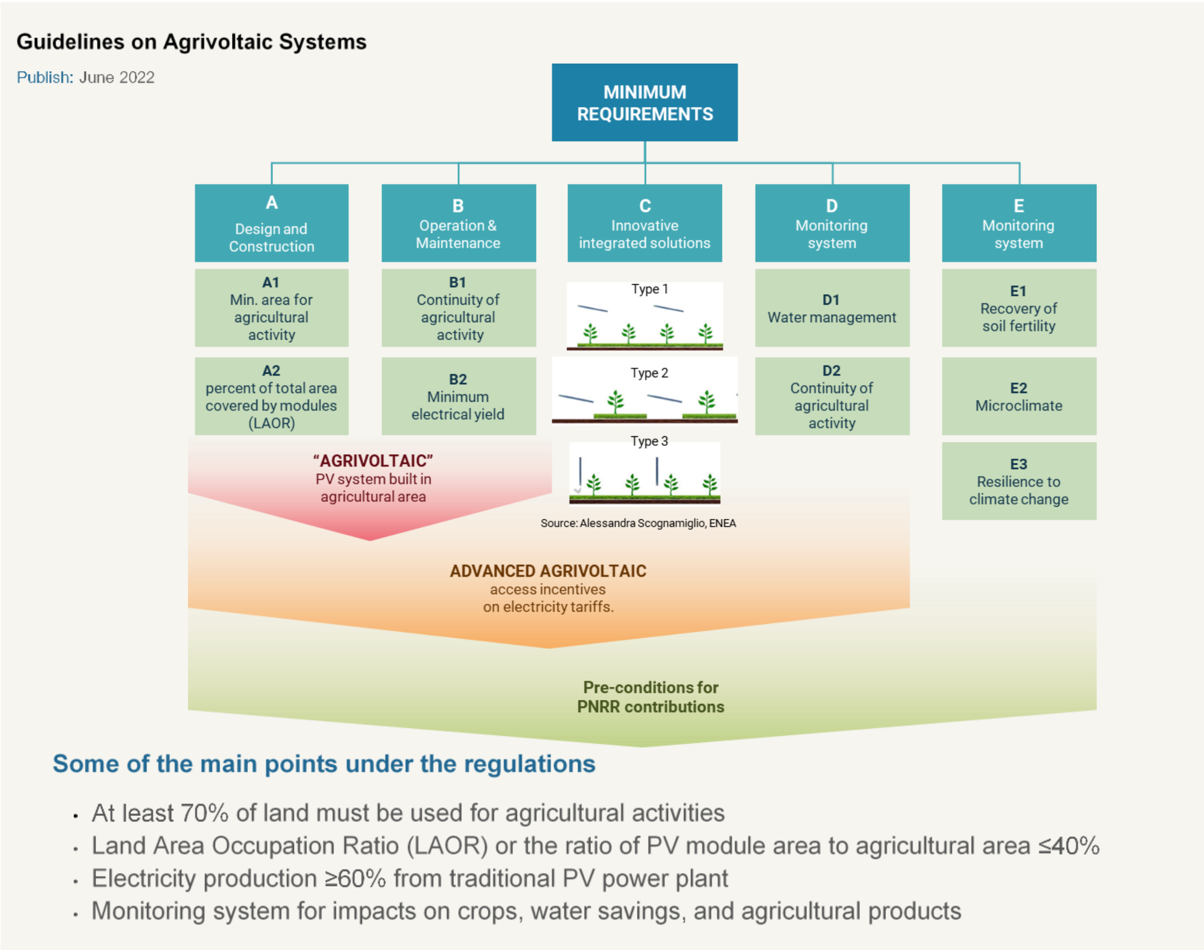


Figure 41 National guidelines for agrivoltaic systems in Italy, published by MITE in 2022.

The guidelines are classified according to the requirements for agrivoltaic systems, ranging from simple (Requirements A-B) to advanced (Requirements A-D). Simple systems allow agricultural activities to continue alongside the installation of solar PV panels, while advanced systems integrate technologies and innovations such as elevated and rotating PV modules, digital agricultural tools, and precise monitoring systems to assess crop impacts and water savings. When a project meets the highest requirements (Requirements A-E), it can qualify for additional government funding from Italy's National Recovery and Resilience Plan (PNRR).

Italy's National Recovery and Resilience Plan (PNRR) allocates a substantial €1.1 billion investment for the implementation of agrivoltaic systems, aiming to cover the investment costs by supporting up to 40% of eligible projects. Additionally, €560 million is allocated to establish incentive electricity tariffs, payable over a period of 20 years, to enable these projects to generate returns. This approach simplifies the regulatory process for agrivoltaic projects in suitable areas, reducing bureaucratic obstacles and making them more attractive to investors. The plan requires the inspection of 1.04 GW of agrivoltaic structures by June 30, 2026, to ensure that the projects meet the required standards. This emphasizes the importance of preserving agricultural productivity while generating renewable energy and ensuring food security through compliance with the plan.

There is also a policy and legal framework supporting agrivoltaics. For example, Article 65, paragraphs 1-quarter and 1-quinquies of Legislative Decree No. 1/2012 facilitates public access to agrivoltaic systems, promotes transparency, and encourages community participation in renewable energy projects. Additionally, Royal Decree DL Energy No. 17/22 authorizes the development of agrivoltaic projects with a maximum capacity of 20 MW, simplifies the permitting process, and encourages the implementation of large-scale projects, as shown in Table 7.

Table 7 Policy and regulation supporting agrivoltaic in Italy

	Policy/Regulation	Description
Italy	• Linee Guida in materia di Impianti agrivoltaici	Guidelines on agrivoltaic systems by MITE Published: June 2022
	• Art. 65 co. 1- quarter and quinquies d.l. n. 1/12	Agrivoltaic systems are eligible for public funding
	• Piano Nazionale di Ripresa e Resilienza (PNRR)	• €1.1 billion allocated for agrivoltaic implementation (covering up to 40% of eligible investment costs). • Incentive electricity tariffs with an approximate budget of €560 million, to be paid over the project's implementation period of 20 years. • 1.04 GW of agricultural systems are expected to be installed by June 30, 2026. • Approved in Strasbourg in November 2023.
	• D.L. Energia No. 17/22: Agri PV up to 20MW	• Simplified Permitting Process (PAS) • No Environmental Procedures (VIA) in appropriate areas
	• UNI/PdR 148:2023	• Integration of Agriculture and Landscape • Integration of Agricultural Activities with Agrivoltaic Power Plant Management • Impacts on Territory, Communities, and Responsible Actors • Technical Requirements: Agricultural Yield (Ra) and Land Equivalent Ratio (LER) • Recommendations and Monitoring of Agrivoltaic Systems
	• CEI PAS 82-93	• safety requirements • Sn - not agricultural area • Many aspects to be defined in a future edition

Adaptation to the Thai context

To adapt the Italian solar agriculture concept to the Thai context, we should focus on integrating solar power systems into local agricultural practices to ensure that both energy production and agricultural yields are preserved. Collaboration with local agricultural and energy research organizations will be essential to develop practices tailored to Thailand's specific climate and crop types. Financial incentives and regulatory support, similar to the Italian National Recovery and Resilience Plan, can encourage investment in solar agriculture projects. Simplifying regulatory processes and providing clear guidelines will help accelerate implementation. Additionally, the introduction of advanced technologies, such as elevated solar modules and precision farming tools, can increase land use efficiency and crop yields. Regular monitoring and tracking will ensure that installations meet standards and operate efficiently, contributing to both energy sustainability and food security in Thailand.

3.3 United States of America

Agrivoltaics is an innovative approach to integrating solar power generation with agriculture in the United States. This method addresses land use and climate goals by utilizing both agricultural and renewable energy sources to maximize land use efficiency, providing synergistic benefits for both the solar and agricultural sectors. It not only helps meet the U.S. government's goal of decarbonizing the electricity sector by 2035 but also supports farmers by diversifying their income streams and enhancing ecological sustainability. With over 2.8 GW of solar farm projects already underway [71], most involving sheep grazing and pollinator habitats, the U.S. is currently exploring the potential of this new business model through research initiatives and state incentives.

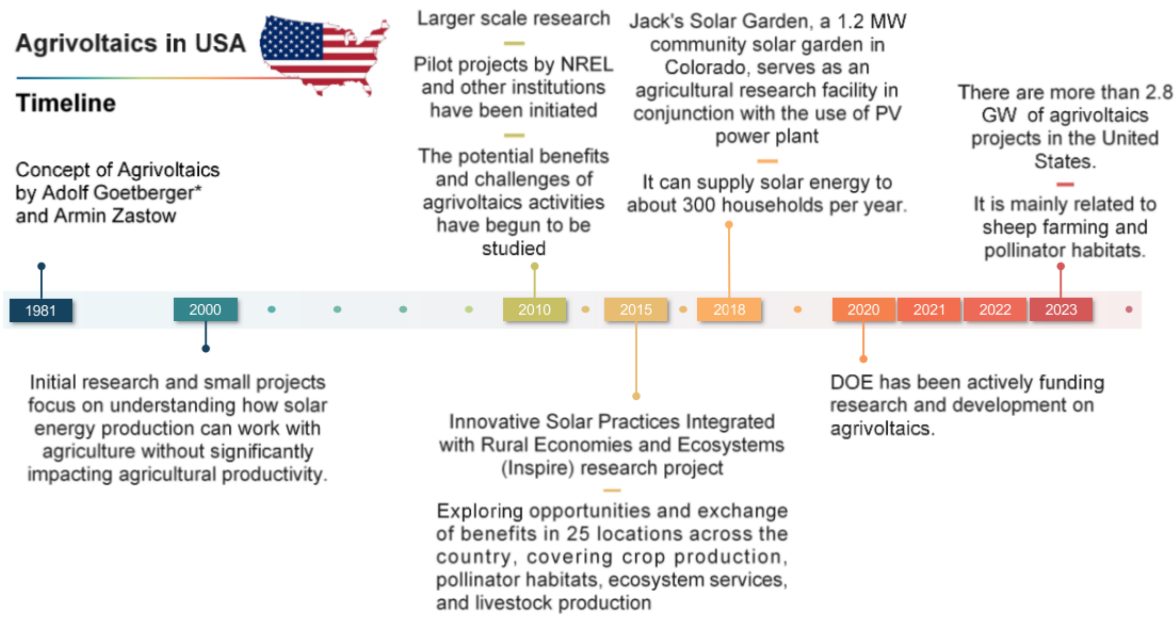


Figure 42 Timeline of agrivoltaic development in United States

In the U.S., the deployment of agrivoltaics—combining solar energy installations with agricultural activities—addresses several key pain points. It mitigates land use conflicts by allowing solar energy and farming to coexist, supports climate change goals aimed at decarbonizing the electricity sector by 2035, provides economic benefits to farmers through additional income streams, benefits from research and incentives such as Massachusetts' feed-in tariff adder, and enhances energy security by diversifying energy sources and integrating solar into agricultural landscapes. In promoting agrivoltaic policies, several challenges are faced:

Firstly, there are land conversion concerns. While solar power development can generate clean energy and economic benefits, converting agricultural land to solar projects can raise local concerns. It is important to balance land use between agriculture and solar installations [72].

Secondly, costs and tax complexity pose significant challenges. Agrivoltaic systems can be more expensive to develop than traditional solar systems, and as a result, state and local tax compliance can be complicated.

Another challenge is rainwater runoff and humidity. Rainwater runoff from solar panels can alter water distribution on a farm, affecting crop growth. Additionally, increased humidity under solar panels due to reduced evaporation can lead to disease or parasites [56].

Lastly, there is the challenge of maximizing electricity production and biodiversity. Agrivoltaic systems must ensure increased peak electricity production without affecting crop yields and must also preserve biodiversity [73].

Despite these challenges, agrivoltaics remains a promising prospect for the sustainable integration of the energy and agriculture sectors. Estimates indicate that agrivoltaic systems could generate 20% of all electricity in the United States [74].

United States: agrivoltaics is the use of land for both agriculture and solar photovoltaic energy generation (**Dual Use Solar**, **Agrisolar** or **Low Impact Solar**)

The National Renewable Energy Laboratory (NREL) highlights the benefits of agrivoltaics, a practice that combines solar energy production with agricultural activities. By integrating photovoltaic (PV) installations with farming, agrivoltaics offers a dual-use solution that supports renewable energy generation while providing space for agriculture or native habitats. This approach can include grazing livestock, growing crops, or cultivating pollinator-friendly plants. The InSPIRE project, led by NREL and funded by the U.S. Department of Energy, has been researching these synergies and has found that agrivoltaics can reduce land-use conflicts, enhance biodiversity, and provide economic benefits to farmers [75].

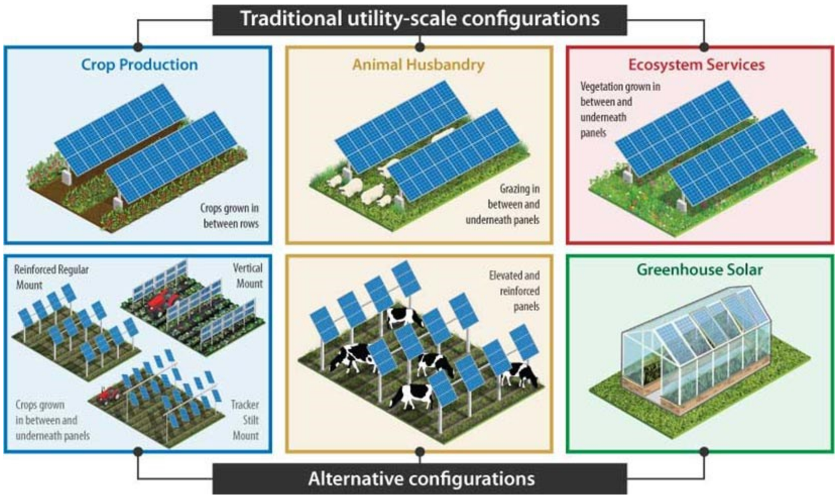


Figure 43 Diversity of agrivoltaics systems to suit different forms of agriculture [75].

A variety of agrivoltaic systems can be installed similarly to solar power plants, or they can be modified to provide additional space for lighting, animals, or farm equipment, accommodating different types of agricultural activities [75].

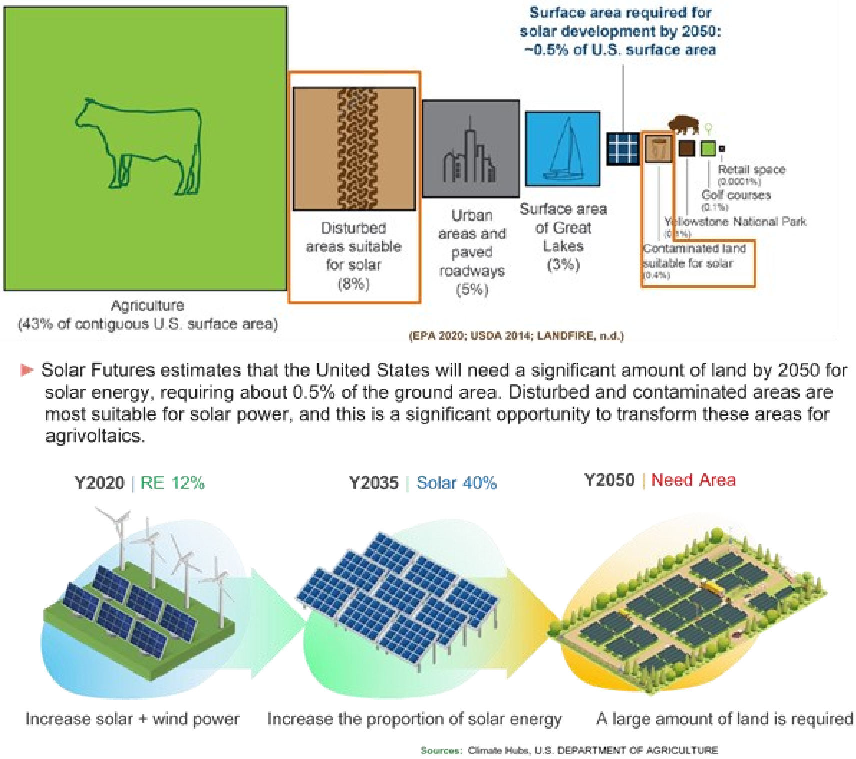


Figure 44 Driving the adoption of agrivoltaic technology in the United States

Case study in United States

Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) Project, sponsored by the U.S. Department of Energy (DOE) and managed by the National Renewable Energy Laboratory (NREL).

InSPIRE aims to advance the shared benefits of solar power, agriculture, and native landscape conservation. Currently, there are 567 projects across the United States with approximately 10 GW of installed capacity as shown in Figure 45. Multi-sector and multi-disciplinary teams are being formed to provide basic information and services to the public and to conduct groundbreaking analytical research in this field.

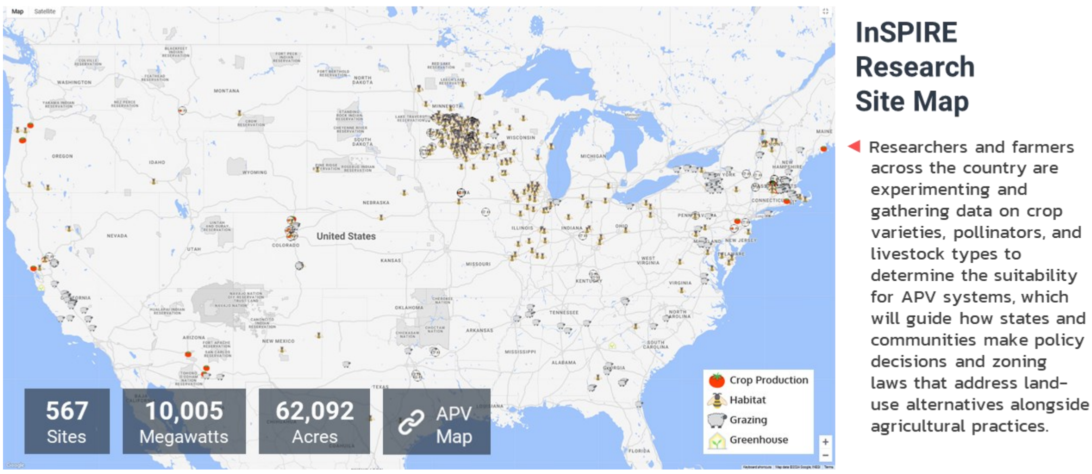


Figure 45 Map of InSPIRE research sites spread across the United States.

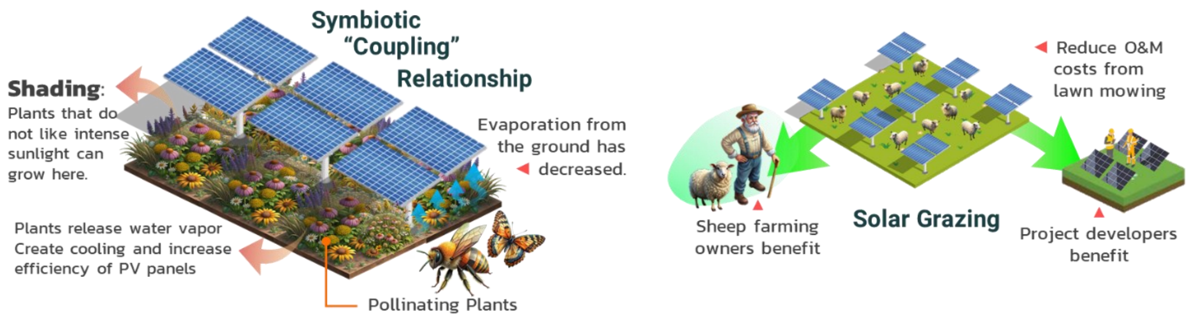


Figure 46 Symbiotic coupling relationship concept

The InSPIRE project identified five key factors for successful agrivoltaics [75] , known as **"the five C's"** as shown in Figure 47:

C1: Climate, Soil, and Environmental Conditions

The location's ambient conditions must support both solar energy production and the growth of the chosen crops or ground cover.

C2: Configurations, Solar Technologies, and Designs

The selection of solar technology, site layout, and infrastructure impacts everything from light availability for solar panels to the ability for tractors to operate under them. "This infrastructure will be in place for the next 25 years, so it must be suitable for its intended use. Its success hinges on this," stated James McCall, an NREL researcher involved in InSPIRE.

C3: Crop Selection and Cultivation Methods, Seed and Vegetation Designs, and Management Approaches

Agrivoltaic projects should choose crops or ground covers that can thrive under solar panels in the local climate and are profitable in local markets.

C4: Compatibility and Flexibility

Agrivoltaic systems should be designed to balance the needs of solar owners, operators, and farmers or landowners, ensuring efficient agricultural activities.

C5: Collaboration and Partnerships

Effective communication and understanding between all parties are essential for the success of any project.

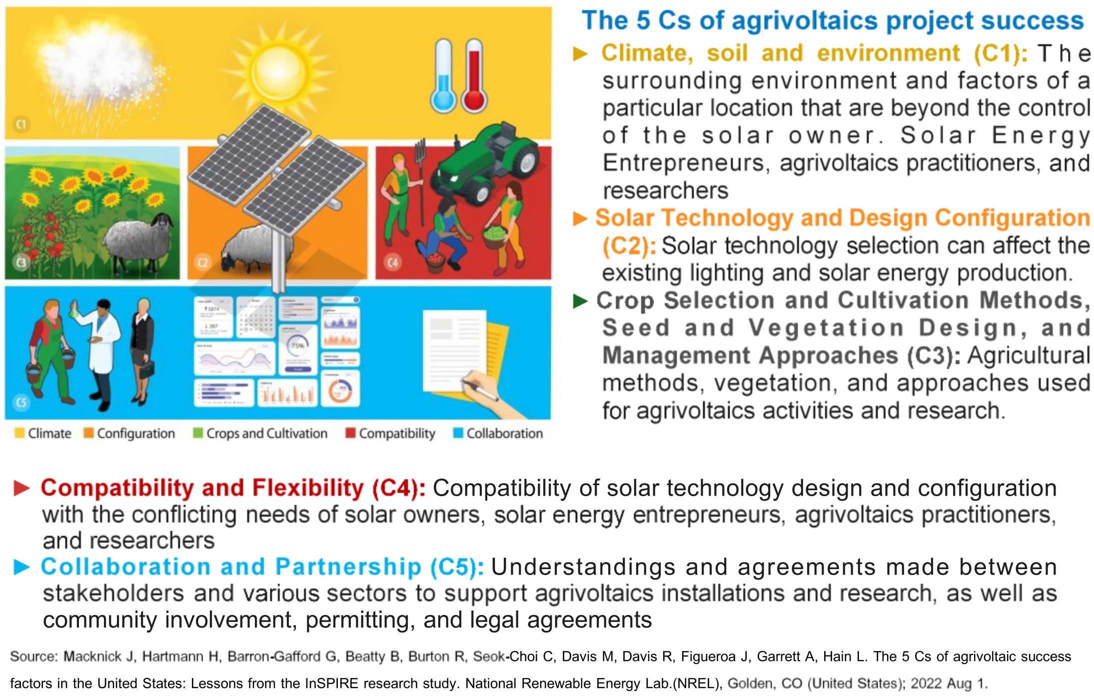


Figure 47 five key factors for successful agrivoltaics [75]

Figure 48 illustrates the largest agrivoltaic project in the United States, situated on a 10-acre blueberry farm in Rockport, Maine. This project has had an installed capacity of 4.2 MW since 2017 (left). Researchers from the University of Maine Extension are assessing the impact of the solar panel installation on blueberry plants and monitoring how the crops grow over time under the solar panels (right).

Figure 48 The largest agrivoltaic project in the US on a blueberry farm in Rockport, Maine.

Table 8 Examples of NREL research projects located in the Northeast of U.S.

Agencies	Details	Purposes of operation
University of Massachusetts Amherst	Researchers are studying the effects of panel placement, solar energy, and joint agricultural operations at up to 8 farms across the state.	This research will help farmers and communities make informed decisions about solar energy.
Cornell University	Researchers are looking for the benefits of growing pollinator-friendly plants in solar farms.	One goal is to see if wildflowers that are grown on solar energy areas can increase the number of pollinators. Another thing is to see if growing wildflowers on solar farms encourages pollinators to visit the flowering plants. Other studies of Cornell are looking at how sheep grazing might affect pollinator habitat and soil carbon sequestration.
Rutgers University	In June 2021, the Dual Use Solar Energy Act was passed in New Jersey.	This Act provides for a pilot program "to allow a limited number of farmers to have another agri-voltaic farming system on their property while the technology is being tested, observed, and developed." The funds are also sent to the New Jersey Agricultural Experiment Station to create and study more about the agri-voltaic farming system on their research farms.
University of Vermont	Last fall, UVM Extension's Center for Sustainable Agriculture hosted a workshop called Solar Energy in Vermont's Working Landscape.	This event brought together experts and stakeholders to discuss the existing practices and barriers to the adoption of solar energy for animal husbandry, as well as the requirements for long-term success in the state. Previously, the center's animal husbandry program worked with the Vermont Bureau of Agriculture, Food and Markets and the Two Rivers Ottauquechee Regional Commission in order to develop a guide on how to "balance community needs and farm-level energy demands with a shared commitment to protecting agricultural lands."

Policy Activity in the Northeast

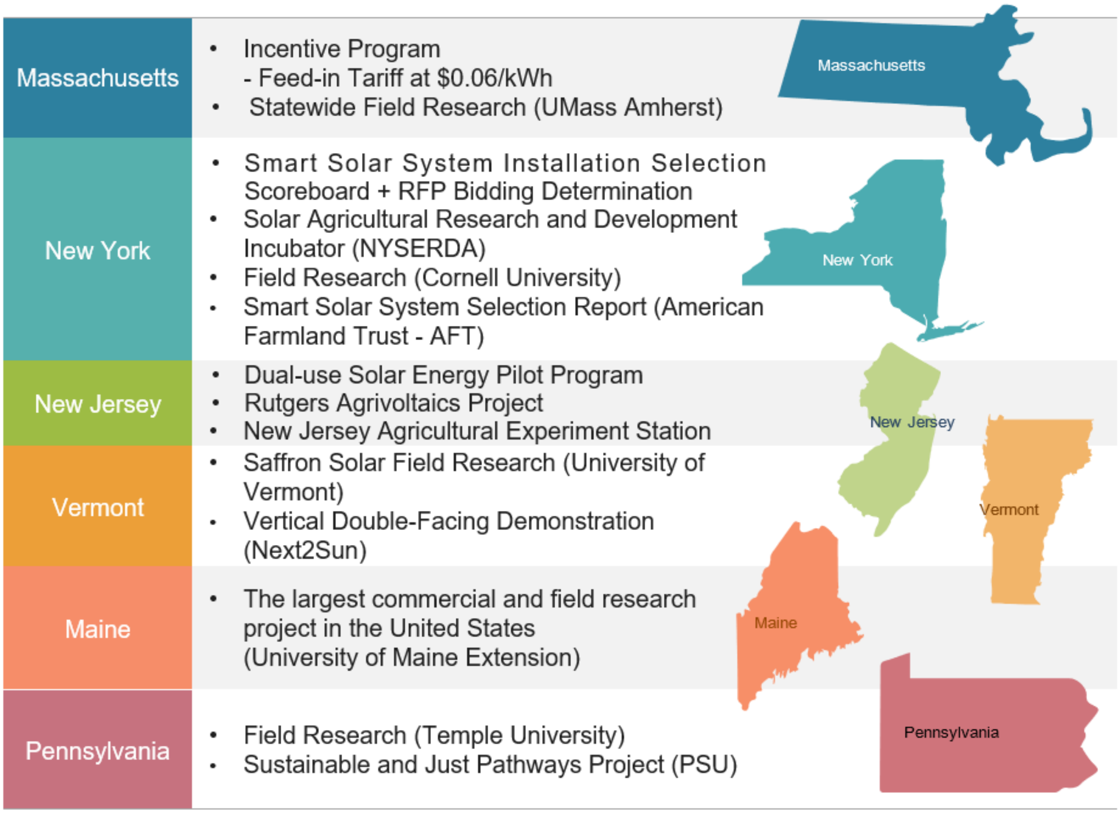


Figure 49 Examples of policies in the United States

Adaptation to the Thai context

There are several important steps to adopt the U.S. solar farm approach in Thailand. The first step is to promote land use for both agriculture and energy production, which can be achieved by establishing specific land use categories for solar farms. Financial incentives, such as subsidies, tax credits, and low-interest loans, can encourage farmers to adopt the technology. Additionally, setting standards for the design, installation, grid connection, and maintenance of solar farm systems can help make operations more efficient and safer. Public-private partnerships (PPPs) can facilitate knowledge transfer and financial support, helping farmers incorporate solar farms into their operations. Finally, integrating solar farms into Thailand’s national plan to reduce greenhouse gas emissions and meet renewable energy targets will align with broader environmental objectives. Collaboration between local farmers, government agencies, and renewable energy companies is crucial to adapting these practices to suit Thailand’s unique climate and agricultural conditions. Furthermore, policy support and financial incentives are essential to support the adoption of solar farms in Thailand.

Key lesson learned from international countries

Adapting agrivoltaic systems to the Thai context requires a comprehensive approach that considers local agricultural practices, climate conditions, and regulatory frameworks. To achieve this, several strategies should be followed:

First, the **choice of crops and climate adaptation** is crucial. Given Thailand's hot and humid climate, it is essential to select crops and solar panel designs that can withstand these conditions. Priority should be given to crops commonly grown in Thailand, such as economically important fruits and vegetables. The response of these crops to partial shading from solar panels should also be investigated.

Second, the **system and technology design** should be tailored to local needs, with sufficient solar panel height and spacing to accommodate traditional farming practices and farm machinery. Efficient water management systems are essential, particularly during the monsoon season. This may include rainwater harvesting and efficient drainage systems.

Third, **socio-economic considerations** are important. Feasibility studies should ensure that agrivoltaic systems are economically sustainable for local farmers by analyzing the costs and potential incomes from both agricultural production and solar power. Involving local communities and stakeholders early in the planning process is also crucial to gain acceptance and support for agrivoltaic projects.

Fourth, **regulatory and policy frameworks** need to be managed in collaboration with local authorities to ensure compliance with existing agricultural, energy, and construction regulations in Thailand. Policy incentives and support, such as subsidies, tax breaks, or grants, are also beneficial.

Fifth, **research and collaboration** are essential. Local universities and research institutes should study the specific needs and challenges of agrivoltaic implementation in Thailand. International collaboration can help adapt best practices from successful agrivoltaic projects in other countries, such as Germany and the United States. Environmental impacts should be considered by promoting sustainable agricultural practices, such as reducing water use and minimizing the use of chemical fertilizers and pesticides. Additionally, assessing the environmental impacts of agrivoltaic systems on local ecosystems and biodiversity is important.

By following these guidelines, Thailand can effectively adapt its agrivoltaic systems to its specific context, promoting sustainable agriculture and renewable energy production.

Figure 50 Key practices related to agrivoltaic from different countries

4

Enhancing Agrivoltaics Potential through Bridging Gaps and Overcoming Barriers in Agriculture, Land Use, and Energy Sectors

Various situations in Thailand, such as the uncertainty of agricultural products affecting food security, inefficient land use, and issue related to land ownership, in which will impact the quality of life for farmers. The high proportion of electricity generation from fossil fuel sources [76-79] also affects Thailand's sustainable development. Furthermore, challenges arising from addressing climate change have intensified various problems, including Thailand's goal of achieving carbon neutrality by 2050 and net zero greenhouse gas emissions by 2065. This highlights the need for well-planned and effectively implemented policies, regulations, or measures. To address the various issues outlined in Chapters 1 and 2, collaboration between the government, private sector, and public sector is essential. Key considerations for Thailand include adopting a cross-sectoral integration approach, addressing sustainable agriculture challenges, and optimizing land and energy production to minimize conflicts across sectors.

Supporting the appropriate framework of policies, regulations, and measures can facilitate the growth of agrivoltaics in Thailand. The report includes a decision tree diagram that analyzes gaps and barriers in existing policies and measures related to agrivoltaics. This analysis is designed for policymakers and regulators, presenting relevant policies and regulations in **Figure 51**. The decision tree for developing agrivoltaics projects in Thailand is based on information collected as of 8 August 2024.

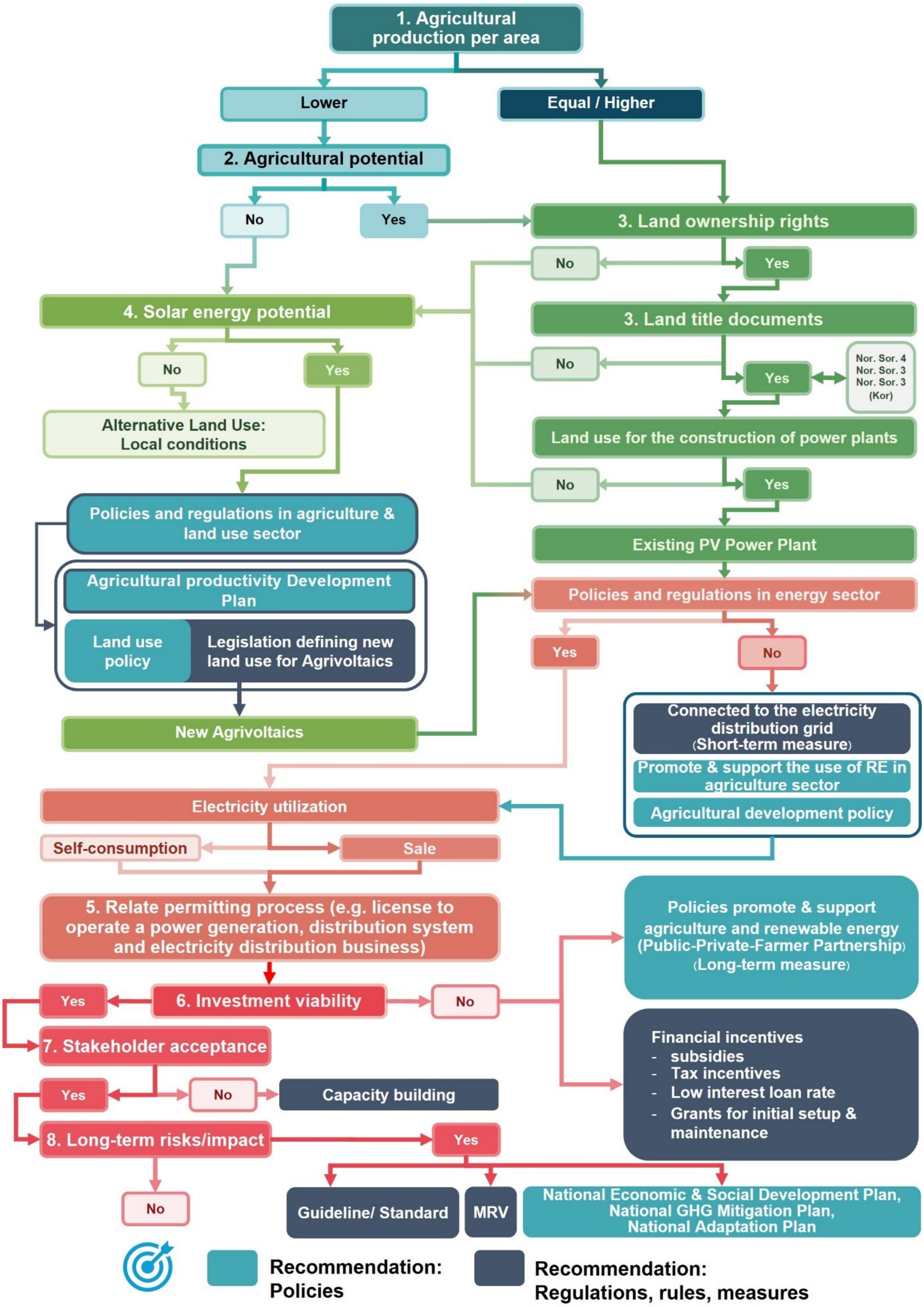


Figure 51 A decision tree for consideration in the development of agrivoltaics projects in Thailand

The related policies, rules, and regulations have been analyzed and can be summarized as follows:

1. Agricultural production per area: To effectively support agrivoltaics, it is essential to consider information from the Office of Agricultural Economics [9] which categorizes agricultural products into three groups: those with production levels below the national average, those that align with the national average and those that surpass it. This classification can help identify areas where agrivoltaic systems may have the most significant impact, promoting sustainable agricultural practices while maximizing land use. To prioritize the development of the agrivoltaics project, areas with production below the national average shall be focus first. Implementing agrivoltaics in these areas may increase the amount of production; for example, installing solar panels in areas suited for shade tolerant plants. This could lead to improved agricultural products.

However, Thailand still has limitations in researching agrivoltaics, such as determining which types of agriculture and crops are most suitable, as well as the optimal configuration of solar panels for different plants. Note that the project can also be implemented in the areas with agricultural productivity per area equal to or higher than the national average.

2. Agricultural potential: The next condition that must be analyzed is whether the area has agricultural potential. This begins with identifying the causes, which may come from factors such as soil, water sources, or weather conditions. The goal is to develop agricultural area to enhance their potential and address specific issues. One of the development methods includes agrivoltaics. For example, in areas with low agricultural potential that are dry due to climate factors, implementing agrivoltaics can help maintain soil moisture.

Therefore, understanding the causes that affect agricultural potential in the area [80] will facilitate appropriate planning for infrastructure and the arrangement of solar panels, promoting agricultural activities simultaneously. For areas with agricultural potential, the topic of solar energy potential will be considered next. However, if agricultural potential exists, land ownership rights and documents will be the next topics to consider, which can be addressed in the following.

3. Land ownership rights and land title documents: In addition to agricultural factors, land ownership and documents are crucial. Currently, agricultural activities can be carried out even without formal land ownership rights; however, this limits the ability to direct, monitor, or receive government support for their land use. Land rights documents include Nor Sor 4, Nor Sor 3, and Nor Sor 3 Kor. These documents can facilitate the use of land to electricity generation. If the farmer possesses a title deed for the land, it can be utilized for installing solar panels to produce electricity. In some areas, solar energy is already being produced, alongside ongoing agricultural activities. This scenario falls under the category of “existing system (Brownfield).” Conversely, in areas where no solar energy production but where agricultural activities are taking place with plans to install solar panels, this would be classified as a “new system (Greenfield)” as detailed in the scope of agrivoltaics in Chapter 1.

Additionally, there is another type of rights document know as Sor Por Kor 4-01, which grants permission to use land reform areas, and serve as a proof of right to farm on that land. The differences among these certificates or licenses are summarized in Table 9 [81-85].

Table 9 The differences in certificates or licenses.

Differences between types of certifications	Nor Sor 4	Nor Sor 3 Kor	Nor Sor 3	Sor Por Kor 4-01
Ownership	Land deed with 100% ownership.	Possession for benefit: This certificate allows you to request a change to a land deed.	Possession for benefit: This is a certificate that allows you to request a change to a land deed, pending a 30-day wait.	Possession for agriculture: This is not a land deed and is intended solely for agricultural use. It is also inheritable.
Trading-Transfer Permission	Trading allowed	Trading allowed	Trading allowed, with 30-day wait.	Trading **not** allowed
Permitting Agrivoltaics Project Development	✓	✓	✓	✓ Note: Permission is required since this type of land is primarily designated for agricultural purposes. A clear allocation of land should be established to ensure effective land management for agrivoltaics.

However, if the agricultural area does not have ownership documents or a permission letter, as mentioned above, the next consideration should be the potential of solar energy.

4. Assessment of solar energy potential: If the land area is deemed to be lack solar energy potential, it should be designated for other alternative uses, such as conversion into a recreational area, depending on the context of the area and environment. Conversely, if the area has solar energy potential, **policies for agricultural productivity and land use** should be established to promote farmers adopting agrivoltaics technology. This includes enhancing **legislation defining new land use categories specifically for agrivoltaics,** in alignment with the **guidelines and standards for agrivoltaics projects**.

5. Agrivoltaics Permissions: in accordance with agriculture and electricity production laws, developing agrivoltaic projects must ensure compliance with necessary permissions, especially electricity production from photovoltaics, which follows a straightforward permitting process outlined in Chapter 2. However, agrivoltaics has yet to be specified in existing policies and plans for both agriculture and energy sectors. Therefore, it is necessary to establish an **agricultural development policy** as well as **policies that promote and support the use of renewable energy within agriculture sector**. Additionally, short term supportive regulations and procedures shall be implemented to **enable electricity generated by agrivoltaics to be connected to the electricity distribution grid.** This measure aims to enhance motivation in support for project operations. In the long-term, it is important to encourage farmers to use that electricity for self-consumption in their farming operations. However, the viability of investment should be carefully considered in each operation period.

6. Consideration of investment viability: Creating incentives for investment is also important, whether through the development of **policies to promote and support agriculture and renewable energy-such as fostering cooperation between the government, private sector, and farmers**-or by determining and implementing **financial support measures.** This measures may include but not limited to financial subsidies, tax incentives, low-interest loans, grants for initial setup and maintenance, and other similar initiatives.

7. Building Stakeholder Capacity for Agrivoltaics: It is an innovation that combines agricultural land use with electricity generation, making it essential to foster acceptance among relevant stakeholders. To achieve this, the government and associated organizations should determine and establish **the capacity building and guidelines for training** farmers and stakeholders involved in agrivoltaics. The training will promote understanding and acceptance across all sectors-agriculture, land use, and energy-enabling the project to be implemented sustainably.

8. Risks and effects: It is an important to consider the long term effect of project implementation, particular in agrivoltaics project not limited to followings are to be considered; changes in agricultural factors, land use, and electricity generation from solar energy. These changes may stem from consistent implementing **agrivoltaics specifications or standards**. Therefore, regulations should be established to provide **guidelines for monitoring, reporting, and verification (MRV)** operations according to the rules and regulations. This will enable relevant government agencies to effectively supervise, monitor, and evaluate policies and measures related to clean electricity production, GHG reduction and community impacts.
In addition, government agencies need to collect evidence-based data for tracking GHG emissions and assess progress in climate adaptation. Thus, agrivoltaics should be integrated into the **national plan** that **aligns with the greenhouse gas mitigation strategies and the climate change adaptation plan**.

5

Recommended Policies and Regulations of Agrivoltaics for Thailand

5.1 Policy Framework for Promoting and Supporting Agrivoltaics

The researchers recommend guidelines for the policy framework aimed at promoting and supporting agrivoltaics in Thailand. These guidelines are categorized into agriculture, energy, land use, and other related areas. The details are as follows:

Agricultural sector

Ministry of Agriculture and Cooperatives shall **encourage farmers to adopt agrivoltaics in agriculture**. By providing knowledge and **financial support** through the measures, which include 1) short-term measures, typically defined as support lasting up to three years, such as subsidies in agricultural product insurance, investment support for agrivoltaics systems, and incentives for market access to purchase produce. 2) For a long-term measure, spanning four to ten years, will focus on fostering cooperation among the farmer, the public sector, and the private sector through Public-Private-Partnership (PPP). For example, farmers or groups of farmers can jointly invest with the private sector and government to install a photovoltaic electricity generation system, allowing them to benefit from agricultural activities, electrical usage, and/ or electricity sales (to private sectors or the grid, depending on the project's design).

The Ministry of Agriculture and Cooperatives **supports the development of the area to increase agricultural productivity.** By establishing the **policies to increase the agricultural production per area** and collaborating with the Office of Agricultural Economics to improve its database for tracking agricultural production, the ministry aims to prioritize the promotion of agricultural land with low income and output. This approach will enable the government sector to be able to identify the factors affecting agricultural production and suitable supporting methods for implementing the agrivoltaics projects.

Energy sector

The Ministry of Energy should **support the generation of electricity from photovoltaic in the agrivoltaics project**. Energy Policy and Planning Office (EPPO) should establish a **policy to promote renewable energy adoption in agricultural sector through agrivoltaics.** The goal is to enhance the share of renewable energy usage. Support and incentives should not be restricted to short term measure, which may **allow for the sale electricity generated from the agrivoltaics project back to the grid**.

Land sector

Ministry of Interior **promotes land use for the benefits of both the agricultural and energy sectors.** The government should implement **land use policies capitalizing on the synergies between agriculture and energy production.** To this end, the Department of Public Works and Town & Country Planning should develop **regulations for agrivoltaics** as a new category of land use. Clear guidelines for land use should be established. Additionally, the Agricultural Land Reform Office within Ministry of Agriculture and Cooperatives, should encourage farmers to recognize that land (Sor Por Kor 4-01) can be converted not only for agricultural operations but agrivoltaics use.

Other related sectors

Government agencies **encourage agrivoltaics to be part of the national plan**.
Ministries work together to designate agrivoltaics as part of national plans. The examples of this are as follows.

The Office of the National Economic and Social Development Council shall identify agrivoltaics as a key solution for addressing challenges in both agricultural and energy sectors within the framework of sustainable national development and include it in the **National Economic and Social Development Plan.**

Similarly, the Ministry of Natural Resources and Environment, through the Department of Climate Change and Environment (DCCE), shall incorporate agrivoltaics as part of the strategies aimed at reducing GHG emissions from both the agriculture and energy sectors in **its mitigation** and **adaptation plans**. This initiative may demonstrate Thailand's commitment to providing options that reduce GHG emissions for farmers, adapt to and mitigate the impacts of climate change, and enhance the collaboration among the agriculture, energy, and land use sectors.

5.2 Regulations and Guidelines for the Agrivoltaics Control and Supervision

This section presents recommendations concerning rules and regulations related aimed at promoting agrivoltaics, as detailed below:

Regulatory on establishing guidelines and standards for agrivoltaics projects

Thai Industrial Standards Institute (TISI), the Electricity Distribution Department, and other relevant government agencies are responsible for **developing the guidelines and standards of agrivoltaics.** These standards should cover the aspects such as design (both agricultural and energy), installation, connection, operation and maintenance, and safety for equipment, individual or communities, and agricultural products. This shall include requirements to prohibit chemicals that could contaminate and leave toxic residues on crops or livestock. Additionally, regulations should be established for connecting to the power grid (as specified in the short-term measure) in order to maximize cost-effectiveness in electricity production and consumption, as well as management after the projects' lifespan.

Regulatory on determining the zoning for agrivoltaics

The Department of Public Works and Town & Country Planning, part of the Ministry of Interior, shall establish new zoning regulations for agrivoltaics. The objective is to increase land use effectiveness beyond traditional purposes to include areas that serve both agriculture and power generation, benefiting all sectors involved, including agriculture and energy.

Regulations and measures for determining financial support

Financial incentives play a crucial role in promoting and supporting agrivoltaics. Therefore, the government sector should develop specific financial measures, such as premiums from the Ministry of Finance via the Excise Department, along with regulations to provide tax compensation or reductions (Tax credits). The Bank of Thailand should offer guidelines for commercial banks to set low interest rates on loans (Low-interest loans) and provide support for system investment and maintenance (Initial investment & maintenance grants). Additionally, the Ministry of Energy and the Energy Regulatory Commission should establish policies and guidelines for purchasing electricity from renewable energy (short-term measures; Feed-in tariffs), among other measures.

Regulatory on establishing guidelines for measuring, reporting, verifying (MRV)

Department of Climate Change and Environment, Ministry of Natural Resources and Environment, shall establishes measurement regulations for reporting and verifying data, related to agrivoltaics projects. These regulations are intended for supervising and monitoring operational data (including GHG emissions) and evaluating potential impacts, ensuring sustainable implementation of the project.

Guidelines for Capacity Building for farmers and stakeholders in agrivoltaics

Ministry of Energy, Ministry of Agriculture and Cooperatives, Ministry of Natural Resources and Environment, and other related government agencies jointly establish guidelines and a certification process for those operating agrivoltaics. The guidelines aim to provide knowledge and skills to farmers and stakeholders involved in implementing agrivoltaics projects, covering standards, monitoring, reporting, and verification. Stakeholders must obtain a certificate before implementing the project and receiving various supports.

5.3 Additional Recommendations

Government agencies have established **demonstration areas or pilot programs** for agrivoltaics projects to study and derive lessons relevant to Thailand's context. Various agencies should promote and support **integrated research in the agricultural, land use, and energy sectors,** which can inform the design of standards and requirements for agrivoltaics in Thailand. Area of study include but not limited to:

- The study on humidity, wind speed, and amount of sunlight under and around the solar panels in agrivoltaics projects.
- The study on optimal solar configuration for agrivoltaics projects in Thailand.
- The study on the impact of sunlight on agricultural production, categorized by types of agricultural activities.

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