

Agrivoltaic systems in Brazil

Techno-economic feasibility and potential study

Version 2.0



Legal Information

Publisher:

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
SCN Quadra 1, Bloco C, Sala 1501, Ed. Brasília Trade Center, 70711-902, Brasília-DF, Brazil
Phone: +55 61 2101-2170
E-mail: ger-bra-ep@giz.de
Website: www.energypartnership.com.br/

Authors:

Kathlen Schneider, Civil Engineer, MSc.
Laís Vidotto, Sanitary and Environmental Engineer
Amanda Mendes Ferreira Gomes, Electrical Engineer, MSc.
Isadora Pauli Custódio, Architect and Urban Planner, MSc., PhD
Victoria Maschio Chaga
Rodrigo da Silva Gomes
Ramom Morato, Agronomic Engineer
Ricardo Rüther, Metallurgical Engineer, PhD
Lucas Nascimento, Electrical Engineer, PhD

Concept & design:

Gustavo Costa

Picture credits

Copyrights of the respective images are noted directly on the images

Last updated:

May/2026

Publication:

August/2026

Content contributions by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) as well as the complete work are subject to the respective copyright law. Contributions of third parties are marked accordingly. Reproduction, further use or distribution as well as any other use not provided for in copyright law requires the written consent of GIZ. Partial reproduction of this work is allowed only with proper source citation.

This study was prepared by GIZ on behalf of the German Federal Ministry of Economic Affairs and Energy (BMWE) as part of the German-Brazilian Energy Partnership. The findings and opinions expressed are solely those of the authors and do not represent the position of the partner or stakeholders of Germany's Climate and Energy Partnerships.

All rights reserved.

Implementing organisation



Energy Partners



Table of contents

1. Introduction.....	10
2. Agrivoltaic technology: concept, history and applications.....	11
2.1 Concept and brief history	11
2.2 Applications and technologies	14
2.3 Business Models.....	15
3. State of the art for agrivoltaic systems worldwide.....	18
3.1 Germany	19
3.1.1 DIN SPEC 91434 – Definitions and categorization	19
3.1.2 DIN SPEC 91434 – Agricultural proposal.....	20
3.1.3 DIN SPEC 91434 – Planning and technical prerequisites for agrivoltaics.....	20
3.1.4 DIN SPEC 91434 – Practical implications of the standard in Germany	21
3.1.5 Example of an agrivoltaic system in Germany.....	21
3.2 Italy	22
3.2.1 Italian guidelines – Definitions	23
3.2.2 Italian guidelines – Categorization.....	23
3.2.3 Example of an agrivoltaic system in Italy.....	24
3.3 Croatia.....	24
3.4 France	24
3.5 China	25
3.6 United States.....	26
3.7 South Korea	30
3.8 Australia.....	32
3.9 Spain.....	32
3.10 Japan.....	33
3.11 Chile.....	34
3.12 India.....	35
3.13 Brazil.....	36
3.13.1 Considerations regarding the national and international regulatory context	37

4. Agrivoltaic systems in Brazil	42
4.1 Existing systems.....	42
4.1.1 Ecolume	42
4.1.2 Pankara Village.....	42
4.1.3 UFAL.....	44
4.1.4 Agri Solar Farm	45
4.1.5 CCampo.....	45
4.1.6 EPAMIG's Cemig and CPQD.....	46
4.1.7 Fotovoltaica UFSC and Repsol Brazil.....	46
4.1.8 Beevolt and Sheep Introduction – EDP Brazil.....	47
4.1.9 Vênus Energia + UFCG.....	48
4.1.10 Agrivoltaic System – Agri-PV Brazil	48
4.1.11 SUNfarming.....	49
4.1.12 Agrivoltaic System for Livestock Production	49
4.1.13 Considerations regarding the existing agrivoltaic systems in Brazil.....	50
4.2 Potential of different agricultural products for agrivoltaics in Brazil.....	51
4.2.1 Socioeconomic aspects.....	52
4.2.3 Case of the North region and Matopiba region	53
4.2.4 Case of Northeast region.....	54
4.2.5 Isolated Electric Power System (SISOL)	55
4.2.6 Agriculture and livestock systems aspects.....	55
4.2.7 Agriculture and livestock.....	55
4.2.8 Water Availability and Irrigation.....	58
4.2.9 Photovoltaic (PV) systems aspects	58
4.3 Business models and financing opportunities for agrivoltaics in Brazil	60
4.3.1 Possible business models within the Brazilian context	60
4.3.2 Existing financing opportunities for solar energy in agricultural lands	61
4.4 Benefits and drawbacks of agrivoltaic systems within the Brazilian context.....	68
4.4.1 SWOT analysis	68
4.4.2 Benefits	69

4.4.3 Challenges	70
5. Case study context.....	71
5.1 Association of the Organic Producers of Iranduba (APOI)	71
5.2 Initiatives CSA Manaus and Green Basket (Cesta Verde).....	72
5.3 Agrivoltaic system design	73
5.4 Economic analysis	77
5.4.1 Electricity costs of the families and industrial kitchen	77
5.4.2 Proposed agrivoltaic Systems power and energy output.....	78
5.4.3 CAPEX of the proposed systems.....	79
5.4.4 OPEX of the proposed systems	80
5.4.5 Potential agricultural productivity loss scenarios and electricity savings associated with the agrivoltaics	80
5.4.6 Economic indicators: NPV, IRR and discounted Payback period	81
5.5 Recommendations on operation and maintenance	81
5.5.1 PV system maintenance guidelines	81
5.5.2 Problem identification and types of maintenance	81
5.6 Conclusions.....	83
6. Conclusions and recommendations for agrivoltaic systems within the Brazilian context	84
References	86

List of figures

Figure 1 – First agrivoltaic models. © Goetzberger e Zastrow (a), A. Nagashima (b).....	11
Figure 2 – Agrivoltaic system with organic fruit at nachtwey, Germany	12
Figure 3 – Agrivoltaic system with organic fruit at nachtwey (2), Germany.....	12
Figure 4 – A farmer harvesting rice under an agrivoltaic system with rice cultivation in the village of Gidong, South Korea	13
Figure 5 – Types of agrivoltaic systems	14
Figure 6 – Concept design for a rainwater harvesting system with storage cistern.....	15
Figure 7 – Bifacial PV modules used as livestock fencing.....	15
Figure 8 – Vertical photovoltaic system associated with greenhouses	15
Figure 9 – Agrivoltaic research site featuring monofacial, translucent, and bifacial PV modules	15
Figure 10 – Typical installation costs for PV systems compared with the costs of different agrivoltaic configurations	16
Figure 11 – Overview of policies enabling agrivoltaics in European Member States	18
Figure 12 – Representation of Category 1.....	19
Figure 13 – Representation of Category 2.....	20
Figure 14 – Heggelbach project built in 2016.....	21
Figure 15 – The dual use of land for agrivoltaics and potato growing increased land-use efficiency	22
Figure 16 – Agrivoltaic system Tützpatz	22
Figure 17 – Agrivoltaic system with citrons at the Lancellotta family farm	24
Figure 18 – Sun’R agrivoltaic system in France.....	25
Figure 19 – Agrivoltaics project at the Domaine de Nidolères vineyard (Pyrénées-Orientales)	25
Figure 20 – Largest existing agrivoltaic systems, with goji berry plantation in China	26
Figure 21 – The 5 Cs of agrivoltaic project success.....	27
Figure 22 – Agrivoltaic farm design to attract pollinators such as honeybees, bumble bees, and butterflies	29
Figure 23 – Harvest under the agrivoltaic system at Jack’s Solar Garden.....	29
Figure 24 – A farmer harvests crops at Jack’s Solar Garden.....	30
Figure 25 – Grafton Solar agrivoltaic project	30
Figure 26 – Agricultural PV system developed by Q CELLS on farmland in Gwandang Village, Namhae.....	31
Figure 27 – Agrivoltaic structure information for this experiment (A) and photo of growing crops under the PV module (B).....	31
Figure 28 – Sheep enjoy the shade of the PV modules on the University of Queensland’s Gatton Solar Farm system.....	32

Figure 29 – First vertical agrivoltaic project in Japan.....	34
Figure 30 – Pilot projects in Chile.....	35
Figure 31 – Percentage of the population lacking access to electricity, by state (2022).....	36
Figure 32 – Agrivoltaic system proposed in the Ecolume project.....	42
Figure 33 – Agrivoltaic system and assembly of aquaponics system below the modules.....	42
Figure 34 – Representatives of the Pankará village and of the Brazil-Germany Cultural Center in the project area.....	43
Figure 35 – Melon plantation in the agrivoltaic system.....	43
Figure 36 – Aerial view of the Engineering and Agricultural Sciences Campus (CECA) of the Federal University of Alagoas (UFAL).....	44
Figure 37 – Agrivoltaic system with seven PV module structures.....	44
Figure 38 – Area where the system was installed, within an existing sugarcane plantation.....	44
Figure 39 – One of the pilot systems at the Agri Solar Farm.....	45
Figure 40 – Members of CCampo, OCB and Fotovoltaica/UFSC in front of the under-construction agrivoltaic system, and cooperative members planting in the control area adjacent to the power plant.....	46
Figure 41 – Aerial view of the Fotovoltaica/UFSC and Repsol agrivoltaic system.....	47
Figure 42 – Fotovoltaica/UFSC and Repsol Agrivoltaic system.....	47
Figure 43 – Sheep at EDP Brazil's Pereira Barreto Power Plant.....	48
Figure 44 – Agri-PV System.....	48
Figure 45 – System with soybeans (left) and system with brachiaria grass (right).....	49
Figure 46 – SUNfarming System.....	49
Figure 47 – Agrivoltaic System for Livestock Production.....	50
Figure 48 – Percentage of establishments classified as family farming in relation to the total number of establishments, by municipalities – 2017.....	53
Figure 49 – Proposed delimitation for Matopiba region.....	54
Figure 50 – Purdue University research agrivoltaic system over soy and corn plantations.....	56
Figure 51 – Solar Irradiation levels per region.....	59
Figure 52 – PV generation potential in annual energy yield (kWh/kWp/year).....	60
Figure 53 – Location of the case-study – APOI Association.....	71
Figure 54 – Crops production from APOI's families.....	72
Figure 55 – Woman farmer from the APOI Association.....	72
Figure 56 – APOI operational model.....	73

Figure 57 – Elevated agrivoltaic location.....	74
Figure 58 – Agrivoltaic greenhouse/shadehouse location.....	74
Figure 59 – Agrivoltaic greenhouse/shadehouse.....	74
Figure 60 – Elevated Agrivoltaic System Design.....	74
Figure 61 – Graph of Energy consumption and Energy production per month.....	78
Figure 62 – Typical PV installed costs compared to different agrivoltaic configuration costs.....	79
Figure 63 – Example of dirty PV modules and clean modules	82
Figure 64 – Bifacial, vertically installed PV modules for fencing applications	84

List of tables

Table 1 – Configurations of different agrivoltaic business models.....	16
Table 2 – Summary of international regulatory frameworks	39
Table 3 – Summary table of the identified agrivoltaic projects in Brazil.....	50
Table 4 – Conditions of the PRONAF Bioeconomy line for financing renewable energy technologies.	62
Table 5 – Conditions of the PRONAF Agroindustry line.....	63
Table 6 – Conditions of PRONAMP credit line.....	63
Table 7 – INOVAGRO financing conditions.....	64
Table 8 – PROIRRIGA financing conditions	64
Table 9 – PRODECOOP financing conditions.....	65
Table 10 – FNE SOL financing conditions for rural producers.....	66
Table 11 – FNO Rural Verde financing conditions for renewable energy projects.....	66
Table 12 – FCO Rural financing conditions for renewable energy projects	67
Table 13 – BNDES FINAME Low Carbon financing conditions.....	67
Table 14 – SWOT analysis of the agrivoltaic technology in Brazil.....	69
Table 15 – PV module characteristics	73
Table 16 – System characteristics	74
Table 17 – Shading analysis	75
Table 18 – Expected energy output	77
Table 19 – Simulated Daily Yield.....	77
Table 20 – Average energy consumption of the four families.....	77
Table 21 – Average energy consumption of the industrial kitchen	78
Table 22 – Average energy consumption of the industrial kitchen.....	79
Table 23 – Estimated elevated agrivoltaic cost	80
Table 24 – CAPEX of the different proposed PV system configurations.....	80
Table 25 – Productivity loss and energy savings scenarios	81
Table 26 – NPV, IRR and discounted payback period	81

1. Introduction

Brazil is a continental-sized country with exceptional environmental wealth, comprising a diversified fauna and flora, hosting more than 5 million km² of the Amazon rainforest and many other local biomes, such as the Cerrado, Pantanal, Caatinga and Atlantic Forest. This diversity and wealth are reflected in Brazilian culture and identity, providing outstanding opportunities for future research on biodiversity conservation for the good of all.

However, the country also faces significant structural challenges related to socioeconomic inequality, with a rural structure in which the large-scale agribusiness industry coexists with urbanization patterns that, in several cases, limit adequate access to resources, infrastructure, and basic services for a significant portion of the population [1]. In this context, certain population segments still live with food insecurity and energy poverty, phenomena that affect more intensely rural populations and groups in situations of social vulnerability.

Despite being one of the largest food producers in the world, having a large-scale agriculture as the basis of its economy, Brazil was recently listed on the UN Hunger Map [2], from which it was removed in mid-2025 [3]. According to a survey conducted in 2024, approximately 19 million Brazilian households face some level of food insecurity, with the most severe levels affecting the population in the Northern and Northeastern regions and rural areas [4].

It is relevant to note that leaving the Hunger Map represents a significant advance, although the remaining challenges demand continuous attention. A relevant aspect of the Brazilian context is that the expansion of monocultures and the agribusiness activity figure among the factors associated with the deforestation of the Amazon and the increased use of pesticides in the country. Since 2019 the widespread use of pesticides in Brazil has been growing at a fast pace [5]. Also, it is observed that the predominant agribusiness model presents tensions regarding the conservation of national wealth and biodiversity, indicating the importance of seeking greater integration between productivity and environmental sustainability.

Another challenge faced by Brazilian rural areas and vulnerable groups is the poor access to reliable and sustainable energy services. Energy is an essential component of all socioeconomic systems, playing a crucial role in the global sustainable development. The lack of access to energy services and the insufficient quality of these services constitute factors that lead to social exclusion processes and hinder the development of communities with these characteristics [6]. Despite Brazil presenting excellent solar radiation resources [7], energy poverty is still present in the national context, affecting mainly isolated communities in rural areas and densely populated urban areas, marked by poverty and limited infrastructure [6].

Through the Brazilian Observatory on Energy Poverty (OBEPE) platform, launched in 2025, it is possible to access energy poverty data based on different sources

and methodologies. Based on data from the IBGE's 2018 Household Budget Survey (POF), 19.8% of Brazilian households are experiencing energy poverty, according to the indicator that considers all households whose electricity consumption (in kWh) is classified as insufficient—that is, lower than half the national median consumption per household [8]. Among the results observed, it is noteworthy that the five States with the highest rates of energy poverty are predominantly concentrated in the Northeastern and Northern regions of the country, evidencing regional inequalities in adequate access to electricity that demand targeted policies.

Solar photovoltaic (PV) technology is considered one of the key solutions to fight climate change, and it has grown significantly in the last decade. According to the report Snapshot of Global PV Markets 2025 issued by the International Energy Agency (IEA), PV installed capacity has reached almost 2,2 TW by the end of 2024 [9]. Despite being a renewable source with a low environmental impact compared to wind power and fossil fuels, solar PV power plants require considerable space, making it challenging to find suitable locations for large PV installations [10]. To address this issue, one solution involves integrating PV systems into various human activity activities, including buildings (Building Integrated Photovoltaics [BIPV]), lakes (Floating PV plant), and land use for agricultural purposes (Agrivoltaic System) [10].

In this context, the dual use of land for agriculture and solar power generation has the potential to become a powerful tool to overcome the above-mentioned challenges. Agrivoltaic systems generate renewable energy without diverting the land areas destined for food production [11]. This technology has also a promising potential to become a resilient tool to address climate change. Agri-PV systems can offer soil protection against excessive solar radiation, heat, and droughts [12]. Therefore, agrivoltaic systems can bring benefits to grazing activities by creating a cooler microclimate and providing shelter from sun, wind, and predators for livestock.

This report aims to present detailed information on the agrivoltaic technology, including its historical applications, regulatory progress around the world, as well as different applications at a global level. It also includes a country-specific overview, presenting the existing agrivoltaic systems in Brazil, the potential of the technology considering the national regional diversity, the potential benefits and drawbacks and the recommendations for the development of the technology in the Brazilian context.

2. Agrivoltaic technology: concept, history and applications

This chapter provides an overview of agrivoltaic systems (Agri-PV) including historical and current applications globally. It also explains the different configurations of agrivoltaic systems, as well as the various component designs and technologies that are currently on the market.

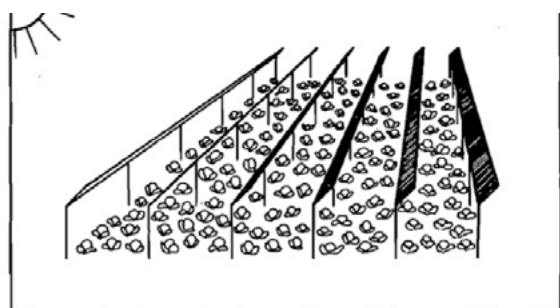
2.1 Concept and brief history

An agrivoltaic system can be defined as a technology that aims to simultaneously use land for agricultural purposes and PV power generation [13]. Agrivoltaics can increase the efficiency of land use, can incorporate adapted support structures and can be implemented in association with various crops. Agrivoltaics are growing rapidly, but standard definitions and designs are still lacking in many states and countries. The systems can be referred to by various terms, such as “dual use”, “co-location”, “Agri-PV”, “Agro-PV”, “agrivoltaic”, “agri-solar”, “solar sharing” or “pollinator-friendly solar”, depending on the region and specific applications around the world [14]. In this document, the term “agrivoltaic” was selected due to its widespread usage and because it is used in the key references utilized for this study, such as the publication

“Agrivoltaics: Opportunities for Agriculture and the Energy Transition” by Fraunhofer Institute for Solar Energy Systems (ISE) in Germany [12].

The agrivoltaic technology was first described in the scientific literature in 1981 by Professor Adolf Goetzberger, the founder of the Fraunhofer ISE, and his colleague Armin Zastrow in an article published in the journal Solar Energy [13]. The article entitled “On the coexistence of solar energy conversion and plant cultivation” served as the initial step in creating the concept of agrivoltaic systems. However, this concept remained largely forgotten for many years until the first system was created in 2004, constructed in Japan by Akira Nagashima, who referred to the model as “solar sharing” [15]. Both mentioned agrivoltaic models are shown in Figure 1.

Figure 1 - First agrivoltaic models. © Goetzberger e Zastrow (a), A. Nagashima (b)



(a) Concept proposed by Goetzberger

Source: [15]



(b) First model developed by Akira

Since then, agrivoltaic systems have been growing rapidly in Europe, Asia, and the United States [10]. These systems exist on various scales, from small setups for farming families to large-scale installations.

Within the international context, there is significant potential for small-scale agrivoltaic systems, which can provide significant social benefits to the involved families. Countries

like Japan, Italy, and South Korea, which have limited land availability considering the proportion of their populations, are already investing in agrivoltaic systems to diversify the income sources within the agricultural sector [10].

Germany is one of the pioneering countries in the development of the agrivoltaic technology (Figure 2 and Figure 3). On the research level, the country hosts several

projects that provide data for the continuous improvement of the technology. Additionally, Germany has played a leading role in developing technical guidelines for agrivoltaic systems. The Fraunhofer Institute for Solar Energy Systems (ISE) and the University of Hohenheim collaborated with the German Institute for Standardization (DIN) and other partners to develop the DIN SPEC 91434 standard [16]. Published in May 2021, this document titled “Agri-photovoltaic systems – Requirements for primary agricultural use” aims to establish a testing method for agrivoltaic systems and to provide standardized agrivoltaic measurement procedures for reporting and documentation to legislative bodies, financiers, approval authorities, as well as for post-testing stages and certification by experts and certification organizations.

Figure 2 - Agrivoltaic system with organic fruit at nachtwey, Germany



Source: [10]

Figure 3 - Agrivoltaic system with organic fruit at nachtwey (2), Germany



Source: [10]

Considering the context of climate change, population growth, and increasing electricity demand, the PV technology is expected to continue expanding and gaining more and more share in the global energy mix. However, there is also a rising need for food production, leading to competition for land and space, particularly in densely populated areas. As conventional PV systems can occupy significant land areas, agrivoltaic technology emerges as a crucial alternative for the efficient use of land [15].

The combined use of land for food production and power generation offers several advantages for both purposes beyond land efficiency [8], such as:

- Agrivoltaic systems can reduce irrigation requirements due to the reduction of evapotranspiration and there is also a possibility of collecting rainwater for irrigation purposes.
- The presence of PV mounting structures can act as a support for the installation of protection or shielding for the crops, reducing the impact of wind erosion or the presence of insects and animals.
- Reduction of pesticide and fungicide application due to enhanced plant protection.
- Providing shade or protection from the elements.
- Some agrivoltaic systems use tracking technology/trackers to optimize the availability of light for the crops, which can enhance conditions for plant growth.
- Agrivoltaic systems can generate better cooling of PV modules, which can result in increased power generation efficiency.
- The design and setup of agrivoltaic systems can improve the efficiency of bifacial modules, which can generate energy from both sides.

Besides the technical benefits that might boost power generation and food production, agrivoltaic technology can also generate economic and social advantages for farmers. These systems bring greater energy independence to farming families (Figure 4) and offer the potential for income diversification through the sale of surplus electricity (or generation and sharing of credits). In Japan and South Korea, for example, the implementation of agrivoltaic projects has been driven by a focus on social benefits for farmers and rural communities. In Japan, the technology was introduced to address the challenges of rural depopulation and declining agricultural income, particularly following the Fukushima nuclear accident, which contaminated agricultural land and crops [17].

Figure 4 - A farmer harvesting rice under an agrivoltaic system with rice cultivation in the village of Gidong, South Korea

Source: [18]

In the case of the above-mentioned countries, by integrating PV energy dual-use, farmers can generate alternative income by selling PV energy, while preserving the cropland beneath agrivoltaic installations for potential future agricultural use. Both Japan and South Korea have designed their regulations to encourage local participation, ensuring a decentralized and equal distribution of agrivoltaic projects [17]. In South Korea, for example, the government planned to install, by 2030, 100,000 agrivoltaic systems on farms to ensure retirement security for farmers, providing them with a monthly income of approximately 1,000 US dollars through electricity sales [10]. Japan and South Korea's focus on smaller-scale projects benefits local farmers and communities, fostering economic resilience and sustainable land use [17].

To ensure the benefits of adopting agrivoltaic technology, it is essential that all stages of planning, design, and installation of the systems are carried out properly. In Brazil, the technology is still in the pilot implementation phase, and in the coming years, it will be crucial to conduct further studies on the suitability of the technology to local climatic conditions and crops. Additionally, these studies and insights gained from pilot projects are fundamental for developing guidelines and/or national regulation frameworks that will steer the development of agrivoltaic systems.

In several countries, there has been a decline in the credibility of agrivoltaic systems due to projects that received subsidies/incentives but neglected agricultural production. For example, according to a report from the Fraunhofer ISE [19],

as clear criteria had not been defined for agrivoltaic systems in the first round of tenders in France, the participation of agricultural production was minimal or even non-existent in some projects. This outcome led to certain resistance towards agrivoltaics in the country, especially within the agricultural sector. Consequently, in 2021, standards for the installation of these systems were developed and published by the French Environment and Energy Management Agency (ADEME) [20], and in the years that followed, the national framework evolved considerably.

Another challenge for the technology implementation is the lack of trained professionals to plan and install projects in the Brazilian market. The technology is still new for PV energy companies and even educational institutions, with limited training opportunities available for energy professionals. Additionally, knowledge of PV energy systems alone is not sufficient for the development of a successful agrivoltaic project. As indicated in technical guide documents such as "Agri-photovoltaic systems – Requirements for primary agricultural use" (DIN SPEC 91434) from Germany and "Guidelines for The Design, Construction, and Operation of Agrovoltaic Plants" [21] from Italy, the presence of multidisciplinary teams is crucial for planning, maintenance, and monitoring of these systems.

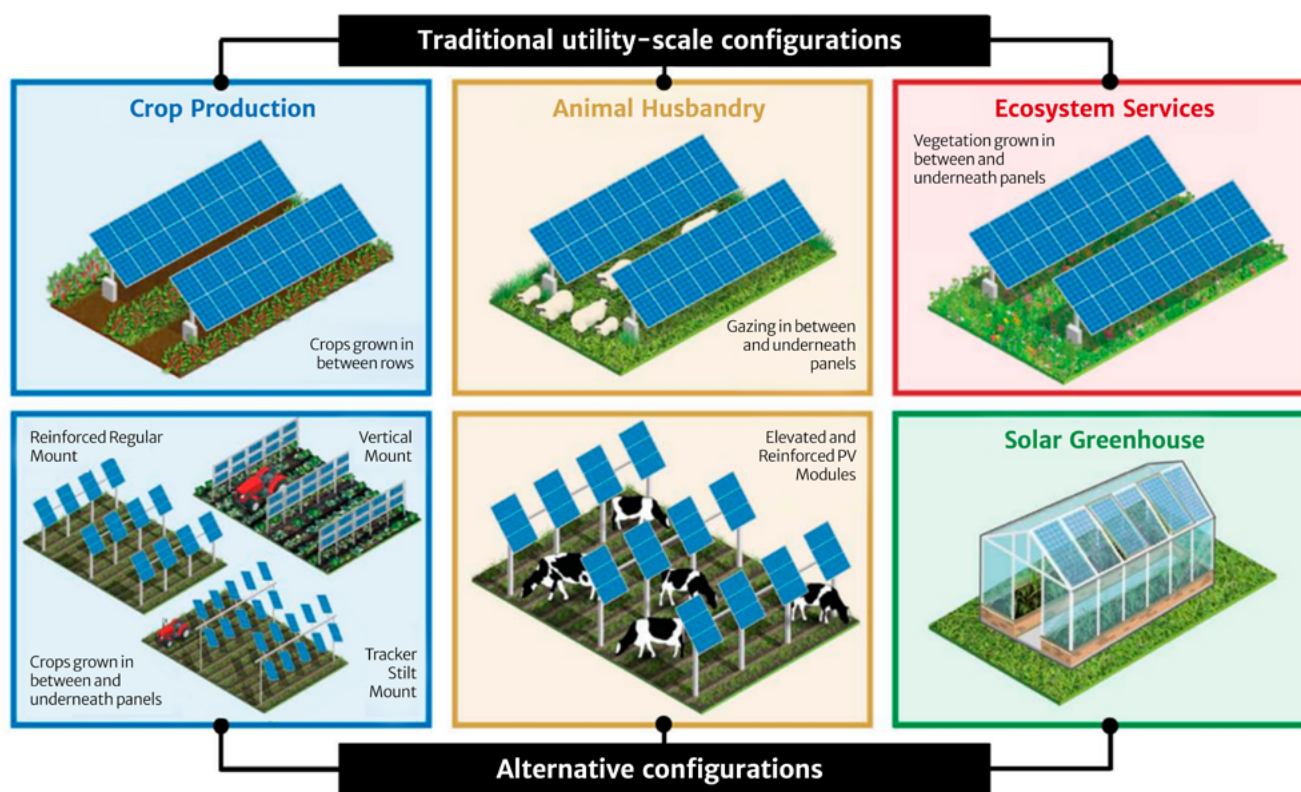
2.2 Applications and technologies

According to Macknick [14], agrivoltaic systems can be categorized into two main configurations: (1) elevated systems with crop production below the PV modules and (2) lower systems with crops grown between rows of PV modules. Therefore, agrivoltaic systems also provide versatility, with options ranging from lower setups, allowing for crop cultivation between rows of modules, to taller structures exceeding 5 meters in height, which enable passage of agricultural machinery beneath the PV modules. These structures can be either fixed or equipped with single or dual-axis tracking systems to optimize power generation.

In terms of applications (Figure 5), the main categories include [14]:

- (1) Crop and food production: cultivation below or between rows of PV modules;
- (2) Livestock production: grazing below or in the vicinity of the systems, providing thermal comfort through shading;
- (3) Provision of ecosystem services through vegetation management: creating habitats for pollinators, soil formation, biodiversity maintenance, and carbon sequestration;
- (4) Solar greenhouses: PV modules installed above greenhouses, utilizing the greenhouse structure for module installation and offering partial shading.

Figure 5 - Types of agrivoltaic systems



Source: [14]

Furthermore, some configurations are designed for specific applications, such as vertical bifacial modules or structures arranged to facilitate rainwater collection (Figure 6). The vertical systems are more cost-effective compared to elevated agrivoltaics, due to the lower substructure, but also offer fewer light management options. One advantage of the vertical agrivoltaic systems could be a reduction in wind speed, which has a positive effect reducing evaporation of the crops [10]. The vertical agrivoltaic system can replace fences used in agriculture

and livestock farming and protect grazing areas (Figure 7).

Another interesting application of vertical agrivoltaics is in association with greenhouses, leveraging greenhouse albedo to increase electricity output (Figure 8). This pilot project was installed in a farm in Colorado, USA, and the design and simulation were developed by the enterprise Sandbox Solar, with their software SPADE Agrivoltaic¹. The project's peak power generation periods are at 9 a.m. and 2 p.m., generating more energy in the times where solar generation is usually lower [22].

1 <https://spadesolar.com/>

Figure 6 - Concept design for a rainwater harvesting system with storage cistern



Source: [10]

Figure 7 - Bifacial PV modules used as livestock fencing



Source: [132]

Figure 8 - Vertical photovoltaic system associated with greenhouses



Source: [133]

Another emerging application refers to mobile PV modules. In April 2022, a Dutch consortium consisting of Npk Design, L'orèl Consultancy, and LTO Noord announced the creation of a mobile agrivoltaic system called the H2arvester. This system comprises 168 PV modules and an irrigation system, which can provide water to the surrounding areas. Regarding PV module technologies, a wide range of options can be applied. Certain technologies, particularly those with transparency or a transparent backsheet, offer advantages by allowing more light through the PV module (Figure 9), which can

significantly benefit agricultural cultivation. Also, bifacial PV modules can make use of increased albedo values [10].

Figure 9 - Agrivoltaic research site featuring monofacial, translucent, and bifacial PV modules



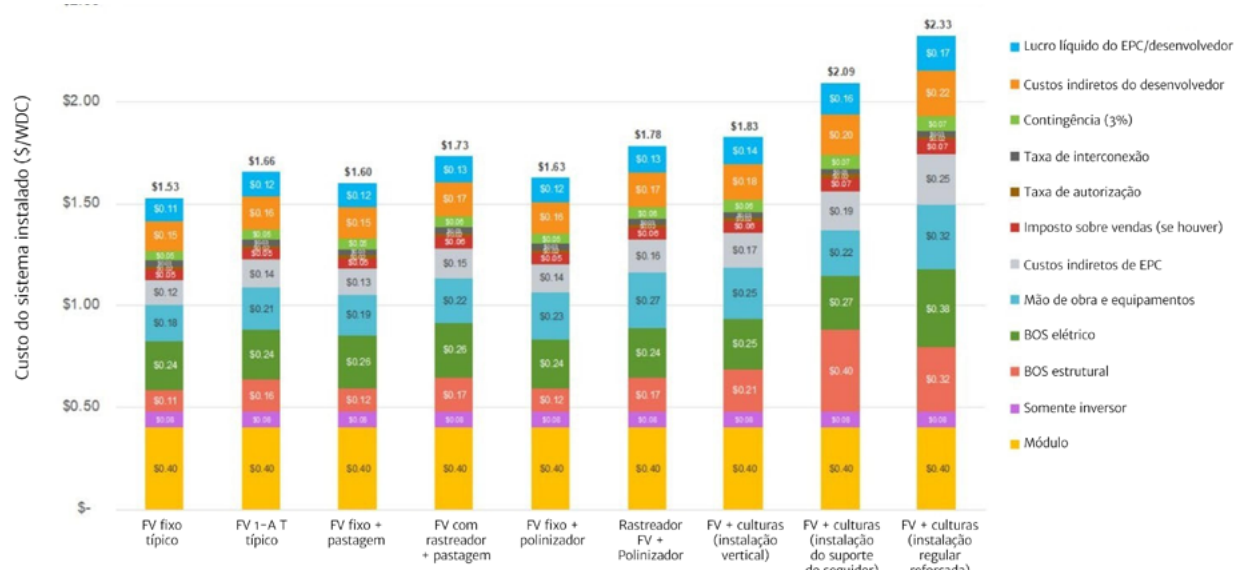
Source: [14]

The specialized PV module models have been developed specifically for agrivoltaic applications, such as modules with increased cell spacing. Such adaptability in applications and innovative technologies contribute to the continued growth and implementation of agrivoltaic technologies worldwide.

2.3 Business Models

Agrivoltaic systems can have higher installation costs compared to conventional PV systems. According to the Report from the National Renewable Energy Laboratory (NREL), “Capital Costs for Dual-Use Photovoltaic Installations: 2020 Benchmark for Ground-Mounted PV Systems with Pollinator-Friendly Vegetation, Grazing, and Crops”, costs for elevated reinforced agrivoltaic systems can be up to 52% higher than a conventional fixed PV system (Figure 10) [23].

The agrivoltaic systems can be completely funded by the farmers themselves, who are also beneficiaries of the system, but other stakeholders can also be involved in the business model, covering four main areas: (1) Land ownership; (2) Agricultural land management; (3) PV system ownership/investment; and (4) PV system operation [10].

Figure 10 - Typical installation costs for PV systems compared with the costs of different agrivoltaic configurations

Source: [23]

In addition to four different areas, there are also four main business models [10].

- **Basic case:** The first would be the simplest one, where all four areas may be the responsibility of the same actor, typically a farming business. One advantage is that costs of project planning and the complexity of contract negotiations are lower.
- **External land ownership:** In this business model the land is leased by an external stakeholder and the other three areas are in the hands of the farming business. This situation would require a long-term land lease agreement, as in the case of ground-mounted PV projects.
- **External PV system investment:** For large PV systems, an external investment for the PV systems is more common than small systems. This business model has the

potential for economies of scale and optimization thanks to a greater division of labor.

- **Shared responsibilities:** In this model there is a mix of players involved in the agrivoltaic system. The ownership of the land, the ownership of the PV system, and the operation of the farm and PV system are the responsibility of different parties, which might add complexity to the project. This model can also be used in conjunction with cooperatives to facilitate collective investment.

Thus, the systems can be self-funded and individually owned or can operate under partial land lease agreements for the installation of the system by a third-party investor, for example. The different configurations of the business models for agrivoltaic systems, with the different actors and functions are displayed in Table 1.

Table 1 - Configurations of different agrivoltaic business models

Business model	Function			
	Providing land	Agricultural management	Providing the PV System	Operating the PV System
1. Base case	Farm			
2. External land ownership	Land owners	Farm		
3. External PV investment	Farm		Investors	Farm
4. Cultivation and operation only	Land owners	Farm	Investors	Farm
5. Cultivation only	Land owners	Farm	Investors	PV Operators

Source: Adapted by the authors of [10]

In the international market practice, the ownership and operational configurations described above have evolved into specific approaches that mitigate high initial costs (CAPEX) and technical risks for farmers. The following practical models are worth noting (based on [24] and [25]):

- **Self-Operating Model (Farmer-Owned):** The farmer or farm invests in the system and manages it entirely, using electricity for self-consumption or selling it to the grid (when possible). Although it maximizes control and profits, it requires a large initial investment and the producer's ability to obtain credit.
- **Lease Model (Developer-Owned):** An investor or energy company leases the farmland to install and operate the agrivoltaic system. The farmer retains control over crop production and receives fixed payments for leasing airspace or land, which ensures a stable source of income and reduces their exposure to financial risks and market fluctuations.
- **Community Model and Producer Organizations (Cooperatives):** Farmers are pooling their land and resources to form a collective organization that will manage the agrivoltaic project. This model shares financial risks and operational responsibilities, enabling small- and medium-sized farmers to access technology through economies of scale. A successful example of a community-based arrangement can be found in Inner Mongolia (China), where agrivoltaic grazing projects combine investments from the government and local herders, and the village cooperative leases the

land to the operating company, generating dividends (annual returns) directly for the producers who serve as shareholders in the project [26].

Furthermore, there are many other projects developed through cooperative models, where both the investment and the benefits of power generation can be shared among the farmers participating in the initiative. Some examples include:

- The Community solar park in Aasen, Germany, built with vertical modules in partnership with the energy cooperative Solverde Bürgerkraftwerke Energiegenossenschaft in 2020 [10];
- The Gidong Village Power Plant in South Korea, which has a partnership with a social cooperative of local residents for “solar sharing,” mostly comprising elderly individuals who are no longer able to work in the fields [18];
- Enerjisa's project in partnership with the agricultural cooperative Komşuköy in Turkey – the country's first agrivoltaic pilot project [27];
- The project by the Agricultural Cooperative CCampo in Santarém – PA, Brazil. This pilot-scale project was conducted with the support of the German Cooperative and Raifleisen Confederation (DGRV), the Brazilian Organization of Cooperatives (OCB), and the Solar Energy Research Laboratory at the Federal University of Santa Catarina (UFSC).

3. State of the art for agrivoltaic systems worldwide

Agrivoltaic technology has increased considerably in the last decade and has benefited from government support programs worldwide. In 2012, Japan launched the first supporting scheme on agrivoltaics systems, and then, other countries like China, South Korea, France, and Germany followed [10]. Policies, regulations and technical guidelines regarding these systems are of great importance in order to foster sustainable development of the sector.

This section gathers information about the context of regulations and technical guidelines regarding agrivoltaic systems in various countries. This content will help build a framework on international best practices, which can help create a national scenario for the technology.

In October 2025, SolarPower Europe released the report “Agrisolar Policy Map,” which provides a comprehensive overview of policies in the 18 Member States, highlighting the status of the regulatory environment in Europe [28]. The survey indicates a rapid, yet still fragmented, evolution of the European landscape. Although 10 of the countries assessed allow the installation of agrivoltaic systems under current land-use regulations, only five have established a clear legal definition for the technology, with Spain currently in the process of implementing one. This shows that, in general, while many countries are introducing new policies to promote the deployment of agrisolar projects,

harmonizing definitions and permitting processes remains a challenge that must be overcome to ensure legal certainty for developers and farmers.

In addition to zoning issues, the report highlights a variety of incentive mechanisms and technical requirements. While four countries already guarantee eligibility for direct payments under the Common Agricultural Policy (CAP)², and three have introduced dedicated energy support schemes, such as specific auctions, there are still gaps, especially regarding environmental and social criteria, which remain absent from the regulations of most of the countries evaluated. Table 11 below summarizes the current status of these regulations in different countries, covering everything from legal definitions and land-use permits to technical requirements, such as the ground coverage ratio (GCR) and financial support schemes.

Figure 11 – Overview of policies enabling agrivoltaics in European Member States

		Belgium	Czech Republic	Croatia	Denmark	France	Finland	Germany	Greece	Hungary	Ireland	Italy	Latvia	Netherlands	Poland	Portugal	Slovenia	Spain	Sweden
Legal definition	A clear legal definition for agrivoltaic systems																		
	Agrivoltaics are permitted under land use and zoning regulations																		
Land use, zoning, and permitting	Simplified permitting process for agrivoltaics																		
	Clear requirements for environmental impact assessments of agrivoltaics																		
Support/incentive schemes	Agrivoltaics are eligible for CAP direct payments to farmers																		
	Agrivoltaics are included in energy incentive programs (feed-in-tariff, auctions, etc.)																		
Technical requirements	Clear rules for ground coverage ratio (GCR)																		
	Clear requirements for height and spacing																		

yes no in progress Under certain circumstances Unknown

Source: [28]

² The Common Agricultural Policy is the European Union policy that provides financial support to the agricultural sector. Its main mechanism consists of direct payments to farmers, with the primary goal of stabilizing their income. <https://www.consilium.europa.eu/en/policies/the-common-agricultural-policy-explained>

3.1 Germany

Germany is one of the leading countries in the development of agrivoltaic technology. According to the report “Agrivoltaics: Opportunities for Agriculture and the Energy Transition” by Fraunhofer ISE [25], it was estimated that there were at least 14 GWp of agrivoltaics installed worldwide, and that Germany alone has a potential of approximately 1.7 GWp for systems designed for crop cultivation beneath PV modules.

The German government has ambitious goals for the expansion of solar energy, aiming to reach 215 GWp by 2030 and between 300 to 450 GWp by 2045. To achieve this goal, agrivoltaics plays a key role, as it prevents a reduction in the areas set aside for agricultural activities. To support the sector, the 2023 Renewable Energies Act (Erneuerbare-Energien-Gesetz, EEG) has consolidated financial support by introducing specific tender segments and a “technology bonus” for elevated systems (with a clear height exceeding 2.1 m). This bonus was initially set at 1.2 euro cents per kWh for tenders in 2023, with gradual reductions planned for subsequent years. With regard to agricultural subsidies, the regulation (GAPDZV) ensures that areas with agrivoltaic systems remain eligible for 85% of the direct payments under the Common Agricultural Policy (CAP), provided that the loss of usable land does not exceed 15% of the total project area, in accordance with the criteria of the DIN SPEC 91434 standard.

The regulatory landscape has made significant progress toward incorporating agrivoltaics into the legal framework. Projects that meet specific requirements can now be classified as “priority” under the Federal Building Code (BauGB), facilitating the permitting process in areas outside urban development plans. The technical basis for these policies is the DIN SPEC 91434 standard (“Agri-photovoltaic systems – Requirements for primary agricultural use”), published in 2021. This document not only establishes testing methods and standardization for measurements but also serves as an official reference for legislative bodies and funders to determine eligibility for subsidies and the classification of systems (Category I for elevated systems and Category II for ground-mounted systems). The primary objective remains to reduce technical risks and ensure that agricultural production continues to be the area’s main activity.

3.1.1 DIN SPEC 91434 – Definitions and categorization

The definition of agrivoltaic systems presented in the guidelines is highlighted below:

- **Agrivoltaic PV system:** Combined use of the same land area for primary agricultural production and secondary electricity generation through a PV system.

The systems are divided into two main categories:

- **Category I:** Agrivoltaic systems with elevated installation: Cultivation under the agrivoltaic system.
- **Category II:** Agrivoltaic systems with ground-level installation: Cultivation between the rows of the agrivoltaic system.

Based on the specifications of eligible agricultural lands, agrivoltaic systems in both categories can be further divided into four usage categories: (A) permanent and perennial crops, (B) annual and perennial crops, (C) permanent pastures for mowing, and (D) permanent pastures.

The document emphasizes the importance of maintaining the crops in good condition, following the European Union’s cross-compliance rules and respective national standards. Furthermore, more detailed explanations about the agricultural activities in agrivoltaic areas must be documented in an agricultural cultivation proposal, which should be prepared in the planning phase prior to the construction of the agrivoltaic system. Deviations from the above categories (e.g., a combination of two categories) are possible but must still comply with the requirements of the agricultural cultivation proposal.

To be classified as Category I, the system must meet certain technical specifications, notably having a minimum height of 2.1 m (ground – bottom of the PV module), as shown in Figure 12.

Figure 12 - Representation of Category 1

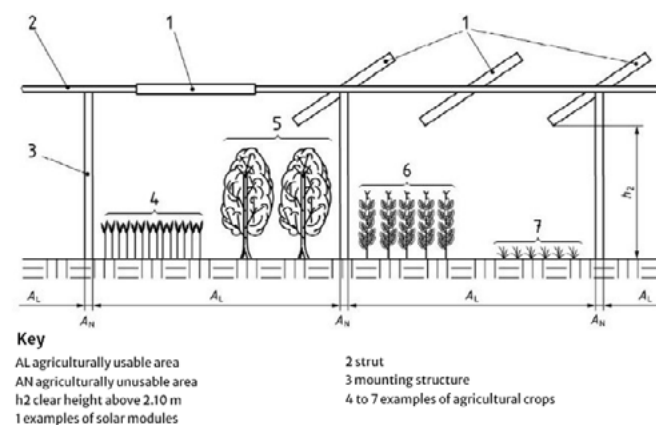


Figure 1 - Representation of Category 1

Source: [16]

On the other hand, Category II is divided into two variants: variant 1, with fixed modules at a specific angle (with module bottom height less than 2.1 m), and variant 2, with modules mounted vertically or in an adjustable manner (with tracking), where the minimum height is typically less than 2.1 m. The area under the modules should be considered unusable land for agriculture (referred to as area An in Figure 13).

Figure 13 - Representation of Category 2

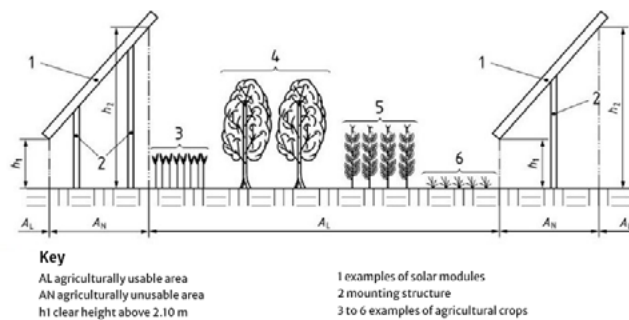


Figure 3 - Representation of Category II, variant 1

Source: [16]

3.1.2 DIN SPEC 91434 – Agricultural proposal

The planned land use and agricultural production must be defined in an agricultural cultivation proposal for the next three years or in a crop rotation cycle. The cultivation possibilities for the area should be tailored to the existing crops and properly listed in the agricultural cultivation proposal.

The agricultural cultivation proposal is jointly prepared by the land user (farmer, leaseholder) and the EPC contractor (PV system installer) and must be attached to the project documentation. The proposal should include detailed information about the following points:

- **Installation:** The PV system installation in both categories must occur in a distributed manner within the project area to preserve its prior agricultural use.
- **Land loss:** The loss of usable agricultural land due to structures should be avoided, not exceeding 10% in Category I and 15% in Category II.
- **Workability of the agricultural area:** The workability of the cultivation area must be ensured.
- **Light availability and homogeneity:** Maximizing homogeneity and light availability is essential to ensure plant growth. These aspects should be verified and adapted to the specific agricultural product needs, as agricultural production is the priority and must be guaranteed.
- **Water availability:** The availability and uniform distribution of water must be ensured for cultivation. To ensure this, an irrigation system may be used or a project with case-by-case evaluation related to the crop's water demand can be demonstrated under usual local climatic conditions.
- **Soil erosion:** The system design should minimize soil erosion effects caused by water runoff on the modules. A rainwater collection or distribution system can be implemented.

- **Residue-free assembly and disassembly:** The agrivoltaic system, particularly its foundations and anchors, must be suitable for disassembly to restore the land to its original usability after dismantling the system.
- **Calculation of economic efficiency:** An economically viable concept for agricultural use from the farmer's perspective must be presented as part of the agricultural cultivation proposal.
- **Land use efficiency:** The crop yield in the total project area after constructing the agrivoltaic system must be at least 66% of the reference yield. The reduction in agricultural crop yield results from the loss of usable agricultural land due to the superstructure/substructure of the PV system and reduced availability of water, among other factors. The reference yield should be determined using the average yield of the last three years if the farmer had already been cultivating before the PV system installation. If not, reference yields from relevant publications of the last three years can be used. The estimation of yield reduction in the remaining cultivable area, which should not exceed one third, should consider the listed factors below, and can be performed by qualified professionals.

3.1.3 DIN SPEC 91434 – Planning and technical prerequisites for agrivoltaics

In order to develop an agrivoltaic project, according to DIN SPEC 91434 [16] there are several technical decisions and prerequisites that must be considered, such as:

- **Light availability and homogeneity:** The verification should encompass all system components that influence light availability. To simplify the calculation, glass materials and encapsulation between PV cells can be considered as free cell space with 100% transparency.
- **Requirements for support structures and stability:** Structures in Germany must be designed according to Eurocode safety concepts.
- **Requirements for PV technology:** Various PV technologies can be used in agrivoltaic systems, but certain aspects need to be considered and adapted to ensure light distribution and homogeneity for cultivation.
- **Installation requirements:** In Category I, a vertical distance of 2.1 m between the top of the crops and the lower base of the PV system must be maintained. Additionally, the non-cultivable area should not exceed 10% of the total area. In Category II (ground-level systems), the size and height of the systems must be adapted to the crop being cultivated, and the non-cultivable area should not exceed 15% of the total area.

- **Other installation planning requirements:** The spacing between module rows is not specified but should comply with the previously listed requirements. Precautions against damage from agricultural machinery, such as protecting module structures, should be included in the planning.
- **Installation, operation, and maintenance requirements:** The continuity of cultivation throughout the project period must be ensured, along with the quality of the soil after the construction and dismantling of the PV system. Compliance with construction, area occupation, and safety requirements is essential. Maintenance of the system should adhere to PV system regulations, and working under the system during extreme weather events should be avoided. Periodic inspection for dirt on the PV modules is recommended, and cleaning should only be done if necessary, with care to avoid any negative impact on the crops when using cleaning agents.

3.1.4 DIN SPEC 91434 – Practical implications of the standard in Germany

The DIN SPEC 91434 standard is reflected in the German context in that applied research institutions, technical consulting firms, and regulatory agencies have a common reference for assessing the compliance of agrivoltaic projects. Recent technical reports indicate that the standard has been used as the basis for integrated analyses that take into account agronomic, energy, and legal requirements, especially in larger-scale projects or those involving unconventional structural solutions, thereby providing greater legal certainty and institutional predictability to the sector.

As a result, DIN SPEC 91434 has established itself as an objective regulatory framework, standardizing eligibility for incentives under the EEG and the Solarpaket 1 by reducing administrative subjectivity in the permitting processes. In addition to setting conditions for access to specific auctions and technology bonuses, the standard now provides a framework for energy and land-use planning, serving as the basis for estimating of the technical and socio-spatial potential of agrivoltaics in the country [29].

3.1.5 Example of an agrivoltaic system in Germany

Research agrivoltaic sites have existed in Germany since 2013 [10], and many of them were of large relevance to the development of the technology worldwide. The Fraunhofer ISE, for example, offers comprehensive R&D services for industry, covering strategy, project development, engineering, procurement, and operation monitoring.

BayWa r.e., that is, a subsidiary of BayWa and majority shareholder of T&G, was an early adopter in this field and actively seeks farms interested in co-investing

in agrivoltaics [30]. Other German companies in the agrivoltaic market are SUNfarming, which provides elevated horizontal systems suitable for fruit and vegetable cultivation, herbs, flowers, and special crops like wine and berries and Next2Sun, which specializes in vertical, bifacial agrivoltaic systems [30].

One good example of an agrivoltaic research site in Germany is at the Hofgemeinschaft Heggelbach farm near Lake Constance in Germany, in 2016 (Figure 14), as part of the APV-RESOLA project. Test crops, including winter wheat, potatoes, celery, and clover grass, were cultivated. To ensure consistent sunlight exposure for the crops, bi-facial double-glass PV modules were installed with a ground clearance of five meters, facing south-west, and with larger gaps between the rows. The design allows for the use of large machinery like combine harvesters without significant limitations. The rows are spaced 9.5 meters apart with a row width of 3.4 meters. The installed capacity of this test system is sufficient to power 62 four-person households annually. However, due to increased row distances, the installed capacity per hectare (ha) is approximately 25% lower compared to conventional ground-mounted PV systems [10].

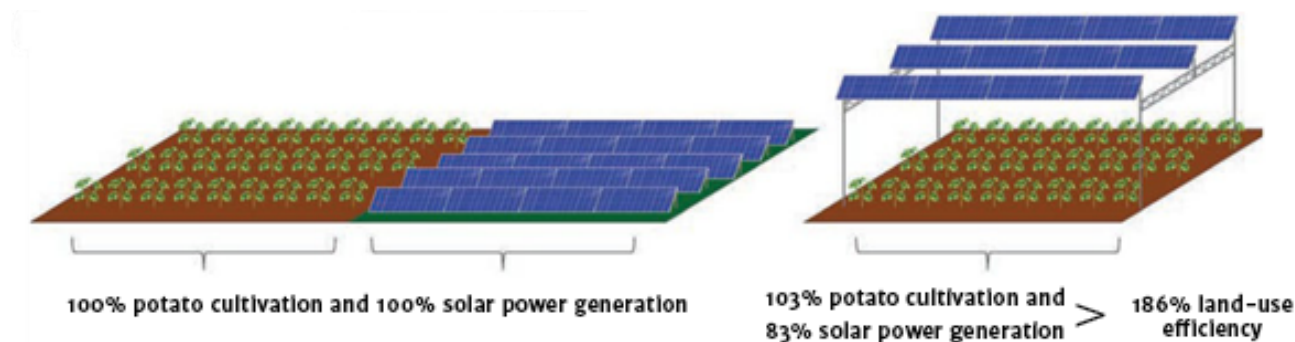
The project's findings revealed that the land-use efficiency increased to 160% in the first year of the project (2017), confirming the practical feasibility of agrivoltaic system. Crops grown under PV modules had a yield of over 80% compared to reference areas without PV modules, making them commercially viable. During the 2018 summer, there were extreme heatwaves and crop yields surpassed the previous year's results significantly. The partial shade provided by the PV modules enhanced crop yields, while the abundant solar radiation simultaneously boosted PV power generation [10]. This led to an 86% improvement in land-use efficiency during the potato crop testing, as shown in Figure 15.

Figure 14 - Heggelbach project built in 2016



Source: [30]

Figure 15 - The dual use of land for agrivoltaics and potato growing increased land-use efficiency on the Heggelbach test site to 186%



Source: [12]

Germany recently inaugurated its largest agrivoltaic project in Tütpatz (Figure 16), marking a step forward in the scale of the technology in the country [31]. The system has an installed capacity of 76 MWp spread over a total area of 93 ha; the PV park combines power generation free of government subsidies with agricultural and livestock activities. The

project, developed by Vattenfall, uses solar tracking systems to allow agricultural machinery to pass through and incorporates mobile chicken coops for raising poultry beneath the PV modules. The project's economic feasibility was secured through a long-term power purchase agreement (PPA) with a subsidiary of Deutsche Telekom.

Figure 16 - Agrivoltaic system Tütpatz



Source: [31]

3.2 Italy

Italy has increasingly adopted agrivoltaics as a strategy to address challenges in rural areas. Over the past three decades, the country has suffered from chronic water shortages in its central and southern regions, as well as the abandonment of 10 to 14% of its farmland since 1990 [32]. The first agrivoltaic plant in Italy, which was one of the pioneering projects in Europe, was installed in 2002. It has a total capacity of 1 MW and is located in Apulia. The deployment of agrivoltaic systems gradually expanded in the country, which gained recognition as a strategy for achieving the decarbonization objectives of the country. In the country, more than 1.5 billion euros were allocated to support the development of technology in rural areas [33].

In March 2022, new national guidelines for agrivoltaic systems⁹ were published in Italy. These guidelines were developed by the Ministry of Ecological Transition, in coordination with organizations such as the Agricultural

Research Council and Agricultural Economics Analysis (CREA), Energy Services Manager (GSE), National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), and Energy Systems Research (RSE).

With regard to business models and incentives, agrivoltaic projects in Italy may be eligible for direct payments under the Common Agricultural Policy (CAP) under certain conditions [28]. The legislation also establishes strong ties to farmers: agricultural companies or associations must use their own land for projects that maintain agriculture as the primary activity, whether individually or in partnership with energy companies. A key point is that, in order to access incentive funds from the National Recovery and Resilience Plan (PNRR), farmers must be co-owners of the proposed projects. Despite the progress, the issue has been the subject of recent debates. The 2024 "Agriculture Decree" has created uncertainty in the sector, as it is not entirely clear whether non-elevated installations are at risk of being banned

under the new guidelines, reflecting a national and regional preference that generally discourages inter-row systems in favor of elevated or vertical structures [28].

3.2.1 Italian guidelines – Definitions

The guidelines, entitled “Guidelines for the Design, Construction and Operation of Agrioltaic Plants,” aim to clarify the characteristics and minimum requirements for a PV system to be considered an “agrioltaic system”. In general, it distinguishes two types of systems: (1) agrioltaic systems that ensure a minimum interaction between energy generation and agricultural production, and (2) advanced agrioltaic systems that meet additional requirements and are eligible for state incentives paid through the electricity tariff, as per the Legislative Decree of March 3, 2011, No. 2810.

The guidelines are based on the Italian Law No. 108 of July 29, 2021, in which agrioltaic systems are defined as those systems that adopt innovative integrative solutions with elevated module mounting from the ground, also allowing module rotation, in any case, so as not to compromise the continuity of agricultural and pastoral activities, allowing the application of digital tools and precision agriculture. Additionally, the German regulation DIN SPEC 91434 “Agrioltaic Systems – Requirements for Primary Agricultural Use” was considered in the Italian guidelines. Some definitions present in the guidelines are listed below:

- **Agrioltaic System:** Refers to a PV system that adopts solutions aimed at preserving the continuity of existing agricultural and livestock activities at the installation site.
- **Advanced Agrioltaic System:** Refers to a PV system that incorporates solutions designed to preserve the continuity of agricultural and livestock activities at the installation site. This system, following the provisions of Article 65 – Decree No. 1 of January 24, 2012, as amended and supplemented:
 - Adopts innovative integrative solutions with elevated photovoltaic module mounting from the ground, also providing for the rotation of the modules themselves, in a manner that does not compromise the continuity of agricultural and pastoral cultivation activities, and may also allow for the application of digital tools and precision agriculture; and
 - Envisages the simultaneous implementation of monitoring systems to verify the impact of the PV installation on crops, water savings, agricultural productivity for different types of crops, continuity of farm activities, soil fertility recovery, microclimate, and resilience to climate change.

According to the Ministry of the Environment, agrioltaic installations can take three main forms: elevated, vertical, and between rows of PV modules. However, regulations at the national and regional levels tend to discourage inter-row

systems [28].

3.2.2 Italian guidelines – Categorization

The guidelines consider five types of requirements (A, B, C, D, and E) for agrioltaic systems. To qualify as a “basic” agrioltaic system, requirements A, B, and (possibly) D.2 must be met.

- **Requirement A.1:** Refers to the area and stipulates that 70% of it should be allocated to agricultural cultivation, floriculture, or livestock grazing.
- **Requirement A.2:** Defines the maximum percentage of the module area, which should not exceed 40%.
- **Requirement B.1:** Relates to the agricultural/livestock productivity yield in €/ha or €/Adult Livestock Unit. This requirement involves comparing the yield of the PV system with the previous years’ yield in the area. If there was no production before the PV system’s installation, the yield is compared to the productive areas nearby or a control area. Additionally, this requirement pertains to maintaining existing crops/production, ensuring that the PV system does not influence changes in the crops produced.
- **Requirement B.2:** Specifies that the PV generation system’s productivity (yield) should be at least 60% of the reference standard system’s yield in GWh/ha/year.
- **Requirement C:** Focuses on integrated innovative solutions into the agrioltaic system to optimize PV generation performance and agricultural productivity. It establishes the following criteria:
 - The minimum module height is designed to allow the continuation of existing productive activities OR (2) it is not designed to maintain agricultural production OR (3) modules are positioned vertically. In cases 1 and 3, the system would be considered an advanced agrioltaic system.
 - To be classified as “advanced agrioltaic systems,” projects must maintain a minimum height of 2.1 meters for crop cultivation and 1.3 meters for livestock/animal production activities
- **Requirement D:** Sets rules for systems with monitoring of impacts on crops, water savings, productivity, and the continuity of activities on involved farms. Average performance values should be maintained throughout the plant’s lifetime. Monitoring is essential to assess various aspects and ensure the associated agricultural production continuity.
- **Requirement D.1:** Monitoring of water savings.
- **Requirement D.2:** Monitoring of agricultural production continuity.

- **Requirement E:** The system allows verification of soil fertility recovery, microclimate, and resilience to climate change.

3.2.3 Example of an agrivoltaic system in Italy

Figure 17 - Agrivoltaic system with citrons at the Lancellotta family farm



Source: [35]

Large-scale projects are present in Italy and the UK company *Cero Generation* has an important participation in the market. The company had a financial close of a 70 MW agrivoltaics facility in the Italian Province of Latina and another of 48 MW in the province of Viterbo in the Lazio region [34].

One example of successful agrivoltaic system implemented in Italy involved the use of PV modules to provide shade for lemon and citron trees (Figure 17), mitigating the impacts of extreme heat and ensuring the preservation of these crops. The results demonstrated that the agrivoltaic system helped reduce the temperature under the PV modules, preventing potential fruit damage and maintaining optimal growing conditions for the trees. Moreover, the combined production of electricity from PV modules and fruit crops was observed to be more profitable than traditional monoculture practices. This implementation of agrivoltaic system illustrates its potential to protect crops, enhance agricultural productivity, and contribute to sustainable renewable energy production [35].

3.3 Croatia

Croatia has recently adopted a legal framework for agrivoltaic systems, marking a significant step toward the development of the technology in the country. The new regulations allow farmers to install PV systems on agricultural land, effectively combining electricity generation with agricultural activities. This legal framework aims to promote the adoption of agrivoltaic systems and facilitate the sustainable development of both sectors [36].

Under the new agrivoltaic regulations, farmers can benefit from subsidies and incentives to set up agrivoltaic plants. Agrivoltaics are now permitted on various types of sites, such as agricultural land, unused plots, and areas with permanent

plantations like vineyards and olive groves. These new rules grant every farmer the opportunity to install agrivoltaic systems on their land. This move is expected to enhance energy security, reduce greenhouse gas emissions, and boost agricultural productivity by optimizing land use. Croatia aims to achieve its renewable energy targets and promote a more resilient agricultural sector [36].

A pilot project was developed in 2016 in the country, in the city of Mecini, region of Slavonia. This system has an installed capacity of 500 kW and a variety of vegetables is grown beneath the agrivoltaic structure, which is under the responsibility of the University of Osijek [37].

3.4 France

The development of the agrivoltaic sector in France reflects the transition from an initially experimental market to one of the most structured regulatory environments in Europe. The technology began to gain momentum during the 2010s, driven by ambitious renewable energy targets and increasing demand among developers for land suitable for PV projects [38]. From 2017 onward, the French government began to promote the sector in a pioneering way through dedicated public auctions [38]. However, the lack of technical criteria and clear definitions in this initial phase allowed the development of projects with varying levels of commitment to maintaining agricultural productivity, often using agriculture merely as a pretext or façade for securing approval for energy projects, which triggered strong resistance from agricultural unions, environmental associations, and civil society [25], [38]. It was precisely to curb these distortions, protect farmers from land speculation, and ensure food sovereignty that the country embarked on a major institutionalization process, marked by the creation of technical standards, independent quality certifications (such as AFNOR's), and the enactment of the 2023 national law, which reshaped the sector.

France has recently undergone a profound transformation in the regulation of the agrivoltaic sector, establishing itself as one of the nations with the most detailed and rigorous policies in Europe. The Law on the Acceleration of Renewable Energy Production (APER Law), passed in March 2023, and its subsequent implementing decrees issued in April and July 2024, established a clear legal definition: agricultural activity must remain the land's primary use, while power generation plays a secondary role [28], [39]. To be classified as an agrivoltaic project, it must provide at least one of four services directly related to agricultural and livestock activities: improvement of agronomic potential and impact, adaptation to climate change, protection against extreme weather events, or improvement of animal welfare.

The new French regulatory framework establishes strict technical criteria to protect food production and prevent land speculation. The module Ground Coverage Ratio (GCR) is capped at 40% (a requirement applicable to projects

with a capacity exceeding 10 MW), and the loss of usable agricultural land cannot exceed 10% of the total project area. The regulation also requires that agricultural productivity be maintained at a minimum of 90% of the reference yield [40]. To ensure this goal is met, projects that use innovative technologies must establish an adjacent “control zone” (or control plot), cultivated under the same soil and climate conditions, for crop yield comparisons. ADEME maintains an official list of “proven technologies,” and only systems that use these validated technologies are exempt from the control zone requirement, subject to audits every five years. The pursuit of technical quality has also led to the creation of independent certifications, such as AFNOR’s “Agrivoltaic Project” label, which certifies projects that exceed the minimum government requirements for agronomic protection [39].

Support for the sector is provided primarily through specific auctions organized by the Energy Regulatory Commission (CRE). The French auction mechanism periodically allocates approximately 600 MW, dividing projects into two main categories: elevated systems (with a height greater than 4 meters and a capacity of less than 10 MW) and inter-row systems (with a height less than 4 meters and a capacity greater than 10 MW) [28]. Today, there are at least 200 agrivoltaic projects in the country, with more than 1,000 projects in the planning stages [41].

Despite this robust system of incentives and controls, the sharp increase in projects has sparked conflicts and disputes at the local level, particularly with opposition from environmental NGOs and rural labor unions concerned about the loss of the landscape’s character and “green grabbing” (the appropriation of land disguised as ecological transition). In the Occitanie region, for example, a survey found that 22 out of 74 projects faced some form of public opposition, often involving green grabbing allegations. To mitigate these risks and ensure that projects retain a genuine social and agricultural commitment, the law imposes strict formal requirements: energy developers are prohibited from terminating rural leases, must establish financial revenue-sharing models with landowners and operators, and, if a farmer withdraws from the project, the energy company has 18 months to find a replacement, thereby ensuring the continuity of food production [28].

Figure 18 - Sun'R agrivoltaic system in France



Source: [134]

One relevant French case study is the agrivoltaic project at the vineyards of the Domaine de Nidolères (Figure 19). The vineyards cover 32 hectares and there is a SunAgri's agrivoltaic installation cover 4.5 ha of the site. In recent years, the region has experienced several effects of climate change effects in the last years, such as rising temperatures, early ripening of grapes and an increased need for water, conditions that agrivoltaic systems can help mitigate. The results of the system include improved organoleptic properties of the grapes/wine produced and a 20% reduction in water consumption [42].

Figure 19 - Agrivoltaics project at the Domaine de Nidolères vineyard (Pyrénées-Orientales)



Source: [135]

3.5 China

China stands out as the global leader in installed agrivoltaic capacity. According to a report by the World Resources Institute (2025), more than 31 GW were assessed across 513 publicly reported projects [26]. In addition to this report, a recent high-resolution geospatial mapping survey identified 1,678 operational projects in China as of the end of 2022, with a total installed capacity of 134.55 GW [43]. The three predominant types in the Chinese market are systems combined with crop cultivation, integration with fishing and aquaculture (aquavoltaics), and systems integrated into greenhouses.

Government support has played a significant role in driving the development of agrivoltaic system in the country, enabling permitting and financing processes. This support is driven by growing concerns over both energy and food security. China imports large quantities of vegetables and fruit, and the independence from these suppliers is considered a priority by the government.

Despite China's leading position in absolute terms, the development of this technology in the country has followed a trajectory described as a cycle of “emergence, boom, and decline” due to political and regulatory factors [26], [44]. The boom took place between 2017 and 2023, a period during which central government policies allowed the leasing of ordinary farmland for PV installations. However, in practice, recent studies have shown that the vast majority of these

corporate megaprojects were built with land coverage ratios exceeding 50%, severely hindering crop cultivation and deviating from the fundamental principle of “dual land use” (where food and energy production must coexist in a balanced manner). This aggressive expansion by energy companies has led to severe social conflicts and disputes with small farmers over fertile land [26], [44].

In response to the direct threat to food sovereignty and the use of projects as an ecological façade (a form of “green grabbing”) the Chinese central government introduced stringent measures. From 2023 onwards, state authorities introduced new regulations prohibiting the installation of new PV projects on ordinary farmland and on so-called “permanent basic farmlands,” which led to a suspension and a sharp decline in the traditional agrivoltaic model in productive rural areas [44].

With access to conventional farmland now severely, the future of China’s agrivoltaic sector is now focused on models for ecological restoration and combating desertification in marginal areas [44]. A pioneering and successful example of this approach already exists: the country is home to the world’s largest agrivoltaic installation, located on the edge of the Gobi Desert (Figure 20). This megaproject has a capacity of 700 MWp (and the Baofeng Group plans to expand it to 1 GW) [45]. The area, which had previously been desertified, saw its soil initially rehabilitated through the planting of alfalfa, and today, PV modules protect goji berry crops, reinforcing the trend that the next steps for the Chinese sector will be intrinsically linked to the environmental restoration of deserts in the western part of the country [12], [44].

Figure 20 - Largest existing agrivoltaic systems, with goji berry plantation in China



Source: [45]

Government support has played a significant role in driving the development of agrivoltaic system in the country, enabling permitting and financing processes. This support comes from the growing need for both energy and food

security. China imports large quantities of vegetables and fruit, and the independence from these suppliers is considered a priority by the government.

3.6 United States

Currently, a significant share of agrivoltaic sites in the United States is associated with sheep grazing and/or pollinator habitat. Initially, the systems were limited to test plots, and now there are at least five commercial agrivoltaic system sites in operation, situated in the states of Colorado, Massachusetts, and Maine [46]. A review commissioned by the Virginia Department of Energy compiles agrivoltaic practices, policies, and programs in the United States at the federal and state levels through 2024, seeking to identify trends and recent efforts to integrate agriculture and PV generation [47]. In the public policy landscape, agrivoltaic policy is developed primarily at the state level rather than at the federal level and can be organized into four policy archetypes: scorecards focused on “pollinator-friendly” practices, use-value property-tax assessment laws, research funding programs, and feed-in tariff-type programs [48].

The agrivoltaic sector in the USA is receiving investments from various organizations. The Department of Energy (DOE) is providing US\$15 million in research funding to assess the technical and economic viability of agrivoltaic systems and their potential benefits for farmers, the solar energy industry, and local communities. At the federal level, measures such as the Bipartisan Infrastructure Law (2021) and the Inflation Reduction Act (2022) have increased funding for the Department of Energy (DOE) and fostered a favorable development environment, alongside incentives such as the Investment Tax Credit (ITC) and the USDA’s REAP program, as well as R&D initiatives by the DOE (Solar Energy Technologies Office, FARMS, and InSPIRE) and the USDA/NIFA. Some states are encouraging agrivoltaic projects through incentives and research initiatives. For instance, Massachusetts has implemented a Feed-In-Tariff adder of US\$0.06/kWh for agrivoltaic projects under its Solar Massachusetts Renewable Target (SMART) program. Also noteworthy are programs and incentives such as the ASTGU in Massachusetts and the Dual-Use Pilot Program in New Jersey, as well as initiatives in Colorado, including property tax exemptions, research funding, and pilot programs [47].

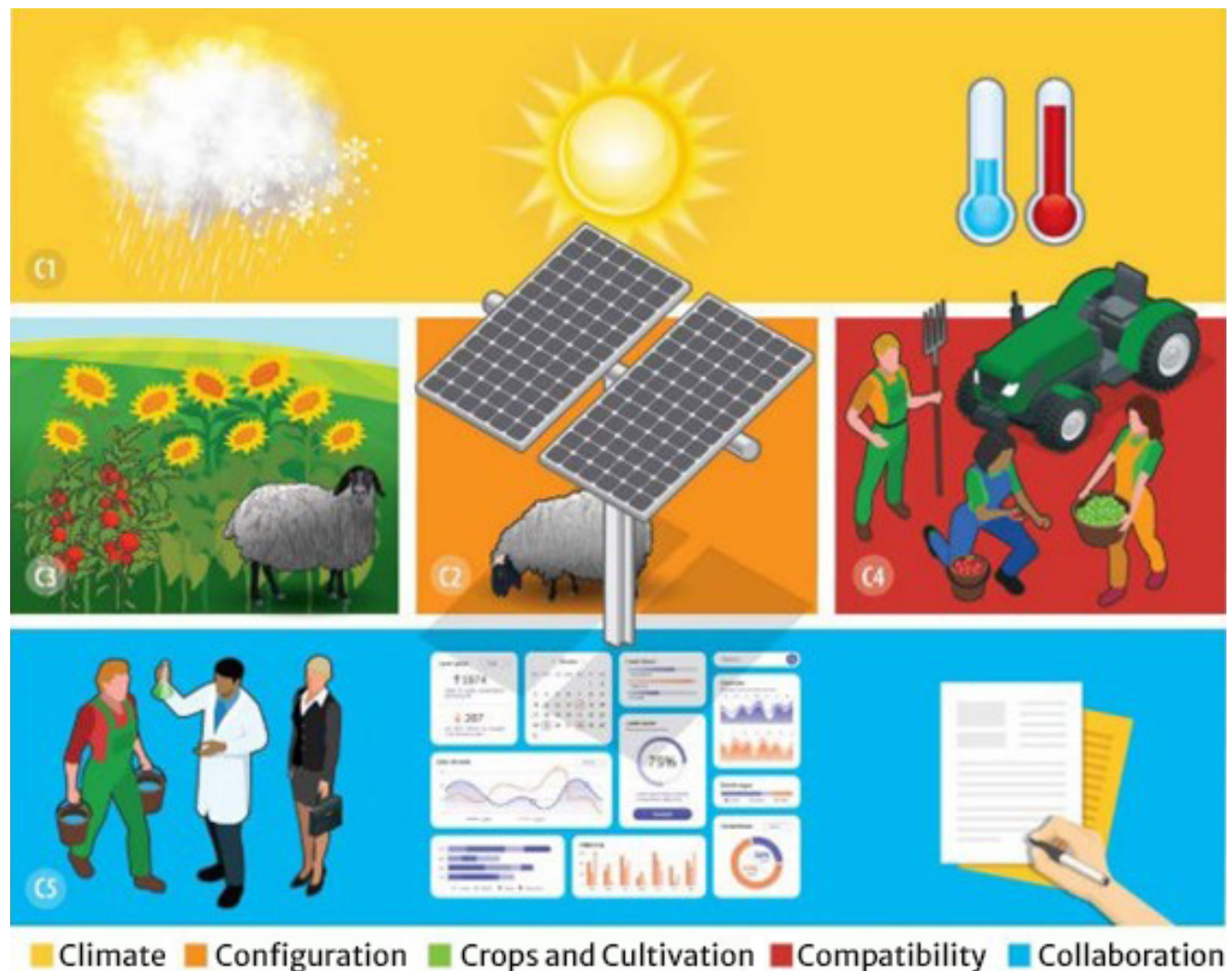
In New Jersey, an agrivoltaic pilot program of up to 200 MW on unpreserved farmland has been authorized, along with funding for an R&D system at the Rutgers New Jersey Agricultural Experiment Station. Colorado is also investing in agrivoltaics research [46]. In Virginia, the DEQ’s Permit-by-Rule provides for reduced mitigation requirements when practices such as managed grazing and crop cultivation are implemented in projects that impact agricultural land with high productive potential [47].

Additionally, the USA's Office of Energy Efficiency and Renewable Energy is collaborating with the Department of Agriculture on foundational research to assess the economic value, trade-offs, and ecological impacts of agrivoltaics projects. On the other hand, DOE is providing funding to develop new technologies that could facilitate the deployment of agrivoltaic systems and reduce associated costs [46]. In general, these initiatives tend to rely on financial incentives (given the higher initial costs) and pilot/demonstration projects to test designs, crop performance, and management practices before scaling up [47].

DOE's research project entitled "Innovative Solar Practices

Integrated with Rural Economies and Ecosystems" (InSPIRE) has been supporting agrivoltaic research initiatives since 2015. The project examined opportunities and trade-offs at more than 25 locations across the country, encompassing agricultural production, pollinator habitat, ecosystem services, and livestock production. The results from the pilot projects that composed the InSPIRE project served as input for a document published in August 2022 by NREL, entitled "The 5 Cs of Agrivoltaic Success Factors in the United States Lessons from the InSPIRE Research Study" [14]. The 5C's are Climate, Configuration, Crops and Cultivation, Compatibility, and Collaboration, as presented in Figure 21.

Figure 21 - The 5 Cs of agrivoltaic project success



Source: [14]

The five factors are described below, based on the InSPIRE report:

- **Climate, Soil, and Environmental Conditions (C1):** The environmental conditions and factors of the specific location that are beyond the control of the solar energy owners, PV energy operators, agrivoltaic practitioners, and researchers.
- **Configurations, Solar Technologies, and Designs (C2):** The choice of PV energy technology, the site layout, and other types of infrastructure that can affect light availability and power generation.
- **Crop Selection and Cultivation Methods, Seed Mixes and Vegetation Designs, and Management Approaches (C3):** The methods, vegetation, and agricultural approaches used for agrivoltaic activities and research.

- **Compatibility and Flexibility (C4):** The compatibility of the solar technology design and configuration with the competing needs of solar energy owners, solar operators, agricultural practitioners, and researchers.
- **Collaboration and Partnerships (C5):** Understandings and agreements made across stakeholders and sectors to support agrivoltaic system installations and research, including community engagement, permitting, and legal agreements.

According to the learnings from the research sites, a module height of 1.8 m appears to be the minimum viable height for planting vegetables below the modules, considering shading patterns and interaction with farmers. However, farmers prefer a height of 2.4 m or more. Researchers from the project are evaluating microclimate, soil characteristics, shading, and interactions with workers in systems with both heights at two locations in the United States.

Module spacing, as well as spacing between rows of modules, and different PV technologies, with or without cell spacing, are being studied by American universities as part of the InSPIRE project, which, together with the results from its pilot projects, will contribute to the development of guidelines for the technology.

The U.S. Department of Energy's Clean Energy to Communities (C2C) program provides technical support and resources to help communities and farmers plan and implement clean energy projects, including agrivoltaics [49]. As part of Agrivoltaics 101, C2C provides introductory materials, connections with experts, and practical guidance to help local governments, cooperatives, and farmers understand the regulatory, technical, and financial aspects of these systems. The initiative aims to reduce information barriers and accelerate the adoption of solutions that integrate solar generation and agricultural production, thereby promoting local economic development and greater energy resilience.

Among the C2C documents, one titled Agrivoltaics Pathway serves as a structured guide for the planning and implementation of agrivoltaic projects on rural properties [50]. It organizes the process into two main phases: planning and implementation. During the planning phase, it emphasizes the importance of farm assessment, a PV feasibility study, the selection of compatible crops or livestock, the determination of technology and equipment, financial planning, and an analysis of regulations and permits. In the implementation phase, it emphasizes guidelines for system installation and integration, monitoring and maintenance, environmental impact assessment and sustainability, community engagement, and continuous improvement. The guide emphasizes that each location has its own specific conditions and that adapting to agricultural, climatic, and regulatory characteristics is

essential to the project's long-term success.

It should also be noted that incorporating actions and adjustments tends to be simpler when done in the early stages of project development, rather than later on. Notable among the recommended resources are the DOE's "Farmer's Guide to Going Solar", InSPIRE's high-level financial calculator, the DSIRE database of state incentives, local regulatory guides (e.g., for Illinois and Colorado), and NREL resources on permitting/inspection/interconnection timelines [48].

In addition to these initiatives, the Department of Energy, through the Solar Energy Technologies Office (SETO), has established the Foundational Agrivoltaic Research for Megawatt Scale (FARMS) program, which investigates how agrivoltaic systems can create new economic opportunities for farmers, rural communities, and the solar industry [51]. In this context, agrivoltaics is defined as the integration of agricultural production—including crop cultivation, grazing and pollinator habitat—with PV systems installed above or between agricultural areas.

FARMS allocated US\$8 million (announced on May 5, 2022), with six projects selected on December 8, 2022. In general, the projects assess the impacts of different agrivoltaic configurations on agricultural production and power generation, explore ways to integrate this practice into existing solar farms, and develop resources to reduce implementation barriers, in partnership with agricultural extension services to support farmer training.

SETO's goal is to facilitate the installation of more than 1 MW of agrivoltaic systems for crop cultivation and more than 10 MW for grazing or pollinator-habitat applications, thereby strengthening the coexistence of agriculture and solar energy as a strategy to reduce land-use conflicts and expand economic benefits, including for underserved communities in agricultural areas.

Among the supported projects, the following stand out: Iowa State University, with a 1.35 MW system to test different heights and configurations (with and without tracking) related to horticulture and beekeeping; Ohio State University, conducting livestock and hay studies at an 180 MW solar power plant already in operation, without any design changes; and Rutgers University, conducting tests at two sites, analyzing 11 crops, grazing practices, and community perceptions, as well as operating an extension network for regional dissemination. Rounding out the selection are the Solar and Storage Industries Institute, which focuses on identifying barriers and producing guidelines for the sector; the University of Alaska Fairbanks, which studies adoption and economic impacts in an 8.5 MW system; and the University of Arizona, which is conducting crop studies on plots within a 121 MW agrivoltaic system to evaluate crop performance and water use in an arid region, organizing technical visits and developing guidelines for farmers in the western United States.

Alongside these initiatives, the American Farmland Trust (AFT) warns that the expansion of solar energy in the USA could increase pressure on agricultural and livestock lands [52]. In the Farms Under Threat 2040 model, the AFT estimates that, without specific policies, 83% of new development in the solar sector will occur in these areas, with nearly half of it on the most productive land, which reinforces concerns about the conversion of agricultural areas, especially in large-scale projects.

In this context, agrivoltaic systems are presented as an alternative because they integrate agricultural production with PV systems, keeping the land in agricultural use. These systems are one of the pillars of AFT's Smart Solar Principles. The AFT also published the document "Policy Recommendations to Increase Agrivoltaic Development" [52], which outlines principles, guidelines, and a recommended statutory definition for agrivoltaic systems and related incentives, with the aim of supporting the advancement of projects that keep land in production and strengthen rural economies.

The AFT notes that research indicates the potential to conserve water, protect crops and livestock from extreme events, and increase farm income, although the effects on productivity vary depending on the crop, site, and system configuration. Research by AFT and the Solar and Storage Industries Institute (SI2) indicates interest: about two-thirds of the farmers/ranchers surveyed would be open to agrivoltaic systems (motivated by supplemental income), and 80% of the PV developers surveyed are planning future projects; nevertheless, agrivoltaic systems account for less than 5% of solar capacity in the USA [52].

Since many agrivoltaic systems can cost more than conventional ground-mounted solar systems and require adaptations, AFT advocates incentives but points out the need for clear definitions and criteria, as eligibility for incentives varies from program to program. It defines agrivoltaic projects based on two elements: the production of a marketable agricultural product throughout the system's entire lifespan, and project design in consultation with producers and/or experts; it includes crop cultivation, grazing, and livestock raising, and excludes pollinator habitat as the sole activity associated with the system. The AFT notes that incentive policies are already in place (such as financial incentives in Massachusetts, reduced mitigation fees per acre in New York and Maine, and property tax reductions in Colorado) and suggests that well-designed programs combine clear definitions, incentives proportional to the additional cost and the area actually in production, as well as annual monitoring with penalties/repayment of the incentive should production decrease or cease [52].

A major agrivoltaic project in the USA is called Jack's Solar Garden [53]. Jack's Solar Garden (Figure 22, Figure 23 and Figure 24) is a 1.2 MW solar farm in Boulder, Colorado, which

generates sufficient energy to supply approximately 300 households and boasts over 50 residential subscribers, in addition to 5 commercial subscribers. Notably, the agrivoltaic system hosts a diverse range of 40 plant types, including blackberries, herbs, and tomatoes. Moreover, the site has been enriched with 3,000 trees, shrubs, and pollinator-friendly plants surrounding the PV modules (DOE, 2022).

Figure 22 - Agrivoltaic farm design to attract pollinators such as honeybees, bumble bees, and butterflies



Source: [14]

Figure 23 - Harvest under the agrivoltaic system at Jack's Solar Garden



Source: [14]

Figure 24 - A farmer harvests crops at Jack's Solar Garden

Source: [14]

Another of InSPIRE's more than 25 research sites is the Grafton agrivoltaic project in Massachusetts [54], United States (Figure 25). This large-scale facility is an innovative 2 MW community solar farm with an additional 1.4 MW of battery energy storage capacity. The project integrates PV power generation, on-site agricultural production, and numerous partnerships within the research community.

Figure 25 - Grafton Solar agrivoltaic project

Source: [136]

3.7 South Korea

South Korea heavily relies on energy imports from other countries, with 95% of its energy supply being sourced from fossil fuels such as coal and oil. The current Korean Agricultural Land Law prohibits any use of agricultural land other than for farming, given the country's small and densely populated nature. Since most Koreans live in apartments, rooftop systems have a small potential of contributing to PV power generation, making agrivoltaics an attractive option for expanding solar generation while maintaining

agricultural land use for the energy transition. In this context, in recent years, several lawmakers have proposed revising the Agricultural Land Law to permit the installation of agrivoltaic systems [55].

As of 2021, there were 44 agrivoltaic projects in the country, mainly pilot-scale and research projects, implemented since 2016. The primary motivation for developing national regulations stems from the potential of agrivoltaic systems to provide additional income to small-scale farmers [55]. The regulatory environment for agrivoltaic systems in South Korea has undergone revisions recently, moving from the proposal stage to legal implementation. In June 2024, fundamental changes took effect, such as the revision of the Agricultural Land Law and the Special Law on the Promotion of Distributed Energy. The revision extended temporary land-use permits from 8 to 23 years (in line with the useful life of PV modules), began to encourage the use of lower-quality agricultural land, and established a rigorous management system to ensure the continuity of agricultural activity. The Distributed Energy Act provided the legal framework to promote various PV models, creating distributed energy zones and introducing regulatory flexibility to enable local government participation [56].

The sector is also anticipating even greater progress: in late 2025, South Korea's Ministry of Agriculture, Food, and Rural Affairs announced plans to introduce, in 2026, landmark legislation dedicated exclusively to the expansion and standardization of agrivoltaics. This new law aims to simplify permitting and approval processes for farmers and provide financial incentives. To support this green transition, the Ministry of Trade, Industry, and Energy (MOTIE) also announced the creation of a National Research Center dedicated to agrivoltaics, focused on developing best practices, conducting studies on the application of PV technologies to specific crops, and providing training to farmers and energy companies [57].

South Korean companies have shown a strong interest in agrivoltaic systems. Hanwha's Q Cells Division was selected as a partner in the Agrivoltaic System Standardization Project by the South Korean government. In collaboration with Yeungnam University and a local enterprise, Hanwha Q Cells is working on advances in agrivoltaic systems associated with various agricultural settings, including rice paddies, farm fields, and orchards. The company has made significant investments in research and development, particularly in next-generation solar power technologies and products and is planning to allocate KRW 1.5 trillion (US\$1.2 billion) into research and manufacturing facilities by 2025 [58]. Q CELLS has created a compact PV module, which is half the size of a traditional PV module (Figure 26). This ensures the efficient utilization of solar energy installations in agricultural settings, allowing electricity generation while simultaneously providing sufficient sunlight for optimal crop growth (QCELLS, 2021).

Figure 26 - Agricultural PV system developed by Q CELLS on farmland in Gwandang Village, Namhae

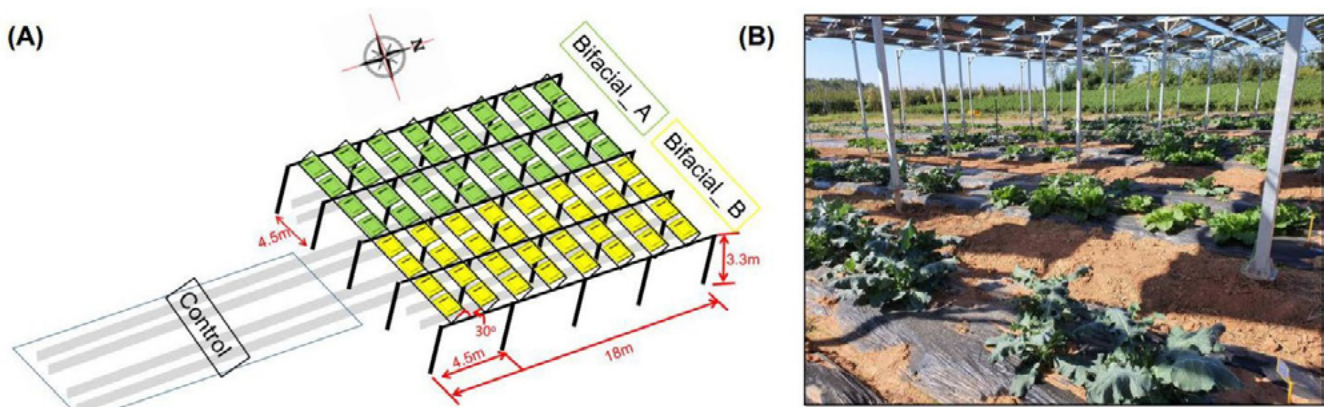


Source: [137]

The use of agricultural land is crucial for national food security, therefore, there is a considerable concern about the impacts of agrivoltaic systems in food production. From the South Korean context there are three key lessons: 1) Research and demonstration projects should demonstrate that agrivoltaics' impact on harvest rates is acceptable for food security; 2) Time should be taken to persuade the agriculture sector and environmentalists about the acceptability of the technology's impact on food security and landscape; 3) Gradually revising the agriculture land law will ensure the interest of all stakeholders, including the government, farmers, and environmentalists [55].

In 2022, researchers from Chonnam National University published the results of a study that assessed the combination of an agrivoltaic system with broccoli and cabbage cultivation (Figure 27). The system utilized bifacial modules at a height of 3.3 meters. The researchers analyzed the microclimate, including photosynthetic photon flux density (PPFD) and soil temperature, under the agrivoltaic system. The study found a slight decrease in crop yield and changes in broccoli metabolites. However, the additional shading in the agrivoltaic system had a positive impact on broccoli's color, which may make the product more attractive to consumers [59].

Figure 27 - Agrivoltaic structure information for this experiment (A) and photo of growing crops under the PV module (B)



Source: [59]

3.8 Australia

Large utility-scale solar farms began to emerge in Australia around 2015, initiating the development of agrivoltaic practices as well, primarily dominated by sheep grazing. Australia's first agrivoltaic project began in 2015 at the Royalla Solar Farm, with sheep grazing, followed by over a dozen other solar farms with grazing activities [60]. By 2020, at least 13 large-scale solar farms in Australia were reported to incorporate sheep grazing (Figure 28). At present, this activity is still the predominant

agrivoltaic configuration in Australia, but other forms of dual land use—including horticulture, viticulture, aquaculture and crop production—also exist in the country, but usually on a much smaller scale [60].

Although Australia developed some pioneering agrivoltaic projects several years ago, the country still lacks a clear policy and regulation for the technology. Knowledge gaps and technical and economic impediments have slowed the development of the sector [61].

Figure 28 - Sheep enjoy the shade of the PV modules on the University of Queensland's Gatton Solar Farm system (Photo Credits: Sarah Haskmann)



Source: [61]

3.9 Spain

Spain has updated its national framework for the Common Agricultural Policy (CAP) to include agrivoltaic systems as eligible for subsidies, provided that agriculture remains the primary land-use activity. This change was established by a decree amending the CAP rules set forth in 2022 and is part of a broader package of updates approved by the European Commission in August 2025.

Under the new decree, dual-use areas, where solar generation and agricultural activity coexist, are now eligible, for the first time, to receive CAP payments. The text stipulates that all cultivated or permanently cultivated farmland located under PV installations will continue to receive subsidies, provided that it is demonstrated that agriculture remains the primary activity. According to the government, the measure aims to promote sustainable models of agricultural and energy production without compromising the agricultural use of land, maintaining food production while, at the same time, expanding opportunities for more farmers to qualify for support and diversify their income.

At the regulatory level, Spain is currently in the process of introducing a legal definition for the technology [28]. The technical criteria that will determine, in practice, how solar and agricultural operations can coexist will be established at a later date and implemented as soon as the

Royal Decree regulating eligibility for the CAP is finalized and enters into force. For the 2023–27 period, the CAP framework in Spain includes direct payments that reward environmentally friendly practices and targeted support for specific sectors such as fruit, wine, and beekeeping, as well as rural development programs aimed at regional economies (PVmagazine, 2025). In addition to the CAP, although there are currently no public energy subsidy schemes dedicated exclusively to Agri-PV, the sector has received government support through the Recovery, Transformation, and Resilience Plan (PRTR), funded by the *Next Generation* EU program. A recent call for proposals allocates funds to 60 projects (with a total capacity of 60 MW), requiring that proposals meet specific requirements related to agricultural yield, innovation, and socioeconomic and environmental benefits [28]. The regulation also stipulates that the relevant authorities and local stakeholders must be consulted during the permitting processes.

In Spain, there are some examples of agrivoltaic systems, such as the “smart” pilot of Iberdrola in Guadamur vineyards, which uses trackers and field data to adjust the positioning of PV modules over the vineyards [62]; the Familia Torres’ pilot installation in the Mas Rabell vineyard, in *Sant Martí Sarroca*, with approximately 1,000 m² and an elevated structure of approximately 5 m to allow machinery to pass [63]; and the system in *Talayuela*, where sheep graze between the PV modules [64].

3.10 Japan

Agrivoltaics are well known in Japan, where there are over 5,000 systems installed, totaling more than 1 GW of installed capacity for these systems [41], [65]. The first pilot project in the country, and in the World, was initiated in 2004 in Chiba municipality by Akira Nagashima. It is estimated that the systems are associated with more than 120 kinds of crops. Most of these farms are small-scale, covering less than 0.1 ha, occupying a total of 560 ha [66].

Several government policies have been fundamental to achieving the country's technological development. In 2011, the Feed-In-Tariff (FIT) scheme was institutionalized in the country, and it was officially operational in 2012. This policy had the most significant impact on the growth of PV power generation in the region, which increased by 76% from 2012 to 2019. In addition to FIT, in 2013 the Japanese government established the world's first financing program for agrivoltaic systems [25], and an official ordinance was issued that stipulated procedures and conditions to allow the conversion of agricultural land for agrivoltaic use, following the key conditions:

- (1) The mounting structure must be only temporary and easily removable;
- (2) The chosen PV module should not obstruct crop growth, ensuring sufficient sunlight penetration for plant growth and a minimum module clearance of 2 m above ground level for agricultural machinery operation;
- (3) The installation must not interfere with agricultural activities on neighboring land, including the agricultural drainage system, or disrupt the implementation of the "Agricultural Promotion Area Maintenance Plan";
- (4) The annual crop yield must be reported and may not fall by more than 20% relative to the pre-installation reference yield.

Initially, the proponent could apply the technology for a maximum period of three years. However, the 2021 revision of the guidelines extended this grace period to a maximum of 10 years, reducing the administrative burden on project developers [67]. That same 2021 revision introduced a significant flexibility of the rules: for land certified as "degraded" (in a state similar to abandonment and where continuing traditional agriculture is difficult), the requirement to maintain 80% of agricultural yield (with a maximum reduction of 20%) may be waived, with the aim of promoting the effective use of these idle areas. The permit, however, still requires the farmer to demonstrate competence in managing these activities. In 2020, the second amendment to the FIT Act was promulgated, bringing several important changes to the

policy, including a significant one for agrivoltaic systems: the requirement for small-scale PV installations (10 to 50 kW) to meet "regional use requirements" to obtain a FIT certificate. The law provides additional preferential treatment to agrivoltaic systems to encourage their development. There are three "regional use requirements": (1) the self-consumption rate must be at least 30%, (2) there must be a way to confirm actual self-consumption, and (3) the generated electricity must be usable during a disaster situation [66].

In 2021, the New Energy and Industrial Technology Development Organization (NEDO) of Japan released new guidelines to develop and construct agrivoltaic facilities in an attempt to increase the presence of these projects in the country, which is struggling with land scarcity. The guidelines were prepared under the supervision of the Ministry of Economy, Trade, and Industry (METI) [68]. The guidelines specify that agrivoltaic projects cannot exceed a height of 9 meters due to building regulations. Additionally, projects using trackers or installations in greenhouses and horticultural sheds were excluded from the guidelines. More recently, in April 2024, a new amendment to the Agricultural Land Law established clearer formal guidelines for the appropriate use of agrivoltaic technology. This amendment strengthened measures against improper practices, such as abandoning crops and allowing weeds to proliferate—a practice known as "green grabbing"—with the aim of supporting legitimate projects that are compatible with agriculture and increasing market transparency. In addition to the Agricultural Land Law, projects in Japan must comply with a complex framework of other laws. This includes the Electricity Sector Act, the Building Standards Act (if the structure is classified as a building due to its foundation or height), the Fire Department Act, the Environmental Assessment Act (for large-scale projects), and the Landscape Act, under which local governments can enforce strict ordinances regulating the color, height, and placement of panels to preserve the regional landscape.

Just as in France, where projects that used agriculture merely as a "pretext" for land acquisition to expand power generation projects sparked strong resistance and led to the adoption of stricter regulations, Japan has also faced severe challenges with systems operating under the same circumstances [41]. The lack of agricultural management, the abandonment of cropland, and the resulting proliferation of weeds under the PV modules had a negative impact on the image and promotion of the technology. In response to these improper practices, the Japanese government began to enforce strict punitive measures: In August and November 2024, the relevant ministries (METI and MAFF) revoked the feed-in-tariff (FIT) permits of 13 energy producers operating 29 agrivoltaic farms, totaling 342 violations of the Agricultural Land Law [41]. These installations, which had

a combined power of 17.5 MW and received approximately 13 million yen in subsidies each month, illustrate how the lack of a genuine commitment to farming forces countries to take active measures to suspend incentives, protect land use, and combat speculation.

The first vertical agrivoltaic project in Japan was built through a partnership between Luxor Solar KK and Next2Sun AG (Figure 29), as reported on the Next2Sun website [69]. By combining agricultural production with

PV modules arranged in a vertical orientation, the project aims to maximize land utilization and power generation while promoting agricultural practices. The plant was built for ISEP – Institute for Sustainable Energy Policy, which is a non-profit research organization founded in 2000 by energy experts and climate activists. The organization aims to provide resources and services to create a sustainable energy society.

Figure 29 - First vertical agrivoltaic project in Japan



Source: [69]

3.11 Chile

According to Jung (2023), Chile is among the countries most affected by climate change, posing a significant threat to its agricultural sector [70]. The country faces the risk of consequences such as the loss of high-quality soils mainly by desertification, erosion, contamination, and inappropriate agricultural practices, which may result in increasing the demand for food and energy [71]. The northern and central regions, for example, experience a drought of over 12 years, leading to severe water shortages that impact small-scale farmers. Besides the severe drought, farmers also face other threats to crop yields in Chile, such as unpredictable weather events like hail, frost, heavy rainfall, and excessive solar irradiation.

In response, the country has been using agrivoltaics as a strategic tool to mitigate thermal stress in plants and reduce water consumption. A major milestone occurred in 2025, when the National Irrigation Commission (CNR) included agrivoltaic systems for the first time in the calls for proposals under the Irrigation Promotion Act. This public policy now provides for state subsidies (which, for

small farmers, can exceed 75% of the initial investment in some scenarios) for projects that combine solar power generation with the adoption of water-efficiency technologies, such as drip irrigation [72].

The development of this technology in the country was a pioneering effort in Latin America, with the installation, between 2017 and 2020, of three 13-kWp pilot projects on the outskirts of Santiago: El Monte, Curacaví, and Lampa (Figure 30) [12]. The project is supported by the local government and the Fraunhofer Chile Institute, and the results of these initial studies were positive: they recorded a 40% reduction in incident solar irradiance, which led to a 29% increase in soil moisture and a jump of up to 187% in land-use efficiency for lettuce cultivation. Since then, the sector has continued to develop, and by mid-2025, the country already had at least 9 installations [72].

Figure 30 - Pilot projects in Chile

Source: [12].

The main milestone in the transition to commercial-scale operations is the “Ayla Solar” project, developed by the company O’Energy near Rancagua. With a total grid-connected capacity of 9 MWp, this plant (built over a cherry orchard) has become Chile’s first large-scale commercial agrivoltaic project. In addition to this, there are projects at the University of Chile’s Energy Center, and new research is advancing in high-value-added fruit farming, such as the system implemented for cherry trees by the Adventist University of Chile [72].

To standardize and guide the market in light of this expansion, the first “Manual for the Development of Agrivoltaic Projects in Chile” was published in 2025; it was developed by institutions such as Fraunhofer Chile and GIZ. The document organizes the technical design into three main crop groups: low-growing crops (vegetables and legumes), extensive crops (such as corn and wheat), and fruit farming. In the Chilean agricultural sector, elevated configurations for high-value fruit production (Group 3) are particularly economically viable. In such cases, the use of PV modules (often semitransparent) actively serves as a physical barrier against frost, hail, and excessive radiation that can damage fruit, offering a sustainable, long-term alternative to the frequent use and disposal of agricultural plastic sheeting and netting [72].

3.12 India

India, one of the world’s leading countries in terms of installed solar capacity, faces a twofold challenge: meeting its growing energy demand while preserving fertile land to ensure food security for its vast population. In this context, agrivoltaic integration has been gaining momentum as a strategic solution to alleviate competition for land use.

Currently, India is home to dozens of installations with capacities ranging from a few kilowatts (kW) to a few megawatts (MW), such as a 4 MW project at Cochin Airport, but it does not yet have any large-scale commercial (utility-scale) power plants. National technical development has focused on three main configurations: ground-mounted PV modules with crop cultivation between the rows (inter-row farming), slightly elevated modules, and the use of fully elevated structures that create favorable microclimates and allow agricultural machinery to operate and farmers to work beneath the structure.

From a regulatory perspective, India still lacks an official, consolidated definition and national regulations dedicated exclusively to agrivoltaics. One of the biggest legal obstacles lies in land-use classification: under current laws, areas designated as rural are reserved exclusively for agriculture, requiring PV projects to undergo a complex process of conversion to “non-agricultural use,” which may disqualify producers from receiving rural tax incentives or protections. At the federal level, the government launched the PM-KUSUM program to promote solar energy in rural areas; however, the program prioritizes the use of arid and uncultivable land. Although there are references to the installation of elevated PV modules in farmland, there are no clear financial mechanisms to offset the high initial cost (CAPEX) of the necessary infrastructure. However, promising initiatives are emerging at the state level, notably the Delhi program (Mukhyamantri Kisan Aay Badhotri Solar Yojana), which authorizes installations on up to one-third of a property, requires a minimum height of 3.5 meters to allow tractors to pass, and guarantees farmers additional rental income [73].

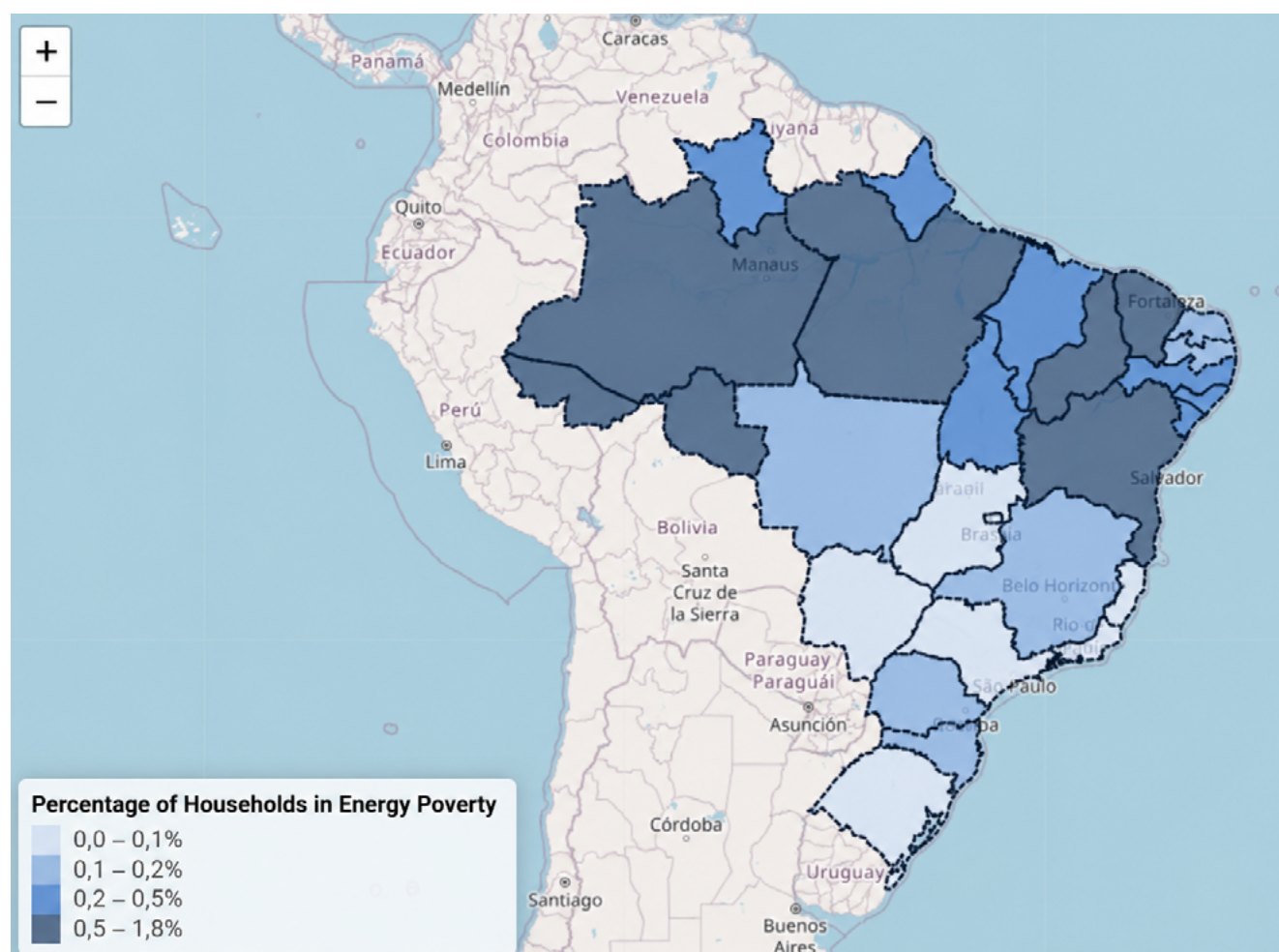
From a production standpoint, given the price sensitivity of the Indian energy market, the feasibility of these projects has often focused on integrating them with commercial crops and high-value-added vegetables, such as tomatoes, eggplants, okra, medicinal plants, and spices, in addition to studies with major crops like rice and bananas [73]. Innovation has also been expanding into aquaculture (aquavoltaics), given that India is highly dependent on fish farming. Studies show that the shade provided reduces evaporation and thermal stress in the water, thereby increasing fish productivity [74]. Technological advances and efforts to overcome the barriers of high costs and a shortage of skilled labor in the country have been driven by major collaborative networks, such as the research conducted by the Central Arid Zone Research Institute (CAZRI), the guidelines issued by the Indian Council of Agricultural Research (ICAR), and the multisectoral efforts of the new India Agrivoltaics Alliance (IAA) [75]. For this approach to be adopted on a large scale, institutions recommend the creation of a specific national land-use category for “agrivoltaic lands”, thereby enabling the legal coexistence of energy and agriculture [76].

3.13 Brazil

Although Brazil is a global leader in both agricultural production and the expansion of PV generation—which already exceeds 70 GWp of installed capacity [77]—it is still in the early stages of developing agrivoltaic technology. Currently, the country has no regulations, specific guidelines, or incentives dedicated to agrivoltaic systems, so the technology is represented mainly by pilot research and development projects. The Brazilian systems implemented that have been identified to date are listed in item 4. Despite the lack of a specific legal framework defining how this dual land use should be implemented, the significant growth of solar energy, combined with the vast amount of farmland and abundant solar resources, positions the country to realize enormous potential for the expansion of agrivoltaic applications [78].

The implementation of these systems today is based on the regulations governing Distributed Generation (DG), which are currently set forth in Law No. 14,300/2022 [79]. This model shows particular promise for family farming, which accounts for 77% of the country's agricultural operations and is responsible for providing about 70% of the population's food supply. The integration of agrivoltaics with DG enables self-consumption and shared generation (through cooperatives), and can be supported by existing credit lines. In addition, there is also synergy between this technology and national programs aimed at universalizing access to energy, such as “Luz para Todos” and “Mais Luz para a Amazônia,” which bring electricity to populations that still lack access—families concentrated mainly in the Northern and Northeastern regions of the country (Figure 31).

Figure 31 – Percentage of the population lacking access to electricity, by state (2022)



Source: [8]

From a technical and agronomic standpoint, the Brazilian landscape presents unique opportunities and challenges. Due to the extremely high levels of solar irradiation in the country, which can reach 2,100 kWh/m²/year in the sunniest regions [80], the partial shading provided by PV modules can mitigate the effects of heat stress on plants, improve soil health, and reduce the need for irrigation. Due to the extremely high levels of solar irradiation in the country, which can reach

2,100 kWh/m²/year in the sunniest regions [80], the partial shading provided by PV modules can mitigate the effects of heat stress on plants, improve soil health, and reduce the need for irrigation. In some cases, this results in actual productivity gains, as demonstrated by the UFAL (Alagoas) project, which reported, among its results, a 43.2% increase in sugarcane productivity under PV modules [81].

In addition, the use of vertical agrivoltaic configurations can serve as a technical solution in areas with limited grid capacity, as it allows for the shifting of peak solar power generation, helping to prevent curtailment due to grid congestion, while also keeping the area largely available for heavy agricultural machinery or providing designated areas for livestock. From a technical and agronomic standpoint, the Brazilian landscape presents unique opportunities and challenges.

In general, one of the main challenges to implementing agrivoltaic systems on a commercial scale is the availability of suppliers capable of meeting the demands of adapted projects. However, in the recent years, several companies in the solar industry have shown growing interest in investing in agrivoltaic projects in Brazil. In 2023, a national manufacturer produced a semitransparent photovoltaic module with wider spacing between the cells, adapted for agrivoltaic systems.

Despite there being no regulation in Brazil regarding agrivoltaic systems, it is possible to adapt agrivoltaic applications to the existing distributed generation legal framework mainly when considering small-scale agriculture. In Brazil, distributed generation was regulated by the National Electric Energy Agency (ANEEL) in 2012 through Normative Resolution REN 482/2012. REN 482/2012 then allowed Brazilian consumers to generate their own electricity from renewable sources or qualified cogeneration and supply the surplus to their local distribution network [82].

REN 482/2012 went through a review process and in 2016 REN 687/2015 came into force, which brought some changes and updates to the previous resolution. In 2022, the legal framework for distributed Micro and Mini-Generation (MMGD) and the Electricity Compensation System (SCEE) was established through Law 14.300/2022³, which is currently the legal instrument in force that regulates and provides all the legal provisions for distributed generation in the country. In February 2023, ANEEL published REN 1.059/2023⁴, which revoked REN 482/2012 and brought improvements to the connection and billing of MMGD plants as well as the rules for the SCEE, bringing the regulations into line with the provisions of Law 14,300. The main impacts of the changes between the old REN 482/2012 and the current Law 14,300 can be found in publications [83].

According to the current legislation, a distributed microgeneration power plant is one with an installed capacity of up to 75 kilowatts (kW). Distributed mini-generation has an installed power above 75 kW and less than or equal to 3 MW for non-dispatchable sources or up to 5 MW for dispatchable sources.

The SCEE allows, for example, the surplus energy generated by a PV MMGD system during the day to be injected into the grid and, at night or anytime, the consumer draws electricity from the grid when local generation is insufficient and supplies additional needs. When the energy generated in a given month is greater than the amount used to offset the energy consumed in that period, the consumer is left with surplus energy that can be distributed in the same month to other consumer units, depending on the type of participation in the SCEE, or transformed into credit to offset consumption in the following months. According to the rules, credits are valid for 60 months.

Under REN 482/2012, all the components of the electricity tariff were compensated, i.e., every 1 kWh injected into the grid meant that 1 kWh was compensated. With Law 14300 currently in force, compensation takes into account all tariff components, with the exception of the so-called “TUSD Fio B”, which represents the costs of the distribution network and is calculated by the ANEEL based on the costs of the distribution utilities, i.e., this value will vary depending on the local utility [84].

Given this context, with the current legal framework for distributed generation, farmers can generate their own energy through the SCEE by means of PV MMGD systems, adapting this technology to the agrivoltaic application. It is understood that DG would therefore be more suitable for small-scale and family farmers since these systems are limited to 3 MW for non-dispatchable sources or 5 MW for dispatchable sources. As a rule of thumb, the calculation for PV plants on the ground can be simplified so that 1 MW of ground-mounted PV capacity requires an average of 1 ha of land. In other words, for large-scale agriculture, a DG system would occupy an average of approximately 3 to 5 ha of land, which is quite insignificant for these large-scale farmers. Agrivoltaic systems that produce energy for the open market could be more appropriate for them. However, due to the complexity of the Brazilian open market usually only big commercial energy companies get involved.

3.13.1 Considerations regarding the national and international regulatory context

Agrivoltaic technology is experiencing global growth, with several countries taking significant steps towards its implementation and maintenance. Guidelines have been established or are currently being developed in countries such as Germany, Italy, Croatia, Japan, the United States, South Korea, France, and Spain. Additionally, several nations, including Japan, France, the United States, and South Korea, have already introduced national funding programs to support the adoption of these innovative systems. General

3 Law 14300/2022: <https://in.gov.br/en/web/dou/-/lei-n-14.300-de-6-de-janeiro-de-2022-372467821>

4 REN 1059/2023: <https://www.in.gov.br/en/web/dou/-/resolucao-normativa-aneel-n-1.059-de-7-de-fevereiro-de-2023-463828999>

incentives, such as the Feed-In-Tariff, that are not specific to agrivoltaic systems, exist in some of these countries and can serve as a tool to enhance the agrivoltaic systems' viability. An important aspect when analyzing the existing guidelines in Italy, Germany, and other countries is the concern for maintaining existing agricultural activities with the introduction of agrivoltaic technology. Actions are mentioned for monitoring and ensuring the continuity of existing agricultural production, with agriculture being the primary activity and power generation being secondary. In Germany, the preparation of an agricultural management plan is required, ensuring the existence of crop planning, monitoring and maintenance.

The lack of national guidelines or regulations in Brazil could lead to some negative consequences, as seen in France in the past decade, where the absence of clear criteria for agrivoltaic systems in the initial round of tenders led to some projects having little or no meaningful agricultural production participation. This outcome has created resistance to agrivoltaics, particularly within the agricultural sector [19].

In Brazil, agriculture constitutes a major pillar of the economy, and electricity from PV generation is experiencing exponential growth. However, agrivoltaic systems have not yet reached commercial scale in the country. As Brazil moves into the commercial implementation phase of agrivoltaic systems, it is essential that all project stakeholders must be aligned on the same page and that the systems be well planned to ensure efficient power generation, food production, and proper crop maintenance, thereby enabling the system to be classified as agrivoltaic throughout its entire lifespan.

A summary of international regulatory frameworks in countries where regulatory developments regarding agrivoltaics have advanced significantly in recent years is organized in Table 2. The table was initially based on the document "Characterizing photovoltaic projects on agricultural land and agrivoltaics", published in 2021 by the ADEME and adapted in accordance with the references used in the development of this study

Table 2 - Summary of international regulatory frameworks

Country	Japan	USA	Germany	Italy	China	South Korea	France
Regulations related to PV on agricultural lands with PV generation	Installation on agricultural lands requires a “temporary conversion permit” under the Agricultural Land Law, valid for a maximum period of 10 years, and it is prohibited to interfere with agricultural practices on adjacent lands. In terms of zoning, more flexible rules apply to land classified as “degraded” or idle (where the requirement to maintain 80% of yield is waived). In addition, projects are subject to the Landscape Act, which allows local governments to enforce strict zoning ordinances governing the color, height, and layout of the panels to preserve the regional landscape [85] [86].	Policies are implemented primarily at the state or municipal level, without a unified federal regulatory framework [48]. There are restrictions in conservation areas, specific to states [86]. In many cases, there are “special / conditional use permits” which include requirements regarding setbacks, height, glare mitigation, decommissioning plans, and area limits	Agrivoltaic projects of up to 2.5 ha may be classified as “priority installations” under the Federal Building Code (BauGB), which facilitates their approval in “outlying areas” (outside regular urban development plans), provided they do not conflict with nature conservation [28]. Municipalities may designate areas with overlapping uses in their master plans, creating a “special area for agrivoltaics.” Conversely, installation (or the receipt of subsidies) is generally prohibited in areas legally designated as nature conservation reserves, national parks, or drained wetlands [25].	National and regional regulations tend to strongly discourage or prohibit “inter-row” (non-elevated) systems in favor of elevated or vertical structures, with the 2024 Agriculture Decree creating uncertainty regarding the ban on low-lying installations on productive land [28]. In certain regions, the conversion of “permanent basic farmland” is prohibited.	Between 2017 and 2023, the country allowed installations on ordinary farmland. However, due to land-use conflicts and threats to food security, new government measures have banned the installation of PV projects on ordinary farmland and permanent basic farmland starting in 2023. Current zoning directs new projects to arid, degraded areas and the deserts of western China [44].	The revision of the Agricultural Land Law (June 2024) extended the land-use permit from 8 to 23 years and established strict monitoring of continued agricultural use. The government encourages the allocation of projects to lower-quality agricultural land. The country is preparing to implement landmark legislation by 2026, aimed at streamlining permits and approval processes [57].	Zoning is strictly regulated by the APER Law (2023) and decrees issued in 2024 to combat land speculation. The zoning law makes a clear distinction: areas considered “uncultivated” or abandoned for more than 10 years may receive ground-mounted PV modules (without agricultural use), but productive areas may only receive power plants if they are strictly agrivoltaic. Zones subject to recent land consolidation or special agricultural protection are subject to severe restrictions and are excluded from the framework permits; exceptions to the coverage limits (above 40%) are granted only for small projects in experimental zones approved by the departmental commissions (CDPENAF) [87].

Definition of Agrivoltaic Systems	Named “solar sharing,” defined as “a PV installation on agricultural lands with continuity of agricultural activities.” Criteria: no deterioration of quality, yield >80% on an annual average, and height >2 m [86]. Mioga ginger, Japanese cleyera, rice, shiitake mushrooms, blueberries, tea, scallion, pasture grass, rice, pumpkins, among others.	There is currently no official definition for agrivoltaic systems. The DOE uses an operational definition: agrivoltaics (or dual-use) refers to the integration of agricultural production (crops, livestock, or pollinators) under or between rows of PV modules [88]. As for the AFT, it describes them as areas that integrate agricultural production into PV parks to keep the land under cultivation [52]. They also mention the term Smart Solar, which refers to PV projects that meet three goals: (1) safeguarding land well-suited for agriculture and livestock farming, (2) strengthening agricultural viability, and (3) accelerating the development of solar energy [89].	The combined use of the same area, primarily for agricultural production and, secondarily, for PV power generation [16].	Divided into “basic” and “advanced” systems. At least 70% of the surface area must be used for agricultural activities, and the maximum coverage of PV modules is 40%. Advanced systems require a minimum height (2.1 m for crop production and 1.3 m for livestock) and the implementation of continuous monitoring systems [90].	Officially classified as dual-use projects or agriculture-solar, fisheries-solar, and solar greenhouse/shadehouse complementary projects. In practice, reports indicate that many projects have ignored the “dual-use” principle, operating with PV module shading rates above 50%, which blocked sunlight and harmed crops, prompting recent government bans [26].	There is no official definition yet, but these systems are treated under the Special Law on the Promotion of Distributed Energy (2024) as a “solar sharing” model. There is a requirement to maintain the property’s agricultural activities on an ongoing basis in order to ensure food security.	The legal definition stipulates that agricultural activity must remain the land’s primary use, with power generation being secondary. To be classified as an agrivoltaic system, it must provide at least one of four direct services: agronomic improvement, adaptation to climate change, protection against extreme weather conditions, or improvement of animal welfare [28], [39].
-----------------------------------	--	--	---	---	--	---	--

Crops / Production associated with agrivoltaics	Mioga ginger, Japanese cleyera, rice, shiitake mushrooms, blueberries, tea, scallion, pasture grass, rice, pumpkins, among others.	Beehives (pollinators), sheep, tomatoes, wildflower, blackberries, herbs, soybeans, and corn, among others.	Wheat, celery, potatoes, grass, blueberries, raspberries, apples, grapes, vegetables, strawberries, among others.	Olives, almonds, figs, tomatoes, lemon, among others.	Tea, grapes, vegetables, mushrooms, blackberries, goji berries, sheep grazing, and aquaculture (fish, shrimp, and crab), among others.	Broccoli, cabbage, rice, potatoes, onion, barley, beans, garlic, lettuce and scallion.	Sheep, beehives, vegetables, arboriculture, cereals, viticulture, and orchards.
Presence of Investments or financial instruments supporting agrivoltaics	A pioneer in the creation of a support scheme in 2012 [25]. Large-scale projects transitioned from the fixed tariff (FIT) model to market-based premiums (FIP) in 2022. Projects that do not support agriculture lose their eligibility for subsidies.	The DOE provides extensive funding for research and implementation (e.g., the FARMS and InSPIRE programs, with millions of dollars allocated) [51]. Direct incentives such as Feed-In-Tariffs.	Solarpaket 1 (2024) introduced dedicated auctions (targets of 800 MW for 2025 and 1,200 MW for 2026). The EEG Act guarantees an additional “technology bonus” in the tariff and 85% eligibility for CAP agricultural subsidies [28].	Projects may be eligible for CAP direct payments under certain conditions. The government has created an incentive package worth between €1.1 and 1.7 billion specifically for agrivoltaics. To access funds from the National Recovery and Resilience Plan (PNRR), farmers must be co-owners of the projects [28].	Between 2013 and 2023, there was massive government support for state-run renewable energy and poverty alleviation programs. With the new land-use restrictions, progress has stalled.	The government announced the creation of a National Research Center dedicated to Agrivoltaics, and the establishment of “distributed energy zones” with more flexible regulations. The proposed 2026 legislation is expected to introduce substantial financial incentives to combat financial volatility and provide retirement security for farmers [57].	The government provides substantial support through specific auctions organized periodically by the Energy Regulatory Commission (CRE). The mechanism periodically allocates approximately 600 MW to this technology, dividing the tenders into two main categories: elevated systems and inter-row systems [28].

Source: Elaborated by authors (2026).

4. Agrivoltaic systems in Brazil

4.1 Existing systems

In Brazil the agrivoltaic technology is not yet widespread when compared to other countries, but some projects have been identified in the country since 2019. The vast majority of the identified initiative are pilot projects and a connection to research institutions. The location and detailed technical description of these existing agrivoltaic projects follow in the subsequent subchapters, along with information about their installed capacity, energy output, agricultural characteristics, and available information on the results of the projects.

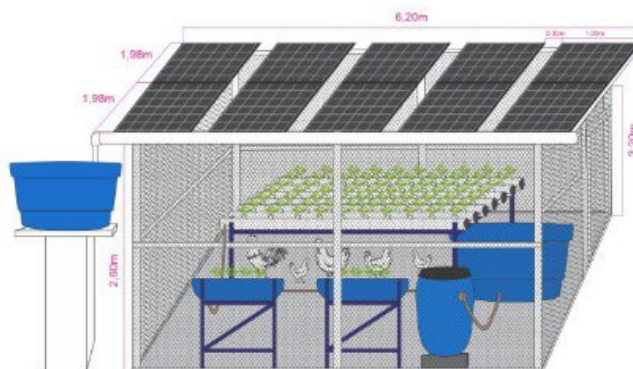
4.1.1 Ecolume

An example of an agrivoltaic system developed for family farming units in the semi-arid region of Brazil is the Ecolume project, located in Ibimirim/PE. The project was developed by a network of over 40 researchers and was installed at an agroecology school in Pernambuco in 2019. The proposed model consists of distributed “family units” that combine power generation with the production of vegetables, fish in tanks, and chickens, aiming to generate environmental, social, and economic benefits for many people in the Northeastern semi-arid region. The Ecolume agrivoltaic system produces 17 types of vegetables using also an aquaponics system and two animal proteins, intended for consumption by the students and staff of the Serta school, as well as umbu seedlings (the umbu tree is native to the Caatinga biome) that are donated for reforestation of the biome (Caatinga is a typical biome of the semi-arid region in Brazil) [91]. Figure 32 shows a schematic of the experimental prototype, consisting of 10 PV modules, and a total installed capacity of 3.3 kWp.

The experimental unit (Figure 33) was designed to suit the region’s climatic conditions and occupies an area of 24 m², with an approximate cost of US\$ 4,000. According to the project’s results, the unit demonstrated a production potential of 4,800 kWh/year of energy, 130 kg of fish, 730 free-range chicken eggs, 816 units or 336 kg of vegetables, and 200 units of native plant seedlings. This production would generate a total annual revenue of around US\$ 2,000.

The project’s findings revealed possibilities for development in the Brazilian semi-arid region, considering aspects of climate change and the significant potential of solar energy in the region through local productive arrangements that contribute to family income generation and the conservation of the Caatinga Biome [92].

Figure 32 - Agrivoltaic system proposed in the Ecolume project



Source: [92]

Figure 33 - Agrivoltaic system and assembly of aquaponics system below the modules



Source: [92]

The system has generated promising results so far, confirming its potential to generate environmental, social, and economic benefits for the region; however, structural challenges were observed, especially the lack of public incentive policies [91].

4.1.2 Pankara Village

Another pilot project in the Northeast region was conceived and developed by the Brazil–Germany Cultural Center/Recife, with representatives from the Aldeia Serrote dos Campos of the Pankará Indigenous People, in 2020. The project received initial funding from the German organization *atmosfair* gGmbH, as well as from the Federal Rural University of Pernambuco (UFRPE) and the Federal University of Pernambuco (UFPE). Subsequently, the initiative also received support from the German NGO *Brasilieninitiative Freiburg e.V.*

The project aims to provide safe drinking water to approximately 150 families and more water from the São Francisco River for vegetable cultivation and sustainable fish farming through a solar-powered water pump, combined with agrivoltaic technology (Figure 34). The project is located in the Brazilian Caatinga Biome, in the Sertão de Itaparica (PE) Microregion.

The project consists of a 33 kWp solar PV system with 3 meters high above the ground, under which a 400 m² vegetable garden was established [93]. According to the report published by atmosfair gGmbH, the shading protects crops from intense sunlight and high temperatures of the Brazilian Caatinga. Melon cultivation has been integrated into the agrivoltaic system in partnership with researchers from the

Federal Rural University of Pernambuco (UFRPE) (Figure 35). Rainwater from the solar panels is still being collected in a 52,000-liter cistern located next to the system. The project prioritizes organic food production, power generation, and environmental preservation, aligning with the concept of agroecology [94]. In addition to the crops grown beneath the agrivoltaic system, an aquaculture facility was also implemented, where the water and wastewater from the fish tanks are used to irrigate and fertilize fruit trees. In addition, an aquaponics system for efficient vegetable and herb cultivation was built [93]. Currently, both fish and vegetables are provided for school lunches at two indigenous schools in the village.

Figure 34 - Representatives of the Pankará village and of the Brazil-Germany Cultural Center in the project area



Source: [93]

Figure 35 - Melon plantation in the agrivoltaic system



Source: [94]

4.1.3 UFAL

The pilot agrivoltaic project was developed by the Federal University of Alagoas (UFAL), in a partnership with the Alagoas Research Support Foundation (FAPEAL) and the Usina Santa Clotilde, located in the municipality of Rio Largo, as shown in Figure 36. The main objective of the system is to assess the performance of sugarcane (*Saccharum*

officinarum) cultivated in association with the PV system, aiming to better understand and determine the land use efficiency under this condition. For this project, research was conducted to evaluate the feasibility of this production method with sugarcane as the crop. Agrivoltaic activities at the site started in December 2021, with planting completed in December 2022 [81].

Figure 36 – Aerial view of the Engineering and Agricultural Sciences Campus (CECA) of the Federal University of Alagoas (UFAL)



Source: [95]

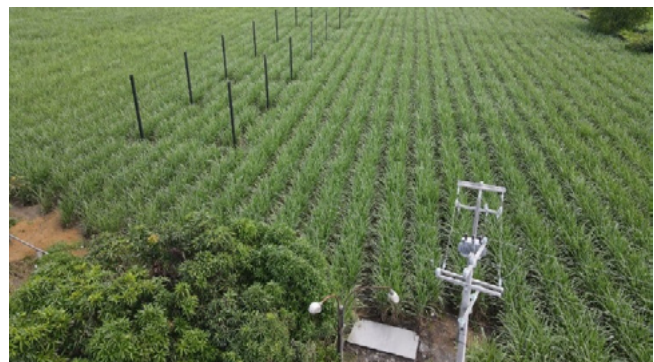
The PV system has a rated installed power of 71.4 kW and was commissioned in 2022. The system consists of two inverters, with rated power of 33 kW and 40 kW, respectively. Structural anchoring is achieved using reinforced concrete foundation blocks, designed to ensure overall stability against permanent and variable loads, including wind loads and other environmental loads. The structural system consists of seven steel portal frames, each comprising two columns made of tubular steel sections (250×150 mm) and a 15-meter horizontal span. The cross beams have a cross-section of 200×75 mm, with flanges 25 mm wide and a thickness of 4.75 mm. The structures are located at a height of between 7 m and 8 m above the ground, allowing mechanized agricultural operations beneath the structures. Each portal frame supports two rows, each containing 15 polycrystalline PV modules rated at 340 Wp each. Agrivoltaic systems for sugarcane cultivation require taller structures than typical agrivoltaic projects around the world, in order to accommodate plants that can grow up to 6 meters tall. Maintenance activities included repainting every six months and applying specialized protective treatments and coatings. were part of the project activities (Figure 37). The foundation is made of reinforced concrete, designed to withstand the region's wind gusts. The agrivoltaic system was integrated into an area where sugarcane cultivation was already established (Figure 38).

Figure 37 – Agrivoltaic system with seven PV module structures



Source: [81]

Figure 38 – Area where the system was installed, within an existing sugarcane plantation



Source: [96]

[81] reports that sugarcane stalk yield was 43.2% higher in agrivoltaic areas compared to a reference area without PV modules, due to a higher leaf area index throughout the cycle. The elevation of the PV modules creates intermittent shading throughout the day, helping to moderate temperatures in the crop canopy. For sugarcane, this effect can reduce thermal stress during critical periods, decrease evapotranspiration, a significant factor in semi-arid regions, and help with soil moisture conservation and maintenance of the leaf area index. However, the system's efficiency depends on the proper design of the spacing and height of the structures, as well as the crop's ability to adapt to the new microclimatic conditions created by the shading.

4.1.4 Agri Solar Farm

The Agri Solar Farm project is located in Sorocaba/São Paulo and is associated with the activities of the Solar Center of Excellence developed by Nextacker in partnership with FIT – Flextronics Institute of Technology, which focuses on R&D, technology demonstration, and project implementation support. The project began in 2022, and the first crop cycle took place in 2023.

The agrivoltaic facility at the Center occupies a dedicated area of approximately 10,000 m², with a capacity of 600 kW, located within an R&D complex that reached approximately 46,000 m² following an expansion in 2024, and which has been used to conduct applied research on how agricultural crops respond how crops perform when cultivated between tracker rows, as well as to test specific software solutions and design recommendations aimed at the dual-use of land [97].

The expansion and structuring of the Center are also described as part of a broader scope of laboratories and outdoor trials dedicated to the life cycle of PV plants (from design to O&M), with an emphasis on integrating power generation with agricultural practices, soil conservation, and technical capacity building, including the training of hundreds of professionals through specialized courses and training programs [98].

In the context of the Agri Solar Farm, the system covers an area of 2,000 m², with 10 north–south-oriented trackers, combining *NX Horizon* and *NX Hail Pro*, with a height of 1.5 m at the torque tube and a row spacing (pitch) of approximately 6 m. The pilot's GCR ranges from 31.4% to 38.2% across different sectors of the pilot [45] [99].

The system covers a wide production range, including vegetables, grains and field crops such as wheat, soybeans and peanuts, as well as cattle grazing, which makes it possible to observe responses under different ecophysiological conditions and management practices. At the same time, studies conducted at FIT's Solar Laboratory suggest an evaluation protocol that combines an experimental design across multiple crops, standardized sampling at positions relative to the tracker (under the tracker, at the drip line,

and in the center of the row), and systematic measurements of Photosynthetically Active Radiation (PAR) with high temporal resolution, ensuring methodological traceability to establish a relationship between light distribution and agronomic performance [100].

Two papers have already been published presenting the results of research conducted at the center, which demonstrate energy performance equivalent to that of conventional PV plants. Furthermore, results indicate that the partial shading provided by the trackers leads to improvements in water efficiency, with increases in soil moisture of approximately 31% for soybeans, 42% for wheat, 39% for zucchini, and 12% for strawberries, thereby reducing evapotranspiration and water stress in the crops. For a set of 14 crops tested, including grains, leafy vegetables, root vegetables, and fruits, it was observed that crops such as wheat, soybeans, black oats, and Swiss chard did not show statistically significant losses in yield compared to reference plots in open fields [99].

In the peanut experiment, although a reduction in biomass was observed compared to the agricultural control, the morphophysiological parameters remained stable and the energy impact was marginal, resulting in an EPI of ≈ 0.96 , a value consistent with the operational variability of commercial plants [101].

Figure 39 – One of the pilot systems at the Agri Solar Farm



Source: [99]

4.1.5 CCampo

In the Brazilian North region, in the state of Pará, another pilot project was recently developed with the support of the German Cooperatives Association DGRV, the Brazilian Cooperatives Association OCB, and the Solar Photovoltaic Laboratory at UFSC (<https://fotovoltaica.ufsc.br/>). The 74.5-kWp agrivoltaic system of the cooperative CCampo was installed in January 2023 and combined agrivoltaic

techniques with agroecological and organic farming practices (Figure 40). CCampo is an agricultural cooperative in the western region of the Pará state in North Brazil, comprising over 200 cooperating families, with a mission to strengthen farming families and provide regional products to consumers with safety and reliability. The agrivoltaic system will produce bell peppers, kale, cilantro, and scallions. Additionally, the project involved training of the cooperative members in agrivoltaic systems and organic agriculture practices.

The energy credits generated by the agrivoltaic system are used to reduce the energy costs of the cooperative's agro-industry, which incurs high energy expenses in the production of fruit pulps, sometimes reaching 8.000 kWh/month, equivalent to a monthly electricity bill of approximately R\$ 10.000. Agrivoltaic systems, as in the case of CCampo cooperative, present a significant opportunity for Brazilian cooperatives, as agricultural cooperatives can invest in agrivoltaic systems and create new Cooperative Energy business models using the generated credits. These energy credits can be utilized to lower the cooperative's own electricity bill, and they can also be distributed to cooperative members and other partner organizations.

Figure 40 - Members of CCampo, OCB and Fotovoltaica/UFSC in front of the under-construction agrivoltaic system, and cooperative members planting in the control area adjacent to the power plant



Source: Autores (2026)

4.1.6 EPAMIG's Cemig and CPQD

One agrivoltaic project in Brazil is located in the state of Minas Gerais, a state with significant agricultural importance and a leading contributor to solar power generation in Brazil. The project was developed in collaboration between the Minas Gerais Energy Company (CEMIG), the Agricultural and Livestock Research Company of Minas Gerais (EPAMIG), and the Center for Research and Development in Telecommunications (CPQD). The project involves the installation of pilot units to test various crop arrangements and adapt technologies to different climate and soil conditions [102].

The project aims to address technical challenges, social implications for small-scale farmers, and the development of potential industry suppliers [102]. The selected agricultural activities for the experimental sites are melons, strawberries, beans, lettuce, and pastures for cattle. The project is expected to evaluate agronomic aspects, water usage efficiency, and the final quality of both energy and food production [103].

4.1.7 Fotovoltaica UFSC and Repsol Brazil

Another project that began in 2024 is the result of a collaboration between the Fotovoltaica Laboratory/UFSC (<https://fotovoltaica.ufsc.br/>) at the Universidade Federal de Santa Catarina (UFSC) and Repsol Brazil, the Brazilian arm of the Spanish oil & gas company Repsol. The project's focus is to assess various PV technologies applied to agrivoltaic systems and analyze their impact on agricultural production. The experimental system has just over 100 kWp and is located in Florianópolis, at 27°S latitude; it has a total installed capacity of 108 kWp, distributed across seven main subsystems, as shown in Figure 41:

- (1) Fixed, north-facing system;
- (2) Conventional single-axis tracker;
- (3) Optimized single-axis tracker;
- (4) Conventional single-axis tracker (semitransparent modules);
- (5) Optimized single-axis tracker (semitransparent modules);
- (6) East-West Vertical;
- (7) Vertical.

Half of the trackers operate with conventional bifacial modules, and the rest use semitransparent bifacial modules designed specifically for use in agrivoltaic systems. The project also includes a control area without PV panels, allowing for more accurate analysis of the effects of shading and changes in microclimates.

Figure 41 – Aerial view of the Fotovoltaica/UFSC and Repsol agrivoltaic system



Source: [138]

Currently, the experimental plot is used to grow lettuce (*Lactuca sativa*) of the Elisangela cultivar, distributed across 37 beds, each with 4 production rows, for a total of 96 seedlings per bed. In addition, future phases will evaluate other crops and adapted tracking algorithms to optimize agricultural performance while maintaining efficient electricity generation. The project aims to evaluate agricultural productivity and differences among structural configurations, allowing for direct observation of these interactions between different PV configurations and plant development under real field conditions, thereby enabling a comparison of real-world Brazilian agricultural scenarios with the results of the same system combined with power generation.

Figure 42 – Fotovoltaica/UFSC and Repsol Agrivoltaic system



Source: [138]

The pilot features a comprehensive sensor system, including environmental sensors for collecting weather data, such as anemometers, thermo-hygrometers, rain gauges, and barometers, as well as sensors specific to the PV system, including pyranometers, reference cells, module temperature sensors, and specific sensors for monitoring crop growth, such as soil temperature and moisture sensors, PAR radiation sensors, and Normalized Difference Vegetation Index (NDVI) sensors. Each subsystem is equipped with a set of sensors to enable comparison of the effects of different agrivoltaic configurations on the microclimate, power generation, and agricultural production.

4.1.8 Beevolt and Sheep Introduction – EDP Brazil

EDP Brazil has two agrivoltaic projects in operation; both of which were developed by adapting existing plants. One of the projects was named BeeVolt, and involves introducing native bees to the Roseira solar power plant in rural São Paulo, with a focus on environmental conservation and biodiversity. A meliponary, which is a set of boxes designed for raising native stingless bees, was added to the existing plant in 2024, introducing colonies of the native mandaçaia bee (*Melipona quadrifasciata anthidioides*), which is considered extremely important for ecological balance and is threatened with extinction. These bees play an essential role in pollination, thereby ensuring the formation of fruits and seeds and contributing directly to the preservation of local biodiversity. The 75-kW Roseira plant not only generates renewable energy, but it is also a socially focused plant that allocates electricity credits to approximately 154 vulnerable families [104], [105].

EDP's other project was implemented in 2025 and focuses on using sheep at a 252 MWp plant as a strategy for vegetation control, instead of mechanical or chemical weeding. In the case of mechanical weeding, notable limitations include high operating costs, dependence on specialized machinery, and risks associated with the operation, including damage to equipment, structures, or adjacent crops, as well as issues related to workplace safety. Chemical control, on the other hand, which involves the application of herbicides, faces increasing permitting and regulatory requirements, greater environmental pressure due to potential impacts on soil, water, and biodiversity, as well as declining social acceptance, especially in contexts that call for more sustainable practices [106]. EDP's other project is focused on using sheep at a 252 MWp plant as a strategy for vegetation control, instead of mechanical or chemical weeding.

The project to introduce sheep for vegetation management was implemented in September 2024. The initiative designates 68 ha as grazing land, in addition to 2.3 ha set aside for quarantine and infirmary areas, ensuring proper health management and flock control. The system has 6 to 8 sheep per ha, a parameter used for flock sizing and planning. The project began with an initial flock of 50 sheep and,

over the course of its operation, expanded to 845 animals, approaching the estimated capacity for the available land. The operation is staffed by a team of three employees and a Border Collie dog, which assists in herding and guiding the

flock. This operational model allows for greater efficiency in moving animals between sectors, contributing to more uniform grazing and proper vegetation management [106].

Figure 43 – Sheep at EDP Brazil's Pereira Barreto Power Plant



Source: [139]

The project uses a partnership model in which the company provides land for grazing but does not own the flock. Livestock activities are carried out by a partner rural producer, who is responsible for managing the animals, including their care, health, and marketing. In addition to reducing the plant's OPEX, other advantages include soil stabilization through the preservation of vegetation cover and root systems, reduced CO₂ emissions resulting from less use of tractors and diesel-powered equipment, increased soil carbon storage, the replacement of herbicides, nutrient cycling through manure, and compatibility with agrivoltaic systems. However, the model also presents significant challenges, such as the scalability of the flock in very large areas, logistical limitations (slaughter capacity and availability of local suppliers), as well as animal behavioral factors, such as selective grazing and reduced performance during periods of drought. These aspects require technical planning and ongoing management to ensure operational efficiency and long-term sustainability [106].

4.1.9 Vênus Energia + UFCC

This initiative was launched in 2025 in the Cariri region of Paraíba, and serves as yet another example of agrivoltaics applied in the context of farming families in Brazil's semi-arid regions. In the year the project was implemented, an event was held in which students, faculty, and technical staff from the CDSA at the Federal University of Campina Grande (UFCG) organized a collective planting effort on the properties. There, they built raised beds and seedbeds beneath PV modules installed more than two meters above the ground, thereby allowing the area to be used simultaneously for agricultural production and power generation [107]. The activity also helped raise awareness about soil conservation and the distribution of organic compost, humus, and biofertilizers to families, integrating various extension projects and bringing together students

from different fields of study in an interdisciplinary effort. The company Vênus Energia Regenerativa contributed to the project by donating and installing the PV structures used in the area, thereby making the implemented system feasible [107], [108].

4.1.10 Agrivoltaic System – Agri-PV Brazil

The Agrivoltaic System – AgriPV Brazil project, located on the Campus of the Luiz de Queiroz School of Agriculture (ESALQ-USP) in Piracicaba-SP, is a partnership between the USP Institute of Energy and Environment (IEE), ESALQ-USP, the Research Center for Greenhouse Gas Innovation (RCGI/USP), Innova Power, and TotalEnergies. The project, coordinated by professors Maurício Cherubin and Roberto Zilles, was designed to test dual-use land configurations under PV modules, assess how the shading and microclimate generated by the modules affect crop productivity and health, and serve as a replicable model for climate adaptation and local energy security [109].

Figure 44 – Agri-PV System



Source: [140]

With regard to the characteristics of the PV system, there are a total of three 60-kWp systems, two of which were designed and installed using classic ground-mounted structures with a double-post design, located in an area where brachiaria grass is grown and another area where the vegetation has been cleared. The elevated system has a module height of 2.5 meters at its lowest point and features wider row spacing in the areas where soybeans, corn, and sorghum are grown.

Figure 45 – System with soybeans (left) and system with brachiaria grass (right)



Source: [140]

4.1.11 SUNfarming

Founded in 2004, SUNfarming has developed various types of PV systems in several countries and, over the past five years, has begun to focus part of its research and development activities on Agri-PV systems, having implemented its first pilot project in South Africa. The company currently identifies Brazil as one of its key strategic markets, due to its favorable climatic conditions and the potential for integrating PV power generation with agricultural production [99].

In Brazil, SUNfarming implemented two pilot agrivoltaic systems in 2025: two in the state of Ceará, in the municipalities of Caucaia and Croatá, and one currently under development in the municipality of Belterra (PA). The Caucaia project is associated with SUNfarming Agri-Solar Research & Training Centre, which was designed to integrate PV generation, agricultural cultivation, and professional training. The system complies with the technical specifications of the German DIN SPEC 91434 standard for agrivoltaic systems, with a minimum height of 2.1 m between the ground and the bottom of the modules, and uses exclusively bifacial PV modules with transparent double-glass panels, allowing solar

radiation to partially reach the crops while also harnessing the soil's albedo to increase electricity generation [99].

From an agricultural standpoint, the Caucaia system employs two structural types: the Agri-Solar table, designed for growing medium-sized vegetables such as tomatoes, and the umbrella system, intended for growing small fruit trees. The project also includes a significant social component, providing hands-on training to approximately 40 people affiliated with a rehabilitation center, in activities related to the installation, mounting, and operation of agrivoltaic systems and associated agricultural practices. In Croatá (CE), an 11.5 kWp system was installed to evaluate the agronomic performance of pitaya (*Hylocereus* spp.) under partial shade, while in Belterra (PA), a 17.25 kWp pilot system will be installed in partnership with the Amabella Cooperative, involving primarily women farmers, with plans for future expansion to 750 kWp, covering approximately 1 ha [99], [110].

In addition, SUNfarming's projects in Ceará will be part of a broader strategy to integrate agrivoltaic systems with green hydrogen production, particularly in regions where solar and wind resources are highly complementary, such as the area surrounding the Pecém Industrial and Port Complex. The proposal involves using electricity generated by Agri-PV systems, combined with wind power, to power electrolyzers for the production of green hydrogen, which is then converted into green ammonia or e-methanol, with a view to industrial applications and potential export markets [99].

Figure 46 – SUNfarming System



Source: [110]

4.1.12 Agrivoltaic System for Livestock Production

The Agrivoltaic System for Livestock Production project was implemented in 2025 at the Lageado Farm, which belongs to the School of Veterinary Medicine and Animal Science at the "Júlio de Mesquita Filho" São Paulo State University, in the municipality of Botucatu - SP. The initiative is funded by the São Paulo State Research Support Foundation. The experimental area is intended for the management of dairy cattle under a rotational grazing system and was

designed to integrate PV power generation with livestock production, with the aim of improving the thermal environment. The system consists of a grazing area divided into six paddocks, with a total of 72 PV modules installed in the center of the grazing areas. Three paddocks were configured with modules in portrait orientation and three in landscape orientation, with 12 modules per paddock in each configuration. The modules (580 Wp, 22.45% efficiency) were installed in east–west rows, with the modules facing true north, at a height of 2.30 m and a tilt of 10°. Each configuration provides approximately 24 m² of usable shaded area per paddock (about 1.2% of the total area). The system has 18 microinverters, arranged in rows of 12 modules, with three microinverters per row and 4 modules connected to each unit.

Preliminary results indicate an improvement in the thermal environment of the area with PV modules, compared to the unshaded area: a 1.5 °C reduction in air temperature, a 4 °C reduction in black globe temperature, and up to an 8 °C reduction in soil surface temperature. This more pleasant environment encouraged comfort-seeking behaviors, such as resting and lying down to ruminate, in the system with the PV modules. In addition, the animals used the metal structures to scratch themselves, a highly motivated behavior in cattle. This highlights the potential of these structures to enhance the environment.

Figure 47 – Agrivoltaic System for Livestock Production



Source: [141]

4.1.13 Considerations regarding the existing agrivoltaic systems in Brazil

Agrivoltaic technology is gaining momentum in Brazil, with only a few projects showcasing its potential in diverse agricultural settings so far. For the most part, Brazilian projects are experimental in nature and involve partnerships with ICTs. These pilot projects highlight the country's diversity regarding climate conditions and agricultural potential, which indicates considerable potential for adapting a wide range of agrivoltaic applications to different regional conditions and needs. A summary of all identified agrivoltaic projects in Brazil as of the date of preparation of this report is available in Table 3.

Table 3 - Summary table of the identified agrivoltaic projects in Brazil

Project Name	Institutions involved	Start Year	Agricultural and Livestock Production	PV Characteristics	Location	Climate [111]
Ecolume	More than 40 researchers and staff from: IPA, Serta, VertSol, Inpe, Embrapa, Insa, and others	2019	Aquaponic system with various vegetables, seedlings of native trees, fish and eggs	3.3 kW, small replicable family units	Ibimirim (PE)	Dry semi-arid
Pankará	Pankará indigenous community, atmosfair gGmbH, CCBA, Funai, UFPE, UFRPE, Brasilieninitiative Freiburg e.V.	2020	Melon, vegetables	3 m high, 33 kWp, associated with a pumping system	Aldeia Serrote dos Campos, Itacuruba (PE)	Dry semi-arid
UFAL	Ceca / UFAL, Fapeal, Usina Santa Clotilde	2022	Sugarcane	8 m height; 71.4 kWp	Rio Largo (AL)	Tropical with monsoons
Agri Solar Farm	FIT – Flextronics Institute of Technology and NextPower	2022	Zucchini, Swiss chard, cotton, peanuts, black oats, broccoli, carrots, cilantro, strawberries, corn, soybeans, sorghum, tomatoes, wheat, and cattle	122.58 kWp, 1.5 m high, 6 m pitch, with 10 north-south orientation PV trackers (5 NX Horizon and 5 NX Hail Pro). 37% GCR	Sorocaba (SP)	Humid subtropical climate with no dry season and a hot summer

CCampo	CCampo (Agriculture cooperative), DGRV, OCB,	2023	Peppers, kale, cilantro, and scallions	2.5 m high; 74.5 kWp	Santarém (PA)	Tropical with monsoons
CEMIG, EPAMIG and CPQD	CEMIG, EPAMIG and CPQD	2023	Melons, strawberries, beans, lettuce, and pasture for cattle	Various PV technologies, three pilot projects—one with 80 kWp and 600 kWh of storage, and the other two with 88 and 81 kWp, respectively, and 700 kWh of storage for both	Jaíba and Prudente de Morais (MG)	Tropical with a dry summer (Jaíba) and humid subtropical with a dry winter and a hot summer (Prudente de Morais)
Agrivoltaic System – Agri-PV Brazil	ESALQ-USP, IEE-USP, RCGI	2023	Soybeans, corn, sorghum, and brachiaria grass	3 systems of 60 kWp—2 with a standard structure and 1 with an elevated structure approximately 2.5 m high and with wider spacing	Piracicaba (SP)	Humid subtropical oceanic climate, with no dry season and a hot summer
Fotovoltaica/UFSC, Repsol, and Epagri	Repsol, Fotovoltaica/UFSC, and Epagri	2024	Lettuce, strawberries, and other crops to be defined	Various PV technologies, including trackers and semitransparent PV modules, totaling 100 kWp	Florianópolis (SC)	Humid subtropical climate with no dry season and a hot summer
Beevolt and Sheep Introduction - EDP	EDP, Bee2Be, NGO	2024	Native bees and sheep	There are 2 existing PV plants; at one of them, sheep grazing was adopted (252 MWp), and at the other, boxes with	Roseira (SP) Pereira Barreto (SP)	Humid subtropical climate with dry winters and mild summers (Roseira) and tropical with a dry winter (Pereira Barreto)
Vênus Energia + UFCG	Vênus Energia and UFCG	2025	Lettuce, cilantro, spinach	100 kWp, associated with a water pumping system	São Domingos do Cariri (PB)	Dry semi-arid
SUNfarming Agri-Solar Research & Training Centre Caucaia and other projects	SUNfarming GmbH, SUNfarming Holding do Brasil Ltda, dena GmbH (German Energy Agency – Deutsche Energie-Agentur)	2025	Cherry tomatoes, peppers, chili peppers, parsley, scallions, papaya, pitaya	2 pilot systems compliant with the German DIN SPEC, with a total capacity of approximately 75 kWp. Caucaia project focuses on training local workers	Caucaia (CE) Croatá (CE) Belterra (PA)	Tropical zone with a dry summer (Caucaia and Croatá) and tropical monsoon (Belterra)
Agrivoltaic System for Livestock Production	FMVZ, UNESP, UTFPR, UFSC, IZ Sertãozinho	2025	Dairy cattle	41.7 kWp distributed across 4 subsystems with PV modules arranged in portrait and landscape orientations	Botucatu (SP)	Humid subtropical oceanic climate, with no dry season and a mild summer

Source: Elaborated by authors (2026)

4.2 Potential of different agricultural products for agrivoltaics in Brazil

Brazil has a great contribution to food production worldwide. In 2023, the country was the world's fourth-largest grain producer, accounting for about 8.8% of global production, at a time when world grain production exceeded 3.5 billion tons [112]. The Brazilian agricultural sector plays a crucial role in contributing to the country's Gross Domestic Product (GDP). Also, this activity is of great relevance because of its high competitiveness and its role in generating jobs, wealth, food, fibers, and biofuels for Brazil and other nations [113]. Regarding the economic impact of the agricultural sector,

according to the Brazilian agricultural census of 2019, the activity is the economic basis for 90% of the Brazilian municipalities with up to 20 thousand inhabitants [114].

In this chapter, different agricultural and livestock productions in Brazil were analyzed, in order to study their potential for agrivoltaic application purposes. The analysis is divided into three main aspects: (1) Socioeconomic aspects, (2) Agriculture and livestock systems aspects and (3) PV systems aspects.

4.2.1 Socioeconomic aspects

In this chapter, an overview of the primary agricultural and livestock practices in Brazil is provided, focusing on their potential for expansion and sustainability. Large and small-scale agricultural scenarios were analyzed, with a highlight in the key regions associated with the main agricultural activities, as well as the socioeconomic aspects related to each of them. Also, a characterization of the farming practices was elaborated, as well as the context of the farmers engaged in this vital sector. The content of this chapter also includes the special case of the Matopiba (Region that comprises parts of the states Maranhão, Tocantins, Piauí and Bahia) and the Northeast region.

4.2.1.1 Large-scale agricultural production

The large-scale agricultural production in Brazil is led by soybeans, corn, coffee and sugarcane, which are the main contributors to the Gross Production Value (VBP). The VBP of the agricultural sector in Brazil is approximately US\$ 250 billion, with over 80% of the revenue concentrated in the Central-West, Southern, and Southeastern regions, according to data from the Ministry of Agriculture and Livestock. These figures indicate the significant impact and contribution of the agricultural industry to Brazil's economy. Soybeans alone account for approximately US\$ 1.00 out of every US\$ 3.55 generated by the agricultural sector in Brazil – the country is responsible for 50% of the global share of soy production [115]. As of 2006, the national production was concentrated in the Central-West region, especially in Mato Grosso state [116]. After soybeans, the second-ranking product in the VBP of Brazilian agriculture is beef cattle, representing US\$ 40 billion in 2020, followed by corn with US\$ 25 billion. Dairy cattle and sugarcane rank third and fourth, respectively, with US\$ 15 billion and US\$ 14 billion. Poultry production, particularly chicken, is also showing significant growth, as well as coffee and pork [115]. Regarding corn production, the top Brazilian producers are Mato Grosso, Paraná, Mato Grosso do Sul, and Minas Gerais, respectively. In particular, Mato Grosso's production alone surpasses that of other Brazilian states together [117].

The estimated total sugarcane production in Brazil, according to data from the 1st survey of the 2022/23 harvest, estimates the total production in the country to reach around 600 million tons. Among the leading states producing sugarcane in Brazil are São Paulo, with over 300 million tons, Goiás, with 75 million tons, and Minas Gerais, with 67 million tons. Globally, there are approximately 1.8 billion tons of sugarcane every year, and Brazil was the leading producer in 2023 [118].

According to Barros et al. in a study published by CEPEA, in Brazil there are nearly 20 million people working in the agricultural sector, which represents close to 20% of the total

Brazilian active workforce [119]. The study used data from PNAD (National Household Sample Survey) which also show that soybeans production had over 504 thousand people and sugarcane over 315 thousand people employed in total in 2022. The most relevant sector regarding to the number of workers is beef cattle production, which had over 2 million active workers in the same year.

4.2.1.2 Small-scale agricultural production (Family farming)

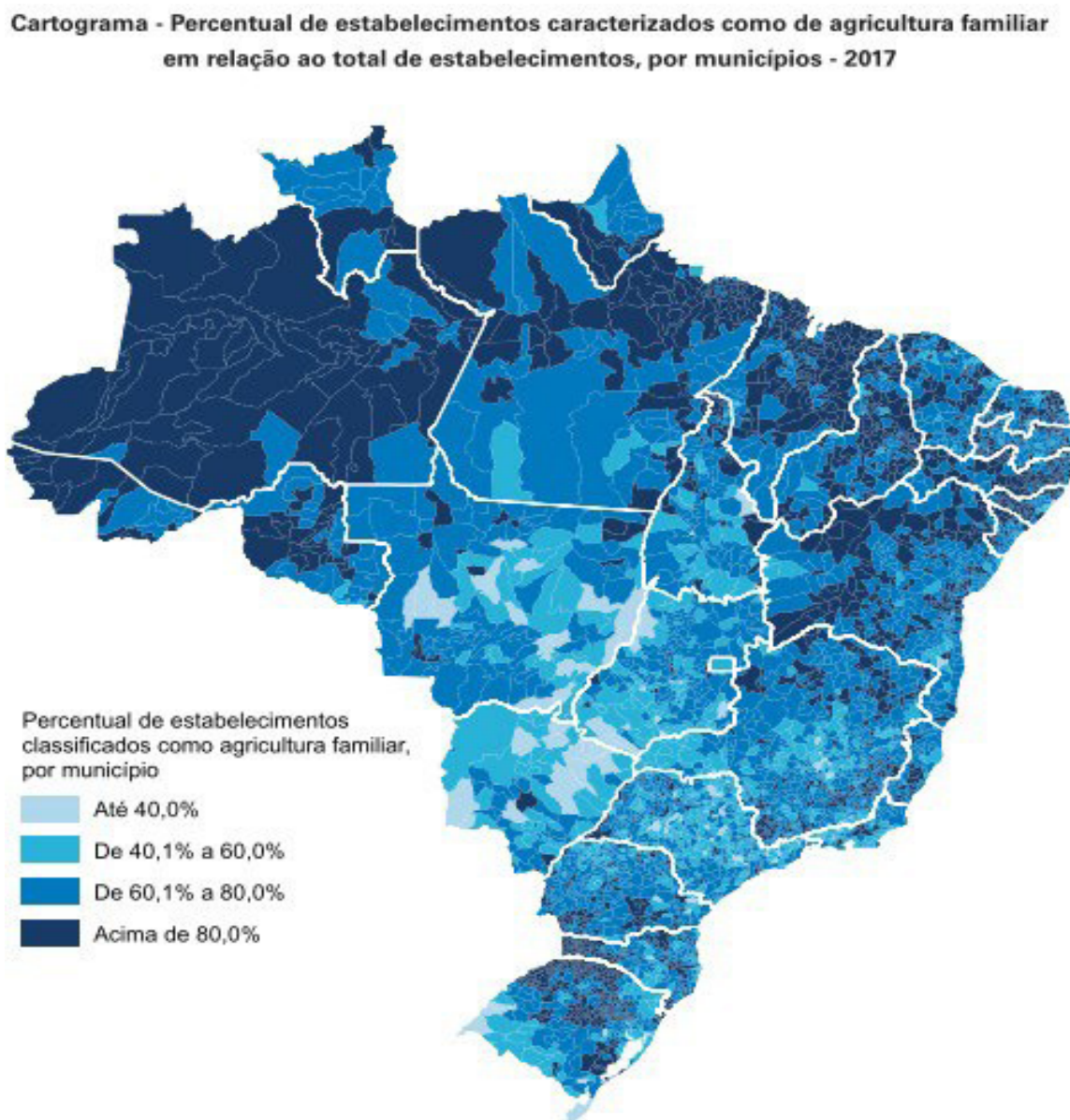
Small rural properties or rural “family farming” possession refers to land that is cultivated through the personal labor of family farmers and rural family entrepreneurs, including settlements, that meet the requirements stipulated in the Law 11,326 of 2006⁵. For instance, such properties must not exceed an area larger than 4 fiscal modules. *devem não exceder uma área maior que 4 módulos fiscais*.

In Brazil, the fiscal module is an agrarian measurement unit expressed in ha, which varies for each municipality, ranging from 5 to 110 ha, depending on the economic activities carried out and on the income that can be obtained from them in the municipality. For example, in the case of some municipalities located in the Cerrado biome (most of the Central-West region of Brazil), a property owner with 4 fiscal modules may have up to 400 ha, and in the Caatinga biome (present in the Northeast region of Brazil), up to 260 ha [120].

According to data from the 2017 Agricultural Census conducted by the IBGE, family farming accounts for approximately 24% of the gross value of agricultural production in the country. The census data also highlights the sector's importance in job creation, as family farming employs about 10.5 million people, representing over 70% of the workforce in the Brazilian agricultural sector. Establishments characterized as family farming are prevalent in many municipalities, particularly in the Northern and Northeastern regions [114]. The Southern and Southeastern regions also have a significant number of municipalities where small scale producers predominate in percentage terms. In contrast, the Central-West region of the country shows a stronger presence of large-scale producers and landowners (Figure 48).

5 https://legislacao.presidencia.gov.br/ficha?legisla/legislacao.nsf/Viiv_Identificacao/lei%2011.326-2006&OpenDocument

Figure 48 - Percentage of establishments classified as family farming in relation to the total number of establishments, by municipalities - 2017



Source: [114]

As mentioned earlier, family farming plays a crucial role in the Brazilian food supply, accounting for approximately 70% of the food consumed by the population; therefore, these establishments are of great importance regarding food security. Notably, family farmers contribute significantly to the production of fruits, vegetables, and staple products. For instance, they are responsible for at least 80% of cassava production, 69% of pineapple supply, and 42% of the total bean consumption in the country [121].

Despite its vital contribution to the food supply, family farming establishments still face challenges regarding food security in the country. The Northeast region is where 47.2% of these establishments are located [121], and yet, it is the second region in the food security ranking. The population under these circumstances in the North and Northeast region gets to 71,6% and 68%, respectively [122]. To address

these challenges and support family farmers, government involvement in essential assistance programs is crucial. Programs like water provision and the Bolsa Família social welfare program are considered essential in ensuring the stability and growth of family farming practices [121].

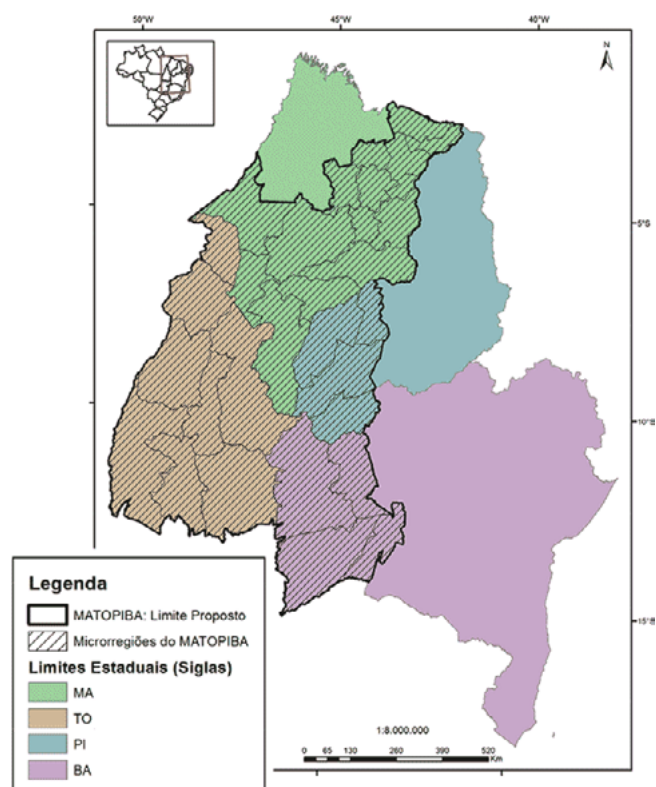
4.2.3 Case of the North region and Matopiba region

The Northern Brazilian region has experienced a substantial growth in agriculture, and in 2020, the region recorded grain exports of approximately 6 million tons, marking a remarkable increase of 15% compared to the previous year. This region is considered an agricultural frontier, and produces a wide range of crops from traditional ones like cassava, maize, and rice to export-oriented crops such as soybeans. This last one has been associated with deforestation in the Amazon rainforest, and also contributes to the decrease in rainfall in the region [123].

One particular state that relies in agribusiness, especially grains agriculture, is Roraima [124]. In this state, soybean cultivation has shown substantial growth in the region, and 2022 projections indicated a 40% increase in productive areas by 2023. One of the origins of the expansion of the extensive agricultural practices to regions such as the North region are economic and financial motivations, which are driving current migrations in Brazil. Agricultural producers seek to maintain or increase their profitability rates and expand their business, which encourages them to move in search of new land with lower costs. Regions within the states of Maranhão, Tocantins, Piauí, and Bahia (also known as Matopiba) are under a trend of expanding cultivated areas in Brazil. This agricultural transition is justified by some essential characteristics of “modern agriculture”, such as extensive and flat areas, potentially productive soils, availability of water, and a favorable climate with long days and high solar irradiation intensity. The transition of land use involves both expansion and conversion of land, particularly in the replacement of pastures with large-scale agriculture, facilitated by mechanization and production intensification [125].

The North region is receiving the main expansion from the Northeast and Central-West large-scale extensive agriculture. The region comprises the Matopiba states and the state of Pará. This Matopiba region is considered a “new agricultural frontier” (Figure 49). It produced 20.5 million tons in the 2016/2017 harvest, and the projections indicate that this production is expected to reach 26 million tons by 2026/2027 [125].

Figure 49 - Proposed delimitation for Matopiba region



Source: [125]

Despite the economic growth associated with this agricultural transition in Matopiba states, the scenario is marked by high deforestation rates. Almost half of the native Cerrado vegetation has been deforested – and out of the 54.5% of the remaining area, 44% is in the Matopiba region [125]. According to an article published by Rodrigues et al. [126], the conversion of the native Cerrado vegetation into grassland and pasture has already caused climate impacts to the region, which became almost 1 °C warmer and 10% dryer.

Given the environmental challenges posed by deforestation and the resulting climate impacts observed in the Matopiba region, there is an urgent need to explore innovative and sustainable agricultural practices in the respective states. In this context, agrivoltaic systems present a promising solution, by generating renewable energy while optimizing land use, and enhancing overall ecosystem and social resilience.

4.2.4 Case of Northeast region

In Brazil, the so-called “modern agriculture”, which refers to mainly large-scale production, seems to benefit only a privileged few, leading to a significant concentration of production and income in rural areas. Data from the latest Census in 2006 reveals that 8% of rural establishments are responsible for generating 85% of the agricultural value, while the remaining 4.7 million properties contribute only 15% to the overall wealth. And these disparities are expected to increase, according to experts [127].

Rural poverty is a widespread issue in Brazil, with the Northeast and North regions experiencing the highest levels of this problem. Brazilian North region accounts with 94% of establishments with an area equal to or smaller than 100 ha, which fall under the ‘very poor’ and ‘poor’ income categories. In establishments larger than 100 ha, the percentage is also high, 74% [127].

In the Northeast region the presence of family farming stands out as an important characteristic, especially in the semi-arid region. On the other hand, Zona da Mata, the most humid part of the region, is dominated by an agricultural system focused on export-oriented monoculture. Horticultural crops, especially fruits like melons, grapes, mangoes, and pineapples, are the main expressions of this region’s agriculture. Also, similar to the Southeast region, the Northeast is also prominently involved in sugarcane production. Furthermore, it exports soybeans, mainly from Bahia and Piauí [128].

The agricultural behavior in the Northeast region of Brazil showed varying trends in harvested areas and crop production between 2002 and 2017. States like Piauí, Maranhão, and Sergipe experienced notable increases in harvested areas, driven by soybean and corn cultivation. In contrast, other states faced declines due to drought effects, particularly in the caatinga biome [129].

Considering the proven benefits of agrivoltaic systems, such as protection from extreme heat and irradiation, reducing evaporation and the need for irrigation, these systems show a potential match with the climate and social characteristics of the Northeast region. One pilot project that represents a model of agrivoltaic system that can address the local challenges of the region is the Ecolume Project, which is explained in detail on the sub-chapter 2.1.1 of this document. The model can provide energy and food security for the family agriculture establishments, while allowing the restoration of degraded or desertified land [130].

4.2.5 Isolated Electric Power System (SISOL)

Brazil currently operates one of the world's largest interconnected electric power systems, known as the National Integrated System (SIN), in a centralized manner; however, some locations face geographical and technical challenges in connecting to the grid and are part of the Isolated Electric Power System (SISOL), which covers approximately 160 locations, serves a population of about 2.0 million people, and has a total demand of 5,718 MW [131]. Agrivoltaic systems could represent a viable solution that complements SISOL, while also serving as a source of income or a way to reduce electricity costs for residents across the country. However, the integration of agrivoltaic systems into SISOL faces some regulatory, technical, and operational challenges.

From a regulatory perspective, the main obstacle lies in the lack of a specific regulatory framework for hybrid systems that integrate PV generation and agricultural production within the same area. SISOL, which is designed to classify projects as primarily agricultural or energy-related, does not clearly address mixed-use land models, which can create legal uncertainty regarding permitting, land regularization, and tariff classification. Law 14,300, which revises the Legal Framework for Microgeneration and Distributed Minigeneration in Brazil and the SCEE, also does not provide for the implementation of these approaches in the region [79].

From a technical standpoint, there are challenges related to the standardization of design criteria, land-use indices, and shading parameters, which differ substantially from those of conventional PV systems. The lack of established guidelines makes it difficult to assess feasibility and ensure proper recording in the system. In addition, the integration of production data (agricultural and energy) requires adjustments to SISOL's monitoring and reporting mechanisms, which traditionally do not use metrics integrated with the Brazilian agrarian sector. Currently, the Brazilian government is still considering the integration of PV systems into SISOL through energy auctions [132] and market penetration strategies [133]. Therefore, the introduction of agrivoltaic systems in SISOL requires regulatory adjustments, the establishment of specific

technical criteria, and the updating of registration and monitoring tools to reflect the dual and integrated nature of these projects. In addition, investments in pilot projects and further studies are needed to ensure that this integration is safe and effective for the Brazilian population.

4.2.6 Agriculture and livestock systems aspects

In this topic the context of the main Brazilian agricultural and livestock is explained, as well as a specific perspective on water availability and irrigation. Also, the situation of the specific Brazilian Northeast region will be highlighted.

4.2.7 Agriculture and livestock

According to the Land Cover and Land Use Monitoring by IBGE, from 2000 to 2018, the agricultural area has grown by 44.8% in Brazil, reaching close to 665 thousand km². This land is equivalent to 7.6% of the national territory, including both land and maritime areas. Certain regions stand out in this land transition, such as the Northeastern part of Mato Grosso, and the municipalities of Santarém and Paragominas in Pará, and Imperatriz in Maranhão, all experiencing an increase in soybean cultivation. On the other hand, the study reveals that in over 18 years, Brazil lost 7.6% of its forest vegetation. The forested area, which was over 4 million km² in 2000, decreased to 3.7 million km² in 2018, representing 42.4% of the country's territory. Additionally, other vegetation, including the biomes of Cerrado, Caatinga, and Pampas, lost more than 10% of its area during the same period[134].

According to a survey carried out by the Institute for Forestry and Agricultural Management and Certification (Imaflora), soybean, corn, sugarcane, rice and beans are the largest crops in Brazilian agriculture in terms of planted area. These 5 agricultural products accounted for over 70% of the total cultivated land in Brazil from 1985 to 2017 [135].

4.2.7.1 Soy

The soybean crop cultivated in Brazil for grain production is an herbaceous plant. The height of the plants varies depending on the environmental conditions and of the variety. Ideally, the plant height should range between 60 to 110 cm, which facilitates mechanical harvesting in commercial fields and helps prevent lodging. The soybean flowering is influenced by the photoperiod, which is the duration of the day. As a short-day plant, soybean delays its flowering and elongates its cycle under long-day conditions. Along with radiation intensity, the duration and quality of the light spectrum significantly affect soybean's morphological and phenotypic characteristics, such as plant height, flowering induction, and ontogeny [136].

In terms of production data, for the 2024/25 harvest, Brazil reported a soybean production of 420.78 million tons on an area of 146.71 million ha. Brazilian soy production accounts to approximately 41% of the world production. Mato Grosso

state stands as the largest soybean producer in Brazil, accounting for 50.59 million tons of production on an area of 12.74 million ha, with a productivity of 3,97 tonne/ha in the same period [137].

Although soybeans are among the crops that suffer the most with shading effects, Italian researchers found, through experiments with agrivoltaic systems, that the impact is less significant than expected [138]. The study encompassed different configurations with various shading rates, and the results showed an average grain yield reduction of soybeans for the whole agrivoltaic system of only 8%, which is largely under the limits established in agrivoltaic plants in Germany and South Korea.

4.2.7.2 Corn

In the Central-Southern region of Brazil, corn cultivation takes place after soybean harvest, with sowing concentrated in the Brazilian Summer/Fall season, commonly known as the second crop. Over the past decades, corn has become the largest agricultural crop globally, surpassing the production of former contenders like rice and wheat, and becoming the first crop to exceed 1 billion tons production [139]. In the 2021/2022 harvest, corn production was globally around

1.22 billion tonnes. According to Conab (2019) state of Mato Grosso has emerged as the leading corn producer in the country, yielding 31.3 million tons, with the second crop of corn accounting for 95% of the total production in the 2018/19 harvest [140]. Corn cultivation exhibits a reasonably distributed pattern across different regions, with the key producing states being Mato Grosso, Paraná, Goiás, Mato Grosso do Sul, and Minas Gerais, in this order [139].

Even though corn and soybeans are considered shade-intolerant crops, researchers in the United States are developing practical studies on the compatibility of these crops with agrivoltaic systems (Figure 50). The researchers are working on determining the optimal spacing between PV modules in order to keep excessive shadows from interfering with the crop production [141].

In addition, an article published by Sekiyama et al. (2019) showed that it is possible to grow corn under the shade of agrivoltaic modules without a relevant yield reduction. The results of the study show that the biomass of corn stover grown under PV modules spaced at 0.71 m intervals was no less than 96.9% that of the production on the control area [142].

Figure 50 - Purdue University research agrivoltaic system over soy and corn plantations



Source: [141]

4.2.7.3 Sugarcane

In 2021, Brazil became the largest producer of sugarcane globally. The value of sugarcane production amounted to over US\$ 15 billion, with over 715 million tons harvested from an area of close to 10 million ha. This performance was spread across over 170 thousand establishments, reflecting the country's robust sugarcane industry. The average yield per ha reached over 70 kg, highlighting the efficiency and productivity of sugarcane cultivation in Brazil [143].

Regarding the 2020/21 harvest, Brazil was responsible for producing 654.5 million tons of sugarcane, dedicated to the production of 41.2 million tons of sugar and 29.7 billion liters of ethanol [144]. Notably, the state of São Paulo took the lead in sugarcane production, contributing to 54.1% of the total quantity produced during the harvest. São Paulo's production numbers included 48.4% of ethanol (14.3 billion liters) and 63.2% of sugar (26.0 million tons) [144], [145]. An example of an agrivoltaic system using Brazilian sugarcane that has

yielded positive results in terms of increased productivity is the one at UFAL, mentioned in this document under the heading “UFAL.”

4.2.7.4 Beef cattle

The beef cattle industry in Brazil is widely developed across all states and ecosystems, exhibiting great diversity in terms of cattle density in different regions, herd growth rates, and practiced production systems. These systems encompass distinct stages of breeding, rearing, and fattening, either independently or in combination, utilizing both native and cultivated pastures, with or without supplementary feeding in grazing or confinement settings. However, more intensive systems, involving pasture supplementation or confinement, have been gaining increasing significance, particularly in the Central-West and Southeast regions. The Brazilian beef cattle industry showcases a wide range of production systems, spanning from extensive livestock farming supported by low-productivity native and cultivated pastures with minimal input usage, to so-called intensive livestock farming, characterized by high-productivity pastures, pasture supplementation, and confinement [146].

Globally, beef production is expected to reach 59.6 million tonnes in 2023, according to estimates from the United States Department of Agriculture (USDA). Brazil had in 2021 a bovine herd of 224.6 million heads (more cattle than people!), according to data from IBGE as part of the Municipal Livestock Survey (PPM). Among the states, Mato Grosso remains the leading cattle producer with 32.4 million heads, accounting for 14.4% of the national herd, followed by Goiás (10.8%). At the municipal level, São Félix do Xingu, in Pará, holds the top position with 2.5 million heads [147]. From January through August 2025, sales increased by 32.62% in value (US\$) and by 14.38% in volume (kg) compared to the same period in 2024. July and August saw the highest export levels on record. In the Northeast region, performance was even more impressive, with an 87.17% increase in sales volume (kg) and a 113.87% increase in revenue (US\$) [148].

The integration of crop-livestock-forest systems (ILPF) in Brazil is a production strategy that combines different agricultural, livestock, and forestry systems within the same area. It aims to optimize land use, increase productivity, and diversify production while reducing the need for opening new areas. ILPF provides numerous benefits, including improved animal welfare, enhanced nutrient cycling in the soil, biodiversity preservation, and sustainability in agriculture [149].

Additionally, it leads to a diversified production output and greater efficiency in utilizing natural resources. The implementation of ILPF is gaining momentum, with approximately 15 million ha already adopting this approach in Brazil [150].

4.2.7.5 Vegetables

The Brazilian vegetable market is characterized by high diversity and segmentation, with the majority of production concentrated in six main crops: potato, tomato, watermelon, lettuce, onion, and carrot. Interestingly, more than half of this production is attributed to the efforts of small-scale family agriculture [151]. According to the 2017 Agricultural Census (IBGE), there were 336 thousand agricultural establishments engaged in horticulture across Brazil, with the distribution as follows: Northeast (41.0%), Southeast (28.0%), South (16.5%), North (9.7%), and Central-West (4.7%). Regarding tomato production, 29.3% of all tomatoes in the country are produced in the state of Goiás, and 21.4% in São Paulo.

The state of Santa Catarina leads in onion production (28.1%), followed by Bahia (15%) [115]. Leafy vegetables are widely grown throughout Brazil, with the Southeastern and Southern regions being the major contributors, accounting for 84% of the production. In the 2016 harvest, São Paulo emerged as the largest lettuce producer, yielding 14,199.3 crates of nine dozen each. Notably, lettuce production in São Paulo is primarily concentrated in the “cinturão verde” or green belt, with key production centers in Sorocaba (54.2%), São Paulo (16%), and Mogi das Cruzes (12.2%) [151].

The estimated total area dedicated to cultivating leafy vegetables in Brazil covers 174,061 ha, with lettuce occupying the majority at 49.9%, followed by arugula (22.8%), cabbage (15.3%), kale (6.1%), spinach (1.0%), and other varieties (4.9%). The total production of over 1,317.6 tons is distributed among different leafy vegetables, with lettuce leading at 43.7%, followed by cabbage (31.7%), kale (9.1%), watercress (7.6%), spinach (3.1%), arugula (2.0%), and other varieties (2.1%) [151].

4.2.7.6 Sheep farming (raising Sheep)

As presented in this report, agrivoltaic systems can alter the local microclimate by reducing direct solar radiation and mitigating temperature extremes, thereby creating favorable conditions for grazing activities [25]. Sheep farming is a widespread livestock activity in Brazil, characterized by its significant production volume and strong regional concentration. This activity is primarily based on grazing systems, in which vegetation management is a recurring cost and operational factor. In 2023, the national sheep population was estimated at 21.8 million head, with the Northeast region accounting for more than 70% of the flock [152].

In the context of agrivoltaic systems, sheep farming stands out as one of the most widespread applications internationally, due to the compatibility between the animals' size, grazing behavior, and the operational requirements of ground-mounted PV plants. As presented in this report, agrivoltaic systems can alter the local microclimate by reducing direct solar radiation and mitigating temperature extremes, thereby

creating favorable conditions for grazing activities [25]. Experimental studies indicate that sheep tend to concentrate their activities in shaded areas, with reports of them spending more than 90% of the day in available shade, highlighting the importance of shade for animal welfare [153].

From a functional perspective, the use of sheep in ground-based PV systems is characterized primarily by the management of vegetation between and under the structures, reducing the need for mechanical weeding and the application of herbicides. This practice also allows access to areas where the use of conventional machinery is limited, helping to reduce the operating costs associated with plant operation and maintenance. Recent data collected through a collaboration between the American Solar Grazing Association and NREL indicate that, in 2024, approximately 129,000 acres of PV sites in the United States were managed using sheep grazing, involving more than 113,000 sheep spread across about 500 PV projects [154]. These figures reflect the establishment of sheep grazing as a standard operating practice at large-scale PV plants. The technical and scientific literature indicates, however, that the effectiveness of this combined use depends directly on the configuration of the PV system (module height, spacing, and the presence of trackers), as well as on stocking rate and pasture management; continuous monitoring is recommended to ensure compatibility between livestock activity and the system's energy performance [155], [156], [157], [158].

4.2.8 Water Availability and Irrigation

On a global scale, the agricultural sector is the largest consumer of land and water resources. Projections indicate a 40% increase in global water demand by 2030 and 55% by 2050, with over 40% of the world's population expected to reside in regions facing severe water stress. In the Brazilian rural context, water usage accounts for 83% of the total Brazilian water intake, with 72% being allocated for irrigation purposes. Irrigation is rapidly expanding in Brazil, with the irrigated land area increasing significantly from 462 thousand ha in 1960 to 6.1 million ha in 2014, primarily through the adoption of center-pivot systems [159].

One of the needs for the present and the future is to enhance irrigation practices' efficiency. Currently, it is estimated that approximately 40% of water is lost due to inadequate irrigation systems or leaks in pipelines in Brazil [159]. Despite having substantial reserves of freshwater, including the world's largest Guarani Aquifer, Brazil faces an uneven distribution of water among its regions: the North holds 68.5%, Central-West 15.7%, South 6.5%, Southeast 6.0%, and Northeast 3.3%.

The IBGE data shows that several crops, including sugarcane, rice, soybean, and corn, are commonly irrigated in Brazil [159]. However, despite the growth in the number of establishments with irrigation (4.7% per year from 2016

to 2021, according to IBGE data) some important crops like beans, coffee, and green corn have irrigation systems just in a limited percentage of agricultural establishments [159].

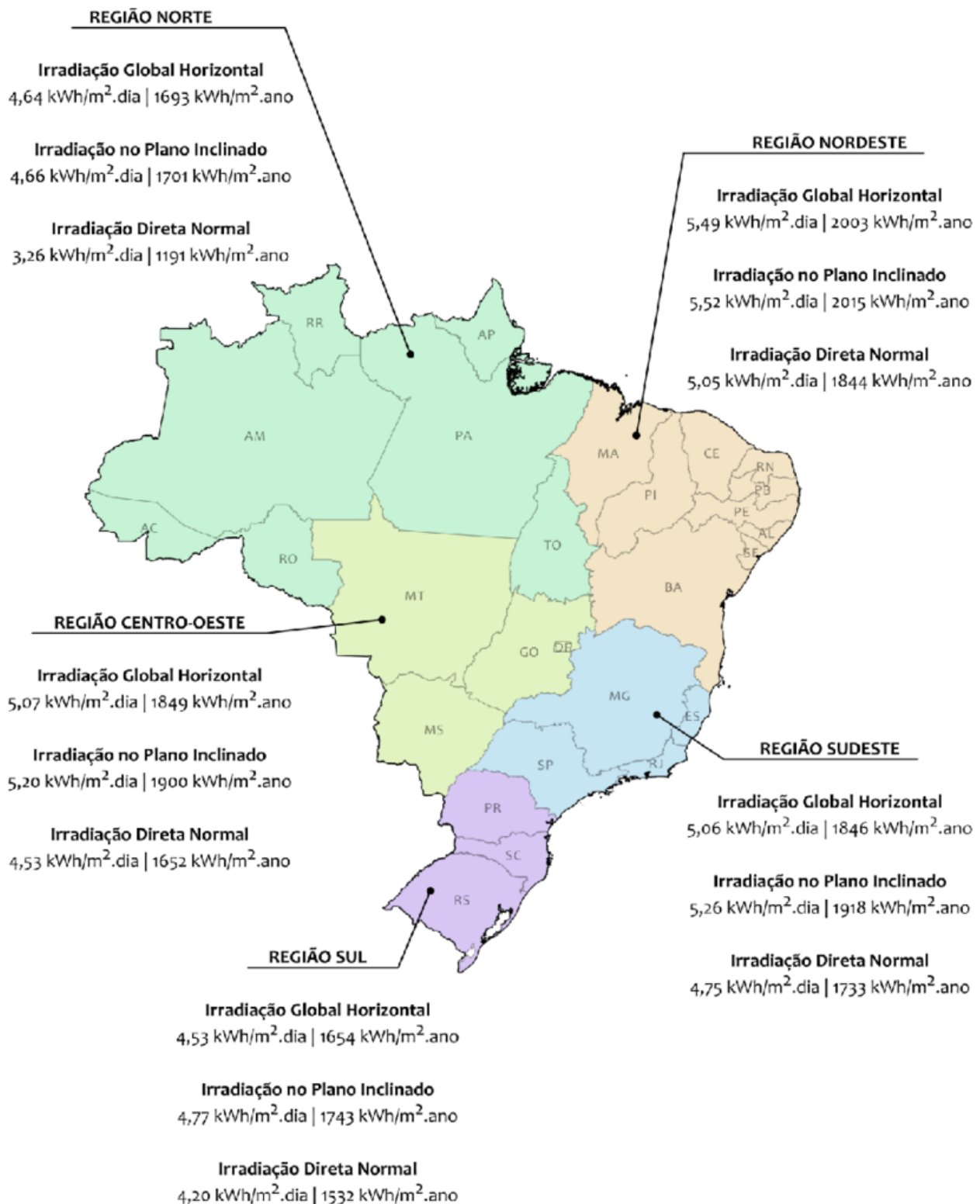
To address water variability in some regions, small reservoirs, underground dams, and rainwater harvesting are potential solutions to enhance water availability and reduce vulnerability in regions with fluctuating water resources [159]. Automation and technology, such as geographical information systems and precision agriculture, can greatly improve irrigation management, optimizing when and how much to irrigate. Additionally, enhancing the capacity and training of the agricultural sector is crucial to effectively implement these advancements [160].

4.2.9 Photovoltaic (PV) systems aspects

The level of solar irradiation varies in the different regions of Brazil due to factors such as latitude, altitude, climate, and cloud cover. However, in all regions of the country, the potential for solar irradiation is notable, which creates opportunities for the development of solar energy projects on different scales. This includes large-scale solar PV plants, as well as the implementation of distributed generation systems in homes, commercial establishments and industries, and agrivoltaic systems.

Figure 51 illustrates the annual average value of total daily solar irradiation in the five regions of Brazil. The Northeast region has the greatest solar potential, with a daily average of global horizontal irradiation of 5.49 kWh/m². The Southeast and Central-West regions have daily horizontal global irradiation values close to 5.07 kWh/m². In the South, the daily average of global horizontal irradiation is 4.53 kWh/m² and in the North it is 4.64 kWh/m². The relatively lower solar irradiation values in the Northern region are explained by the climatic characteristics, with frequent cloudiness reducing the amount of solar radiation incident on the surface. As a result, the average daily global irradiation in the horizontal and inclined planes is close to that of the Southern region, and the normal direct irradiation is lower than in all the other regions of the country.

Figure 51 – Solar Irradiation levels per region

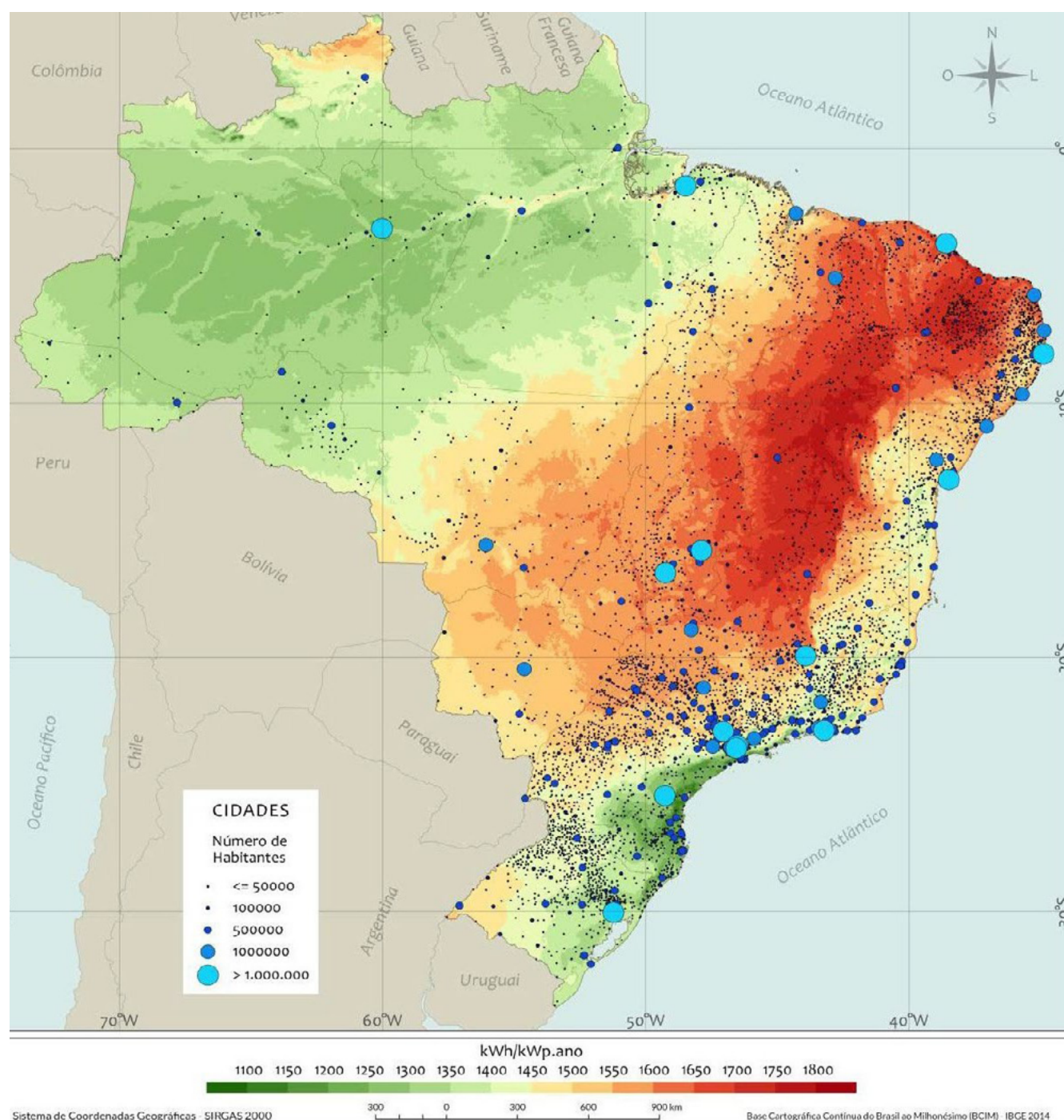


Source: [7]

In Brazil, the generation of electricity using PV modules has immense potential, as can be seen in the map shown in Figure 52. The map illustrates the maximum annual energy yield (measured in kWh of electricity generated per year for each kWp of installed PV energy) throughout Brazil. In addition, the figure shows blue circles spread across the Brazilian territory to highlight areas of population concentration. Even in regions with lower solar

incidence, such as the South and North, it is possible to generate more solar electricity than in highly sunny parts of Germany, for example.

Therefore, there is a huge potential for PV generation in Brazil in all regions of the country, which is already proven with the significant growth of solar distributed generation systems in the country.

Figure 52 - PV generation potential in annual energy yield (kWh/kWp.year)

Source: [7]

4.3 Business models and financing opportunities for agrivoltaics in Brazil

The concluding section of this Informational Report will primarily describe existing business and financing models currently utilized in Brazil, highlighting their potential applicability to agrivoltaic systems. In addition to presenting an overview of the current context and opportunities, this report offers recommendations for policy incentives to promote the adoption of agrivoltaic systems, drawing inspiration from global best-case practices.

4.3.1 Possible business models within the Brazilian context

In Brazil, with the current legal framework for distributed generation farmers can generate their own energy through the SCEE by means of MMGD systems, adapting this technology to the agrivoltaic application.

It is understood that distributed generation would therefore be more suitable for small-scale and family farmers since these systems are limited to 3 MW or 5 MW. For large-scale farmers, agrivoltaic systems into generating energy to the free market might be more suitable. However, the free market

it is a very complex market where usually only big players from the electricity market get involved.

According to the Brazilian Law 14,300, the distributed generation can be applied in four different modalities. They are:

- **Local self-consumption:** energy is generated and consumed in the same consumer unit;
- **Remote self-consumption:** energy is generated and consumed in different consumer units, as long as both are under the name of the same owner (whether an individual or a business) and in the concession area of the same distributor;
- **Development with multiple consumer units:** generation of energy for the common areas of a complex with multiple consumer units located on the same property or on adjoining properties, as long as they are not separated by public roads or third-party properties that are not part of the complex;
- **Shared generation:** generation for a group of consumers who are organized in a cooperative, consortium, voluntary civil or building condominium, or any form of civil association set up for this purpose, as long as all the consumer units are in the concession area of the same distributor.

All of the aforementioned distributed generation options provide the legal framework needed to make the business models for agrivoltaic systems viable as the ones mentioned in Table 1 shown in the sub chapter 1.2 Business Models. In this context, it is seen a huge potential of the shared distributed generation modality, for example, to be applied to existing family farming cooperatives and associations, which could easily adapt their existing legal structure to share energy credits through agrivoltaic systems in their existing agricultural productions.

4.3.2 Existing financing opportunities for solar energy in agricultural lands

In recent years, different types of financing options for solar energy projects have emerged in Brazil. Some of them are exclusive to individuals or businesses, while others cover both. There are also those exclusive to the rural sector, which aim to foster the development of rural producers and rural businesses. This chapter aims to present the currently available financing opportunities available to agricultural properties for the use of solar energy technologies.

The Safra Plan is one of the main programs of the Brazilian federal government, via the Ministry of Agriculture, to promote rural production in the country by guaranteeing credit for investment and cost of agricultural production. The Safra Plan is mainly aimed at small and medium-sized rural producers and every year, since 2003, the government has

allocated funds for the program. For the 2025/2026 edition, the government has made available a record amount of R\$ 475 billion in various rural credit options, with subsidized rates for operating costs, investment, and agricultural insurance. This funding is intended to support everyone from family farmers to medium- and large-scale producers.

The credit lines of the Safra Plan belong to various programs, the main ones being the National Program for Strengthening Family Farming (PRONAF) and the National Program to Support the Medium-Sized Rural Producer (PRONAMP). There are also resources allocated for programs focused on sustainability and technology, such as INOVAGRO and RENOVAGRO (formerly the ABC Program). Each program of the Safra Plan has specific subdivisions, with interest rates that vary according to the program. The classification in one or another modality varies according to the activity carried out by the rural producer, according to the corresponding annual income and the size of the property. This differentiation exists precisely to stimulate the production of small producers, since they tend to have lower competitive advantages compared to large-scale producers. In general, the financing terms for each line, including interest rates, credit limits, and payment terms, vary according to the current Safra Plan and the size of the project submitted.

Another financial instrument that can be used by rural farmers to adopt solar PV energy systems is the Constitutional Financing Funds (FCO, FNE and FNO). These funds are established in the Brazilian Constitution, through Law 7827 of 1989, which aims to promote the economic and social development of certain regions [161].

Another financing option that may be interesting for farmers is FINAME (Financing of Machinery and Equipment). FINAME is a BNDES (National Bank for Economic and Social Development) program that offers credit for the acquisition of machinery, equipment, vehicles and other capital goods to be used in the exercise of the client's economic activity.

These financing lines and programs are presented in more detail in the following sub-chapters.

4.3.2.1 Program for Strengthening Family Farming (PRONAF)

The National Program for Strengthening Family Farming (PRONAF) is a federal public policy that offers rural credit lines under differentiated conditions (lower interest rates, as well as tailored payment terms and limits) to support rural production activities in Brazil. These lines are set annually by the Family Farming Safra Plan, which establishes priorities, interest rates, and funding amounts for the current cycle.

PRONAF is present in almost all Brazilian municipalities and is operated through public and private banks, credit cooperatives, and the BNDES. Access to credit requires, among other requirements, an active PRONAF Eligibility

Declaration (DAP) or PRONAF Eligibility Registration (CAF), which identifies the rural production household.

The main credit lines available under PRONAF in the current cycle include programs designed to finance production, investments, microcredit, and specific groups, such as:

- **PRONAF Custeio** – to finance inputs and expenses related to the production cycle;
- **PRONAF Mais Alimentos (Investment)** – for the purchase of machinery, equipment, and infrastructure;
- **PRONAF Agroindústria and Industrialização** – to support processing and adding value to production;
- **PRONAF Agroecology and PRONAF Bioeconomy** – focused on sustainability and agroecological practices;
- **PRONAF Woman** – intended for projects led by women farmers;
- **PRONAF Youth** – aimed at young farmers;
- **PRONAF A and A/C** – aimed at agrarian reform settlers, indigenous peoples, and quilombolas;

Each credit line has specific terms regarding credit limits, interest rates, and payment terms, as established by the Safra Plan. These resources help strengthen food production,

promote sustainability, increase household income, and foster local and regional development. Among these available lines, the ones that can finance PV systems are PRONAF Bioeconomy and PRONAF Agroindustry, both presented in more detail in the following sub-chapters.

4.3.2.1.1 PRONAF Bioeconomy

The PRONAF Bioeconomy financing mechanism allows financing for investment in the usage of renewable energy technologies, environmental technologies, water storage, small hydro-energy uses, forestry and the adoption of conservation practices and correction of soil acidity and fertility, aiming at its recovery and improvement of productive capacity [162].

This line is available to farmers and family farmers who meet the PRONAF criteria, have a valid PRONAF Eligibility Registration (CAF), and qualify under the rules of the Safra Plan. The credit is intended to finance projects that are technically and economically viable and are aligned with the sustainable objectives set forth in the bioeconomy policy. Table 4 presents the general conditions of this financing line for the acquisition of renewable energy technologies. It is important to note that the availability of the credit line may vary according to the region and the bank branch, in addition to the credit conditions offered.

Table 4 - Conditions of the PRONAF Bioeconomy line for financing renewable energy technologies.

Interest rate	Up to 3% p.a.
Maximum financing amount	R\$ 250 k
Maximum financing period	10 years
Maximum grace period	3 years

Source: Elaborated by authors (2026)

4.3.2.1.2 PRONAF Agroindústria / PRONAF Agroindustry

PRONAF Agroindustry is a credit line designed to finance investments in the processing, storage, and marketing of family farm production. Its main objective is to add value to agricultural products, increase the income of rural families, and strengthen the integration of family farming into local and regional markets [163]. Its main objective is to add value to agricultural products, increase the income of rural families, and strengthen the integration of family farming into local and regional markets [163].

The line provides financing for both individual and collective projects, and can serve family farmers either individually or as members of cooperatives and associations. Eligible items include the construction, expansion, or modernization of agroindustries; the acquisition of machinery and equipment; the establishment of storage structures; sanitary upgrades; and the acquisition of cold storage units, food processing facilities, and renewable energy systems related

to agroindustrial activities. Family farmers who meet the PRONAF criteria and have an active Family Farming Registration (CAF) may apply for this line.

PRONAF Agroindustry contributes to production diversification, job creation in rural areas, and the strengthening of short supply chains, serving as a strategic tool for the sustainable development of family farming in Brazil. Table 5 presents the general conditions of this credit line. It is important to note that the availability of the line may vary according to the region and the bank agency, in addition to the credit conditions offered.

Table 5 - Conditions of the PRONAF Agroindustry line

Interest rate	Up to 8% p.a.
Maximum financing amount	Individual – Up to R\$ 210 k Legal Entity – Up to R\$ 8 million (dairy farmers) and R\$ 450 k (other producers) Cooperative - Up to 50 million, with R\$ 75 k per cooperative member
Maximum financing period	Up to 10 years
Maximum grace period	Up to 3 years

Source: Elaborated by authors (2026)

4.3.2.2 National Program to Support the Medium-Sized Rural Producer (PRONAMP)

PRONAMP is a rural credit line designed for medium-sized rural producers, with the goal of strengthening agricultural and livestock production, expanding production capacity, and promoting greater competitiveness in the sector. The program is open to producers whose annual gross income falls within the limits set by the National Monetary Council (CMN) under the current Safra Plan [164]. PRONAMP offers financing for both agricultural and livestock production costs and for investments in infrastructure, technological modernization, the acquisition of machinery and equipment, storage, and productivity improvements. Interest rates are subsidized and are generally lower than those charged on conventional rural credit lines, although they are higher than those under the PRONAF, reflecting the economic profile of

the target audience.

Payment terms and credit limits vary depending on the purpose (costs or investment) and are updated annually by the Safra Plan. The program is implemented through public and private banks authorized to provide rural credit, such as Banco do Brasil, credit cooperatives, and other accredited financial institutions.

PRONAMP plays a strategic role in Brazilian agricultural policy by supporting the transition from family farming to larger-scale commercial production, thereby contributing to increased agricultural productivity, income generation, and regional development. Table 6 presents the PRONAMP financing conditions in more detail. It is important to note that financing conditions and criteria may vary according to the financial institution offering the credit line.

Table 6 - Conditions of PRONAMP credit line

Interest rate	10% p.a.
Maximum financing amount	Up to R\$ 600 k (for PRONAMP investments in individual businesses)
Maximum financing period	Up to 8 years
Maximum grace period	Up to 2 years

Source: Elaborated by authors (2026)

4.3.2.3 Program to Promote Technological Innovation in Agricultural and Livestock Production (INOVAGRO)

INOVAGRO is a rural credit program designed to finance investments in technologies that promote productivity gains, efficiency, and sustainability on rural properties. The program is part of the federal government's rural credit policy and operates under the Safra Plan, with terms set annually by the National Monetary Council (CMN) [165].

INOVAGRO provides funding for the adoption of innovative technologies, such as precision agriculture, automation and digitization of production processes, management software, climate monitoring systems, traceability, efficient irrigation, and renewable energy, as well as equipment and infrastructure that enhance the competitiveness of agricultural production. Improvements aimed at animal welfare, biosecurity, and reducing environmental impacts may also be supported.

This program is available to rural producers, whether individuals or legal entities, who meet the eligibility criteria established for rural credit. The resources are managed by authorized financial institutions, such as public and private banks and credit cooperatives. In general, this is a line aimed at producers who seek to modernize their production systems and incorporate technological solutions to increase efficiency, reduce costs, and improve the sustainability of rural activities.

INOVAGRO is, therefore, a strategic tool for driving digital and technological transformation in the Brazilian agricultural and livestock sector, contributing to greater competitiveness and innovation in the field. Table 7 presents in more detail the INOVAGRO financing conditions. It is important to note that financing conditions and criteria may vary according to the financial institution offering the credit line.

Table 7 - INOVAGRO financing conditions

Interest rate	12.5% p.a.
Maximum financing amount	Individual enterprise - R\$ 4 million
Collective enterprise - R\$ 12 million, within individual limits	Até 10 anos
Maximum financing period	Up to 10 years
Maximum grace period	Up to 2 years

Source: Elaborated by authors (2026)

4.3.2.4 Financing Program for Irrigated Agriculture and Protected Cropping (PROIRRIGA)

PROIRRIGA is a rural credit line designed to support investments in irrigation, water infrastructure, and efficient water management on rural properties. The program is part of the federal government's rural credit policy and operates under the Safra Plan, with terms set annually by the National Monetary Council (CMN) [166].

PROIRRIGA's main objective is to increase agricultural productivity, reduce climate-related risks, and promote the rational use of water resources, thereby contributing to greater production security and environmental sustainability. Eligible items for financing include the implementation, expansion, or modernization of irrigation systems (such as center-pivot, drip, and sprinkler systems), the acquisition of pumping equipment, the construction of reservoirs, dams,

and water collection and storage structures, as well as power generation systems associated with irrigation.

This line is available to rural producers, whether individuals or legal entities, who meet the criteria established for rural credit. The resources are managed by authorized financial institutions, such as public and private banks and credit cooperatives. In general, the payment terms are consistent with the return on investment and may include grace periods appropriate to the time required to implement and begin operating the irrigation systems.

PROIRRIGA plays a strategic role in the expansion of irrigated agriculture in Brazil, contributing to greater production stability, water use efficiency, and adaptation to climate change. Table 8 presents the financing conditions of PROIRRIGA. Financing conditions and criteria may vary according to the financial institution offering the credit line.

Table 8 - PROIRRIGA financing conditions

Interest rate	12.5% p.a.
Maximum financing amount	Individual enterprise - R\$ 3.5 million Collective enterprises - R\$ 10.5 million, respecting the individual limit
Maximum financing period	Up to 8 years
Maximum grace period	Up to 2 years

Source: Elaborated by authors (2026)

4.3.2.5 Programme of Cooperative Development for Adding Value to Agricultural and Livestock Production (PRODECOOP)

PRODECOOP is a rural credit line designed for agricultural and livestock cooperatives, with the goal of enhancing competitiveness, modernizing production structures, and adding value to cooperates' production. The program is part of the federal government's rural credit policy and operates under the Safra Plan, with terms established annually by the National Monetary Council (CMN) [167].

PRODECOOP provides financing for investments in infrastructure for the storage, processing, and processing of the agricultural and livestock production; the acquisition of machinery and equipment; and the modernization of

industrial facilities, logistics, management systems, and sanitary and environmental upgrades. Projects focused on energy efficiency, sustainability, and technological innovation in cooperatives may also be supported. Among the objectives is the implementation of systems for power generation and cogeneration.

Individual and central agricultural and livestock cooperatives may access this line, provided they are in good standing and meet the requirements established by rural credit regulations. The financing is managed by authorized financial institutions, such as public and private banks and credit cooperatives.

PRODECOOP is a strategic tool for strengthening the Brazilian agricultural and livestock cooperative sector by

promoting greater productive organization, added value, and expansion of access to domestic and international markets. Table 9 presents the financing conditions of PRODECOOP.

Financing conditions and criteria may vary according to the financial institution offering the credit line.

Table 9 - PRODECOOP financing conditions

Interest rate	13.5% p.a.
Maximum financing amount	Up to R\$ 150 million per cooperative, with more than one financing permitted per agricultural year, subject to the program's limits and conditions
Maximum financing period	Up to 10 years
Maximum grace period	Up to 2 years

Source: Elaborated by authors (2026)

4.3.2.6 Constitutional Financing Funds (FNE, FNO and FCO)

The Constitutional Financing Funds are public credit policy instruments created by the 1988 Federal Constitution (art. 159, I, "c") to promote the economic and social development of the North, Northeast and Central-West regions of Brazil. These funds are composed of a percentage of the revenue from the Income Tax (IR) and the Tax on Industrialized Products (IPI) and constitute one of the main sources of long-term financing for productive activities in these regions [168].

The strategic management of the Funds is coordinated by the Ministry of Integration and Regional Development (MIDR), while the financial operations are carried out by specific federal banking institutions:

The Northeast Constitutional Fund (FNE) is administered by the Banco do Nordeste do Brasil (BNB);

- The Northern Constitutional Financing Fund (FNO) is administered by Banco da Amazônia (BASA);
- The Constitutional Financing Fund of the Central-West (FCO) is administered by Banco do Brasil (BB).
- Every year, each Fund operates based on an Annual Financing Plan (PAF), which sets sectoral priorities, credit limits, and financial conditions in line with regional development and sustainability guidelines.

The resources can be used to finance productive projects by individuals and legal entities, covering sectors such as agriculture and livestock, agribusiness, manufacturing, commerce, services, tourism, infrastructure, and energy. The financing terms include differentiated interest rates, extended payment terms, and grace periods consistent with the investment cycle, and may vary depending on the beneficiary's size, the enterprise's location, and its eligibility for priority programs.

In recent years, the Constitutional Funds have incorporated guidelines focused on environmental sustainability, technological innovation, and the energy transition,

including specific lines or preferential terms for projects related to renewable energy, energy efficiency, efficient irrigation, and low-carbon agriculture. In addition, it is common to offer payment compliance bonuses, with a reduction in the effective interest rate for payments on or before due date.

For rural producers, especially those interested in installing PV systems in rural areas, the Constitutional Funds represent a strategic financing alternative, combining long-term credit with terms tailored to regional and productive realities.

4.3.2.6.1 FNE SOL – Banco do Nordeste

FNE SOL is a credit line offered by the Northeast Constitutional Fund (FNE), administered by Banco do Nordeste do Brasil (BNB), designed to finance distributed micro and mini-generation power projects using renewable sources. The line aims to encourage on-site power generation, reduce operating costs, and promote environmental sustainability in the region covered by SUDENE (the Northeast, northern Minas Gerais, and northern Espírito Santo) [169]. The program provides funding for the implementation of PV generation, small-scale wind, biomass, biogas, and small hydroelectric power systems, including equipment, inverters, mounting structures, batteries, hybrid systems (on-grid and off-grid), and installation services. Rural producers, individuals, companies, and cooperatives located within the Fund's coverage area are eligible to apply.

Financing terms, such as interest rates, payment terms, and grace periods, are set annually in the FNE Plan and vary depending on the beneficiary's size and the project's eligibility. In general, the line offers long-term payment terms and the possibility of payment compliance bonuses, and is considered strategic for supporting the energy transition and sustainable development in the Northeast region. Table 10 presents the FNE SOL financing conditions available from BNB for rural producers

Table 10 - FNE SOL financing conditions for rural producers

Interest rate	Rural sector: pursuant to National Monetary Council (CMN) Resolution No. 5,235/2025. Other sectors: pursuant to National Monetary Council (CMN) Resolution No. 5,013/2022.
Maximum financing amount	R\$ 100 k (approx. US\$ 20 k)
Maximum financing period	12 years (companies and rural producers) 8 years (individuals) 2 years (Micro and Mini DG System Leasing Projects) An additional period of 2 years (Companies controlled by women or in which women hold more than 40% of the share capital)
Maximum grace period	3 years (companies and rural producers) 6 months (individuals) 1 year (Micro and Mini DG System Leasing Projects) An additional period of 1 year (Companies controlled by women or in which women hold more than 40% of the share capital)

Source: [169]

4.3.2.6.2 FNO Rural Energia Verde – Banco da Amazônia

FNO Energia Verde is a credit line offered by the Northern Constitutional Financing Fund (FNO), administered by Banco da Amazônia (BASA), designed to finance power generation and use projects using renewable sources in the North region of Brazil.

The line aims to promote sustainable development and enhance energy security in the Legal Amazon by encouraging investments that reduce operating costs, increase production efficiency, and contribute to the energy transition. Financing is available for PV energy systems (on-grid, off-grid, and hybrid), biomass, biogas, small hydroelectric plants, and small-scale wind power systems, including equipment, structures, associated civil works, and installation services [170]. Financing is available to rural producers, businesses, cooperatives, and individuals located

within the FNO's coverage area. The line aims to promote sustainable development and enhance energy security in the Legal Amazon by encouraging investments that reduce operating costs, increase production efficiency, and contribute to the energy transition.

FNO Energia Verde is an important tool for enabling self-generated energy in rural and urban areas of the North region, contributing to regional development with a focus on the environment and technology. In addition to investments in renewable energies, this line also supports enterprises with the adoption of electric, hybrid or renewable energy vehicles, including the electric supply structure; ecological works; projects that support biodiversity and activities within the scope of Low Carbon Agriculture. Table 11 outlines the financing conditions for renewable energy systems from FNO Rural Energia Verde.

Table 11 - FNO Rural Verde financing conditions for renewable energy projects

Interest rate	Varies according to the size and purpose of the credit
Maximum financing amount	Varies according to the beneficiary's payment capacity
Maximum financing period	12 years
Maximum grace period	6 years

Source: [170]

4.3.2.6.3 FCO Rural – Banco do Brasil

The FCO has lower interest rates than those of the market, longer payment term and longer grace period than most financing lines, and R\$ 100 million is the maximum amount financed by the Fund. The beneficiaries of the FCO are rural producers or entrepreneurs (from micro to large) who develop their activities in the states of Mato Grosso, Mato Grosso do Sul, Goiás or the Federal District [171].

One of the available FCO lines for rural producers at Banco do Brasil is the FCO Rural line, which is available to production cooperatives, rural producers, individuals or legal entities and associations located in the Central- West region. FCO Rural aims to serve the agricultural and agro-industrial production sector. Table 12 presents the financing conditions of the FCO Rural offered by Banco do Brasil.

Table 12 - FCO Rural financing conditions for renewable energy projects

Interest rate	7.65% p.a. – 10% p.a., depending on the beneficiary's profile
Maximum financing amount	R\$ 20 million, or R\$ 100 million in exceptional cases
Maximum financing period	Up to 20 years
Maximum grace period	Up to 12 years

Source: [171]

4.3.2.7 BNDES Finame Low Carbon

BNDES Finame Low Carbon is a credit line offered by the National Bank for Economic and Social Development (BNDES) designed to finance equipment, machinery, and systems that contribute to reducing greenhouse gas emissions, energy efficiency, and transition to a low-carbon economy. This line supports the acquisition of solutions that improve the environmental and energy performance of projects in various sectors of the economy [172]. Companies headquartered in Brazil, rural producers (individuals and legal entities), cooperatives, sole proprietors, independent carriers, and public institutions are eligible for this financing. The line includes the following items eligible for financing:

- PV power generation systems;
- Wind turbines (wind energy);
- Solar collectors and heaters;

- Machinery and equipment for energy storage (batteries, hydrogen);
- Energy-efficient equipment and technologies, such as high-efficiency electric motors, inverter-based refrigeration systems, heat pumps, and heat exchangers;
- Biomass converters that produce energy or high-value-added products; and installation services related to the equipment.

To be eligible, the goods must be new, manufactured in Brazil, and listed in the BNDES Finame Register of Manufacturers and Items (CFI). The acquisition may include both industrial equipment and solutions for the rural sector, including technologies for renewable power generation and energy efficiency on farms. Table 13 presents the financing conditions of this line.

Table 13 - BNDES FINAME Low Carbon financing conditions

Interest rate	TFB interest rate, TFB interest rate, TLP interest rate, LCD rate, Pre-FAT rate, or Pre-FAT rate for MPME + BNDES rate (0.75% p.a.) + Financial Agent Rate (negotiated with the institution) ⁶
Maximum financing amount	Varies according to the project and the company's financial capacity.
Maximum financing period	Up to 10 years
Maximum grace period	Up to 2 years (For TFB financing, the grace period is up to 1 year)

Source: [172]

4.3.2.8 Mechanisms to encourage innovation and sustainability

In addition to traditional credit lines, financing for agrivoltaic systems in Brazil can benefit from specific mechanisms designed to technological innovation. Below are some mechanisms for promoting innovation that are suitable for agrivoltaic projects:

- **Inovacred (FINEP):** The Brazilian Funding Authority for Studies and Projects (FINEP), through the Inovacred program, offers specific lines for innovation financing.
- **Target Audience:** The program is intended for private-sector companies and legal entities, ranging from micro-

Finep Inovacred aims at increasing competitiveness of Brazilian companies by supporting the development of new products, processes, and services, or the significant improvement of those already in place. The program operates through decentralized repayable financing, using resources from the National Fund for Scientific and Technological Development (FNDCT) disbursed by accredited financial agents [173].

6 The rates of the FINAME Low Carbon line are calculated by indirect operations and are composed of the Financial Cost, BNDES Fee and Financial Agent Fee [Understand how this is calculated](#).

sized and small businesses with annual gross operating revenue of up to R\$ 4.8 million to Level II Medium-Sized Companies (with revenue of approximately R\$ 300 million).

- **Eligible Items and Restrictions:** The funding is comprehensive, covering expenses related to in-house staff, training, software, raw materials, third-party services, and travel. However, there are specific limitations to physical infrastructure:
 - The purchase of equipment (domestic and imported) is limited to 70% of the financed amount.
 - Civil works and installations are limited to 30%.
 - The sum of these two categories (equipment + civil works) may not exceed 80% of the project's total value, thereby encouraging the remainder of the resources to be focused on intellectual effort and innovation development.
- **Credit Cooperatives:** Credit cooperatives typically offer lines linked to public rural credit policies (such as PRONAF, Pronamp, or resources from the Safra Plan) through partnerships with public banks or using their own resources, with special terms for members. They can finance agricultural expenses, the acquisition of machinery, investments in infrastructure, productivity, technologies, and the adoption of sustainable practices [174]. Institutions such as Cresol, Sicoob, and Sicredi play a vital role in expanding credit availability, broadening access for small- and medium-sized producers who are often overlooked by large banks.
- **Lei do Bem:** For companies that operate under the Real Profit regime and invest in Research and Development (R&D), the Lei do Bem may represent a significant tax incentive for agrivoltaics. The following is allowed with this mechanism: A deduction of 60% to 100% of R&D expenses from the tax base for Corporate Income Tax (IRPJ) and Social Contribution on Net Income (CSLL).

- A deduction of 60% to 100% of R&D expenses from the tax base for Corporate Income Tax (IRPJ) and Social Contribution on Net Income (CSLL).
- The possibility of recovering up to 27% of the tax owed.
- The generation of “tax cashback” that frees up cash flow for companies, allowing them to reinvest in new areas of technological innovation in the agro-energy sector.

4.4 Benefits and drawbacks of agrivoltaic systems within the Brazilian context

This section comprises an analysis of the strengths, weaknesses, opportunities, and threats regarding the agrivoltaic technology in the Brazilian context, as well as the technical, economic and social benefits of agrivoltaic applications, considering the different regions and analysis of the previous topics. Also, it includes the potential drawbacks and challenges to the implementation of agrivoltaic systems in these regions.

4.4.1 SWOT analysis

The main aspects of agrivoltaic technology in the Brazilian context were organized in a SWOT matrix. This SWOT analysis is available in Table 14, and offers a comprehensive view of the prospects for agrivoltaic technology in Brazil, including the identified strengths, weaknesses, opportunities, and threats.

Table 14 - SWOT analysis of the agrivoltaic technology in Brazil

	STRENGTHS +	WEAKNESSES -
INTERNAL FACTORS	+ Solar energy sector well established and growing rapidly. Agricultural sector drives the economy of the country. + Abundance of natural resources (irradiance and agricultural land). + Agricultural diversity. + Existing funding opportunities for solar energy. + International collaboration. + Environmental and climate change awareness increase. + Existence of internationally recognized research centers and universities in solar energy and agriculture research. + Existence of R&D programs. + Demand for renewable energy applications in rural areas.	- Technology still unknown in the country. - High CAPEX. - Few projects in the country and worldwide. - Lack of components and structures specifically designed for agrivoltaic systems. - Lack of technical knowledge on the integration between local crops and agrivoltaic systems. - Lack of professionals specialized in agrivoltaic systems. - Lack of data on agrivoltaics crop and animal production.
	OPPORTUNITIES +	THREATS -
EXTERNAL FACTORS	+ Creation of funding opportunities specific for agrivoltaics. + Technology development. + Increased environmental awareness and financing opportunities for climate adaptation solutions. + Promotion of food and energy security (especially on semi-arid regions). + Creation of new business models and qualified jobs. + Possibilities in distributed generation. + Cooperation between organizations and sectors. + Potential to increase family agriculture resilience and income diversification. + Potential tool for addressing the water-food-energy nexus challenges. + Existing agricultural cooperatives or associations model adopts the shared solar energy model and generates energy credits to its associates/cooperates.	- Competition for land between sectors. - Lack of national guidelines and regulation. - Low educational level of family farming population. - Low power of investment of the small rural establishments.

Source: Elaborated by authors (2026)

4.4.2 Benefits

As mentioned in sub-chapter 2.2, the two basic categories of agrivoltaic systems, according to [14], are elevated systems with crop production below the PV module, and lower systems with crops grown between rows of PV modules. As mentioned in sub-chapter 2.2, the authors also define the two basic categories of agrivoltaic systems, according to [14], are elevated systems with crop production below the PV

module, and lower systems with crops grown between rows of PV modules. The authors also define the main application categories as Crop and food production, Livestock production, Provision of ecosystem services and Greenhouses. Among these various applications, the technical configurations of agrivoltaic systems also vary, and their benefits can range from providing shading, protection against frost or extreme heat to reducing evaporation rates. Also, the authors

identified 5 relevant success aspects for agrivoltaic projects: Climate, Configuration, Crops and Cultivation, Compatibility, and Collaboration (see sub-chapter 3.7).

The wide range of possible agrivoltaic configurations might be a good aspect of the technology for Brazil, considering the vast diversity of agricultural establishment scales and climate characteristics. The North and the Matopiba region, for example, could benefit from the dual-use aspect of the technology. In the context of high deforestation rates for creation of new pasture and agricultural lands, the dual-use might be a tool to create additional income for local families, avoiding the removal of native forest vegetation for the creation of new agricultural fields. Also, the income increase for small scale farmers of the region could make it possible for these farmers to have a better profitability per area and to have resources to transition to more sustainable agricultural practices.

In the Central-West region, the higher structures configurations adapted to large machinery could be suitable for the large-scale agriculture in that region, and the benefit of reducing evaporation and the need for irrigation would benefit many of the local crops, such as soybeans and corn plantations. The Southeast region leads with the highest percentage of irrigated areas, accounting for 39.8%, followed by the South with 25% [175]. Agrivoltaic systems can optimize existing irrigation systems where available and, also offer benefits in regions where such systems are not present, making them economically feasible. This irrigation optimization aspect is also relevant considering the Northeast region conditions, which is considered semi-arid and suffers from water scarcity and high irradiation levels, as mentioned in sub-chapter 4.2.1.4. Additionally, as this region is also marked by high rates of rural poverty, these systems can offer relevant social and economic benefits.

In general, agrivoltaic systems present social and economic opportunities for farmers in various regions of the country, offering greater autonomy in power generation for self-consumption and the potential to create an income aggregation to farmers through leasing or to create energy credits through the distributed generation system. As an inspiration, a national funded program for agrivoltaics in small-scale farmer context, such as the ones in Japan and South Korea, could create dual-revenue streams and increase the quality of life of these populations.

4.4.3 Challenges

In Brazil, agrivoltaic systems are not yet widely adopted, which may present an initial barrier for implementing these projects as installers may not have access to appropriate project models, adapted modules (such as those with larger spacing between the PV cells), and adapted structures (e.g., taller structures or fewer support pillars) for agrivoltaic systems. In addition, the lack of professionals with technical experience in agrivoltaic projects and integration between

these systems and the crops may hinder or prevent the implementation of the technology at this stage. Also, agrivoltaic system have higher CAPEX compared to regular PV installations, which can represent a relevant challenge, especially for family farming establishments, which have, in most cases, a low power of investment.

In addition to the initial limitations concerning equipment, professionals and costs, the lack of national guidelines or regulations in Brazil might be a barrier for the development of agrivoltaic projects at first. The adoption of the technology without an adequate study of the climate context, agricultural practices compatibility and the agrivoltaic configuration may compromise the resulting productivity and impact the credibility of the technology, which has already happened in France and Japan, for example.

5. Case study context

The utilization of PV systems has emerged as an important strategy to address energy needs while optimizing land use. These systems of dual-use of land, for power generation and agriculture, agrivoltaic technology, constitute the context of this case-study. The present case-study revolves around the Association of the Organic Producers of Iranduba (APOI), situated in the Amazonas state of Brazil. Founded in 2017, APOI is dedicated to fostering small-scale family farming.

The heart of APOI's initiatives lies in the adoption of the "Comunidade que Sustenta a Agricultura" [Community Supported Agriculture] (CSA) business model—a pioneering venture in sustainable agriculture. Besides the regular household energy consumption of the APOI members, the association plans to build an industrial kitchen, with support of the Amazon Fund.³⁰ The industrial kitchen would increase considerably energy expenditures of the association.

In this context, the main objective of this Case Study is to develop a technical & economic feasibility study of an agrivoltaic project, with two specific configurations. The results aim to support the APOI association in future PV projects, and to serve as an inspiration to other agrivoltaic projects in the Brazilian context.

This initial section provides an explanation of the definition process and offer contextualization of the Case Study site. Additionally, a comprehensive characterization of the chosen site will be included in this section.

5.1 Association of the Organic Producers of Iranduba (APOI)

The chosen initiative for the case-study – Associação dos Produtores Orgânicos de Iranduba (APOI) – is led by President Neiliane Paz, and was funded in 2017.

APOI Association is located in the municipality of Iranduba (Figure 53) in the state of Amazonas. The families involved in this case-study reside in the areas of Ramal do Peixe Boi and Ramal do Pupunhal. The organic small-scale family producers who participate in the association were displaced from the banks of the Solimões River due to the phenomenon of landslides, where water erosion causes the riverbanks to collapse, affecting the land they used to cultivate food as their source of income. The main crops produced by the families are vegetables, cabbage, arugula, lettuce, chives, gerimum, coriander, parsley, banana, lime and cupuaçu (Figure 54 and Figure 55). Their farming practices include organic and agroforestry strategies.

Figure 53 - Location of the case-study - APOI Association



Source: Elaborated by authors (2024)

Figure 54 – Crops production from APOI's families

Source: [142]

Figure 55 – Woman farmer from the APOI Association

Source: [142]

Regarding their energy consumption, currently, the main energy expenses for the producer families are for air conditioning systems for their homes, for water pumping from wells, and water pumping for irrigation. There is currently a project to build an industrial kitchen to support the local farmers. The goal of the industrial kitchen is to allow the farmers to better clean, explore processing alternatives and storage their products. It will enable activities such as vacuum-packing cassava and vegetables, processing (minimally) vegetables, and making fruit pulp. The kitchen is planned to be built with resources from Amazon Fund and was is expected to start operating between the second

semester of 2024 and 2025. This project would increase the energy bill of the association and the agrivoltaic project can assist with this energy bill. The families' energy bills ranged from R\$ 200 to R\$ 450/month (equivalent to 300–600 kWh/month), but this would increase with the operation costs of the industrial kitchen.

When it comes to the climate conditions of the region, Iranduba is in the heart of the Amazon Forest, which means it is under an equatorial climate characterized by high temperatures with minimal variations year-round. Daytime temperatures range from 25 °C to 32 °C, with nights remaining relatively warm. The region experiences heavy, consistent rainfall, and is marked by two main seasons: a wet and a dry one.

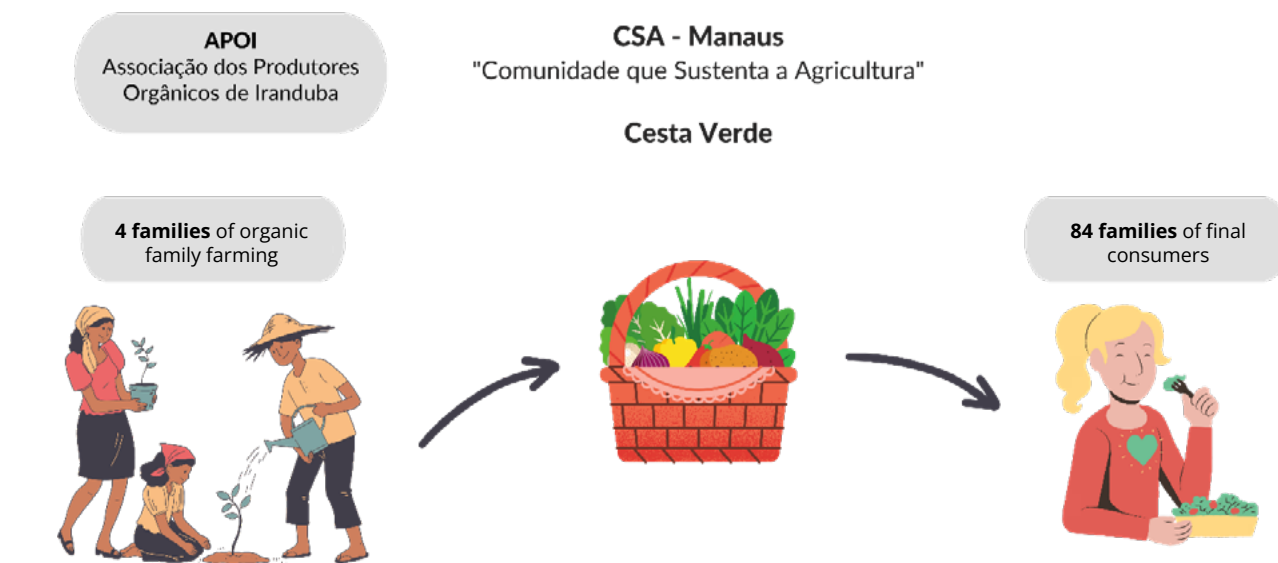
The wettest period spans from December to May and the drier season from June to November, though rainfall persists even during the drier period.

5.2 Initiatives CSA Manaus and Green Basket (Cesta Verde)

APOI has a goal of bringing sustainable agriculture to community-driven farming, and it makes use of a business model known as “Comunidade que Sustenta a Agricultura” or “Community Supported Agriculture” (CSA). CSA model is a partnership between farmers and consumers in which the responsibilities, risks and rewards of farming are shared. It has emerged as a successful model and it thrives on collaboration, uniting organic and agroecological food producers with conscientious consumers in a shared commitment to support local agriculture.

For a successful CSA model, a fixed group of consumers commits to covering the annual budget of the agricultural entity for a period, typically a year. In return, these consumers receive the farm's produce through monthly “food baskets” without any additional costs. This approach allows the farmer to dedicate themselves freely to cultivation without the pressures of the market and pricing. This model has been active in Brazil since 2011, and it is present in almost all of the country states [176].

While the study was under development, 12 families of agricultural producers were associated with APOI, which forwards their production through CSA model (CSA Manaus Initiative), and another initiative called “Cesta Verde” (Green Basket). This last one consists of the same model of “food baskets”. Besides supporting the producers, APOI also aims to provide healthier food to consumers by incentivizing the associates to adopt agroecological production techniques. Four of the 12 families produce organics and supply 84 consumer families, which receive the monthly production and support the business model financially (Figure 56). These four families are the ones considered in this case-study.

Figure 56 – APOI operational model

Source: Elaborated by authors (2024)

5.3 Agrivoltaic system design

The main objective of this case study was to evaluate the technical and economical viability of an agrivoltaic energy project to attend to the specific needs of small-scale farmers. Thus, the design of the systems was proposed to align with the economic realities of these farmers, as well as their resource availability. In order to define the agrivoltaic system designs, a few steps were followed:

- Information regarding the future plans of the association was gathered, as well as number of associates and the way the association business model functions;
- The location of the farms and existing infrastructure was investigated;
- The climate conditions and irradiation data was obtained in data bases;
- The needed PV systems size was estimated;
- Definition of the PV system components and project aspects;

- Simulations on PVSyst showed energy output;
- Simulations on Google Sketchup showed shading impacts.

Across the study, two systems were proposed: an elevated agrivoltaic system and a greenhouse/shadehouse agrivoltaic system. The latter is a structure similar to a greenhouse, but it is open in the sides and it has the objective of protecting the crops from heavy rain. As mentioned, the shade that affects the crops was simulated, in order to avoid intense shading in the agricultural production and find the best system design. Some of the aspects of the systems proposed and their components are available in the following topics.

PV module technology:

For the greenhouse/shadehouse and elevated agrivoltaic, bifacial PV modules were chosen. The simulation was done using PV modules that are available in PV Syst software (Table 15), which are from a manufacturer known to be reliable according to ratings such as the PVEL and PV-tech. The modules were also chosen because they are widely used in the country on a commercial scale.

Table 15 – PV module characteristics

System	Module Material	Bifacial	Power	Dimensions
Ground System	Mono PERC, Double Glass	Yes	440 Wp	2117mm x 1052mm
Greenhouse/Shadehouse	Mono PERC, Double Glass	Yes	440 Wp	2117mm x 1052mm

Source: Elaborated by authors (2024)

PV module tilt, angle and orientation

For the positioning of the systems, it was taken into consideration the geographical position of the sites and existing structures and agricultural production. The main objective is to minimize any impact that the agrivoltaic

system proposed might cause on the existing agricultural production. Results are available in Table 16.

Throughout the shading analysis, it was possible to observe that the best orientation for both systems, in this aspect, would be facing west (azimuth 90°), because in

this orientation the shading on the crops would be better distributed if the crops were positioned differently, but it was opted to maintain the original orientation, facing north (azimuth 0°), since the crops are already established and one of the premises used in this project was to make the least

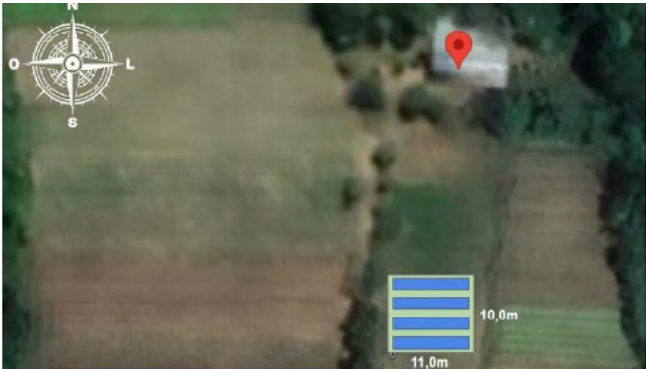
Table 16 – System characteristics

System	Coordinates	Module Tilt	Azimuth
Elevated agrivoltaic system	-3.2528 S, -60.1365 W	10°	0° North
Greenhouse/ Shadehouse	-3.2528 S, -60.1365 W	10°	0° North

Source: Elaborated by authors (2024)

The proposed locations for the systems would be the elevated agrivoltaic system installed on Doquinha’s farm, as in Figure 57.

Figure 57 – Elevated agrivoltaic location



Source: Elaborated by authors (2024)

And the green house system installed at Dona Walda’s household, as shown in Figure 58, where there are other green houses already installed.

Figure 58 – Agrivoltaic greenhouse/shadehouse location



Source: Elaborated by authors (2024)

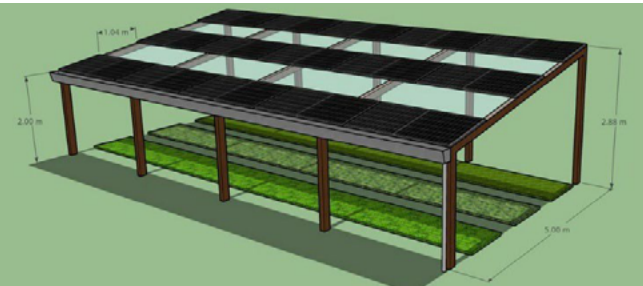
Mounting structure design:

For the agrivoltaic greenhouse/shadehouse and elevated agrivoltaic system, the aim was to create a system that could be replicated and to use materials that are already used by the families, such as wood for the physical structure and plastic film in the greenhouse for the areas without modules. Instead of plastic, glass panels could also be applied to the greenhouse.

possible interference in the existing agricultural production. A simulation with the system facing west showed that, with this orientation, the energy production decrease would be small compared to the north and ideal orientation – 0.78% for the elevated system and 0.76% for the greenhouse.

The agrivoltaic greenhouse/shadehouse system is approximately five by eleven meters with fifteen modules as seen in Figure 59.

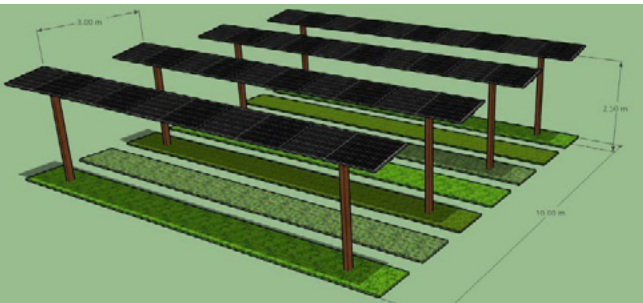
Figure 59 – Agrivoltaic greenhouse/shadehouse



Source: Elaborated by authors (2024)

A water capture system was designed for the possibility of adding a water reservoir to irrigate the plantations. This application would work better with glass panels instead of plastic film in the transparent sections. The elevated agrivoltaic system occupies an area of approximately eleven by ten meters with twenty modules divided in four roles of five modules, as shown in Figure 60.

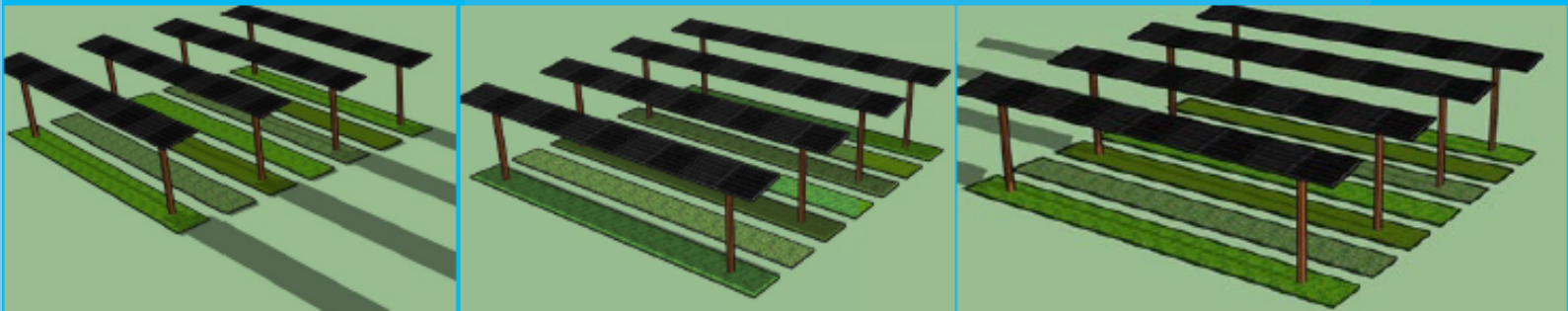
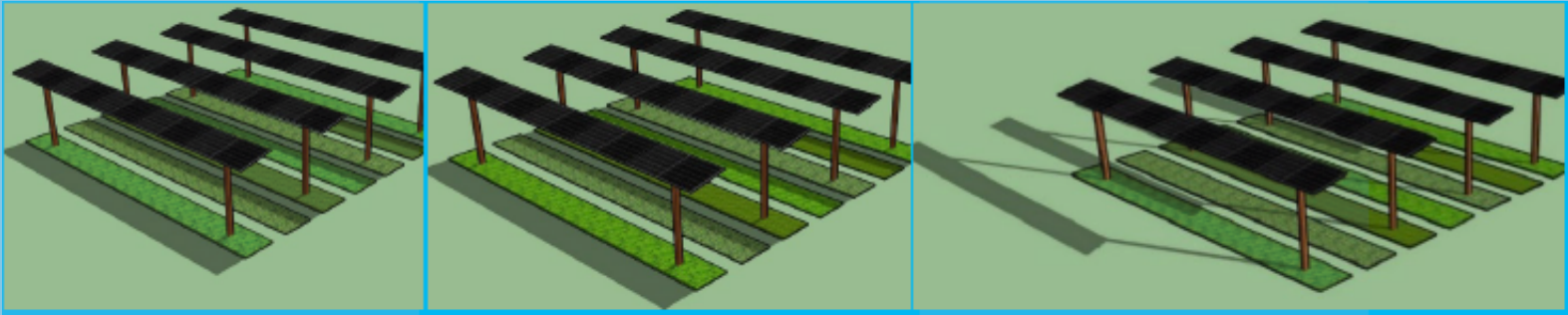
Figure 60 – Elevated Agrivoltaic System Design

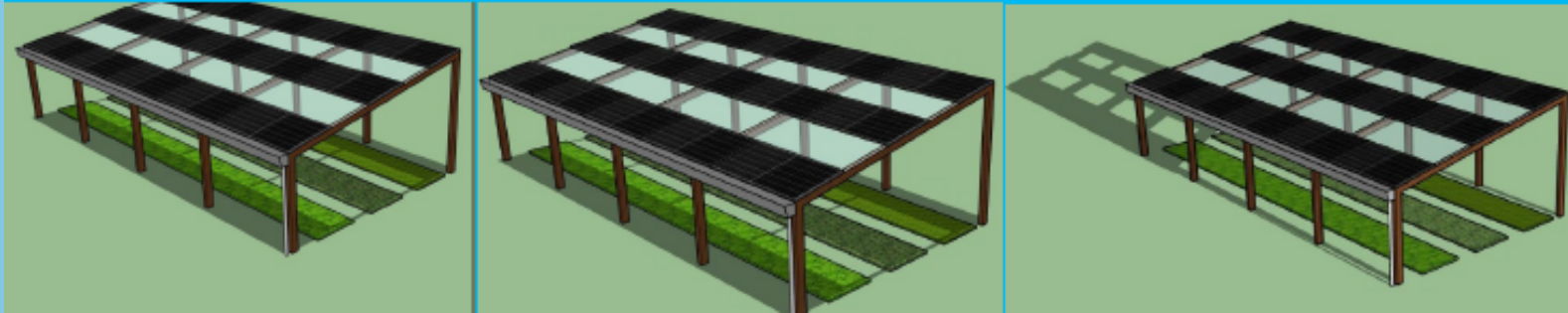
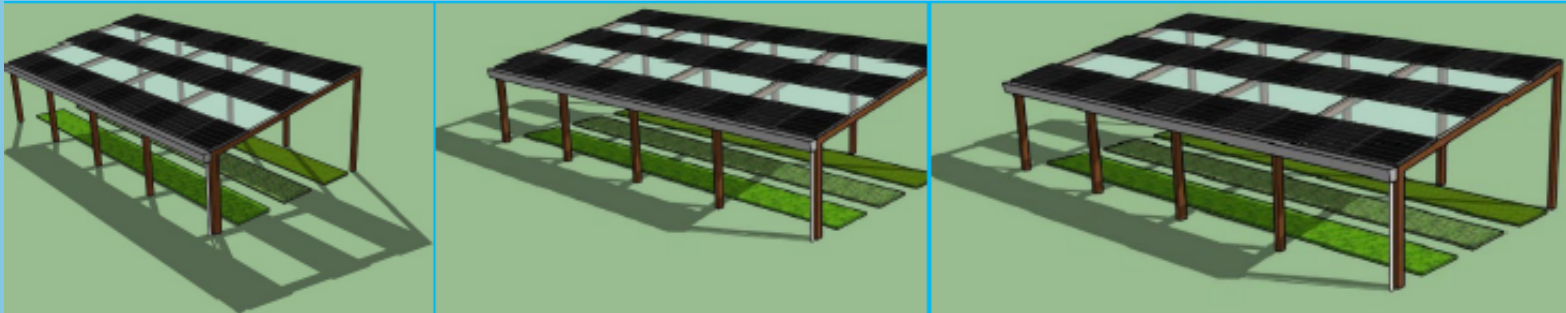


Source: Elaborated by authors (2024)

Another factor considered when designing the agrivoltaic systems was the amount of shade in the crops during the day. A shading analysis was made using SketchUp for the days September 22nd and December 22nd, dates close to the seasons of the highest and lowest temperatures, respectively, which are also the dates for the equinox and solstice (Table 17).

Table 17 – Shading analysis

System	Date	Shading
Ground System	22/09	Shading on the area beneath the module row starts at 6:50am and ends by 5:00pm. The shade is above of the plantation, below the respective row throughout midday. The plantations between rows are not shaded during this day. 
	22/12	Shading varies throughout the plantation during the morning and stabilizes between plantations around 12:00am. Then, it begins to vary along the plantation again. 

Green House	22/09	Shading starts at 6:30am centered on the plantations, around 12:00am it covers the middle plantation completely and the adjacent ones partially. Shading stops around 5:00pm.	
	22/12	Shading covers most of the two plantations beneath the lower part of the roof around 8:30am, then shifts to the space between the plantations during midday, goes back to covering the two initial parts around 3:30pm.	

Source: Elaborated by authors (2024)

Analyzing the shading pattern, we can conclude that during the hottest season, in September, the shade covers the plantations beneath the modules, while during December, when the temperatures have cooled down, the shade covers between plantations. Although there can be a more equalized shading pattern with the system facing west, it was opted to follow the existing plantation pattern.

- **Expected energy output:** The expected energy output of the two mentioned systems was calculated and is available in Table 17.

Table 18 – Expected energy output

System	PV Power	Yearly Energy Output
Ground System	8.8 kWp	12.3 MWh/year
Green House	6.6 kWp	8.9 MWh/year

Source: Elaborated by authors (2024)

- **Expected yield:** The daily yield expected by the simulations follows Table 18:

Table 19 – Simulated Daily Yield

System	Yield.
Elevated agrivoltaic system	3.8 kWh/kWp/day
Greenhouse/shadehouse	3.7 kWh/kWp/day

Source: Elaborated by authors (2024)

It is recommended that all plantation areas receive a minimum of 6 hours of direct sunlight throughout the day, ideally around 8h. Another suggestion is that leafy vegetables and tomatoes, which are more prone to dehydration, can be planted in areas with shade around noon.

5.4 Economic analysis

One of the main challenges of agrivoltaic technology in the Brazilian context, specially in the family agriculture cases,

is the cost of the system. Thus, this study comprises an economic analysis of the proposed agrivoltaic project. In order to develop the economic analysis, some methodology steps were followed:

- (1) Gathering current electricity bills of 4 producer families involved in the project;
- (2) Estimating the future electrical consumption of the industrial kitchen;
- (3) Calculating the power capacity and energy output of the proposed pilot agrivoltaic systems aiming to attend the energy consumption from the 4 families + the industrial kitchen;
- (4) The CAPEX and OPEX of the proposed systems were calculated;
- (5) Comparing potential agricultural productivity loss scenarios with the electricity savings associated with the agrivoltaic systems;
- (6) The following economic indicators were calculated: NPV (Net Present Value), IRR (Internal Rate of Return), and discounted Payback period of three different subsidy scenarios:
 - 100% farmers investment
 - 80% farmers investment
 - 60% farmers investment

A period of 25 years was defined for the project in order to calculate the economic indicators for the project. The methodology steps are detailed in the topics of this chapter, as well as the main results of the economic analysis.

5.4.1 Electricity costs of the families and industrial kitchen

Electricity bills from the 4 farmer families were gathered in order to calculate the total average electricity cost for their households. These data are available in Table 19.

Table 20 – Average energy consumption of the four families

Household	Average energy consumption (kWh/month)	Average energy consumption (kWh/year)
Household 1	475.2	5702.5
Household 2	486.3	5835.0
Household 3	296.8	3561.5
Household 4	270.1	3241.0
Total	1.563,1	18,340.0

Source: Elaborated by authors (2024)

Also, the electricity consumption of the industrial kitchen was estimated, considering some of the appliances associated

with the activities and products the families produce. This estimative is available in Table 20.

Table 21 – Average energy consumption of the industrial kitchen

Appliances	Qtd	Power (W)	Daily hours of use	Average consumption (kWh/month)
Pulper	1	245	3	14.7
Freezers	2	-	-	144.2
Vacuum sealer	1	700	3	42.0
Industrial blender	1	1000	2	40.0
Electric oven	1	5000	6 per week	120.0
Total				360,90

Source: Elaborated by authors (2024)

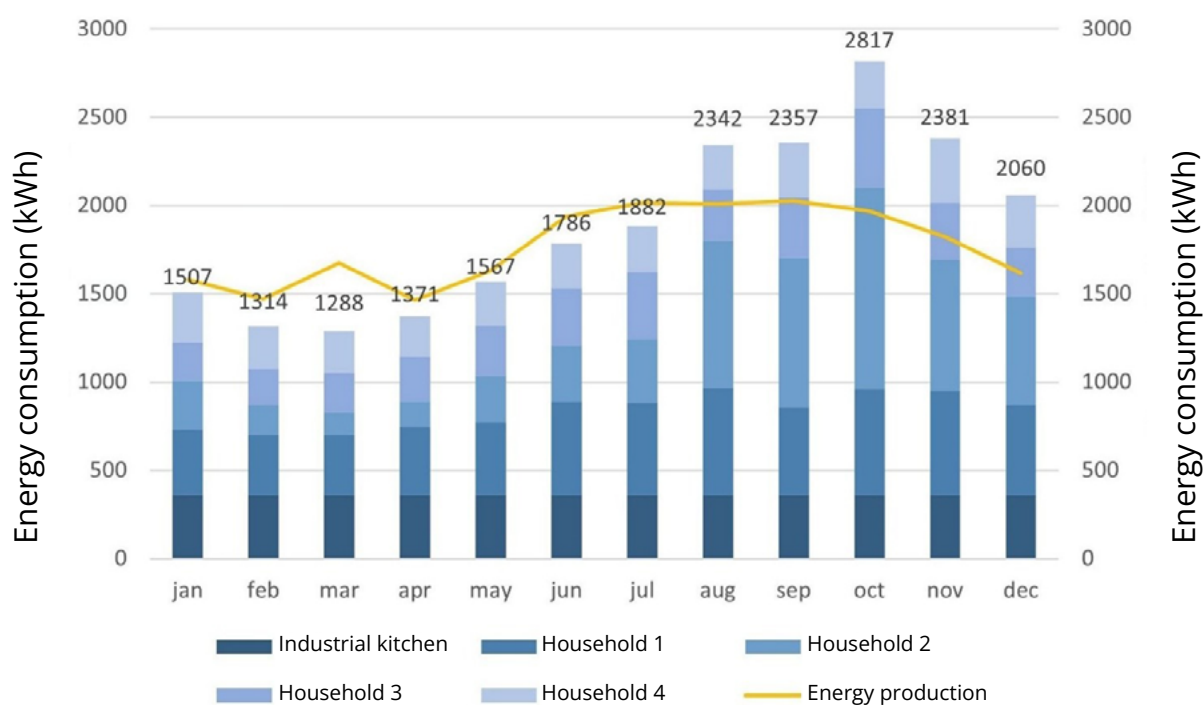
In total, the estimated average energy consumption is 1889.2 kWh/month, which results in an average annual consumption of 22.7 MWh/year.

5.4.2 Proposed agrivoltaic Systems power and energy output

Considering the agrivoltaic systems proposed in this document, and the PV modules of the brand JA Solar, the

estimated power of the project would be 15.4 kWp.

The estimated energy output of the agrivoltaic systems was calculated, resulting in average electricity production of 1767.3 kWh/month, what results in an average annual electricity production of 21.2 MWh/year. The average electricity consumption of each of the households and the industrial kitchen, as well as the estimated electricity production are represented visually in the Graph of Figure 62.

Figure 61 – Graph of Energy consumption and Energy production per month

Source: Elaborated by authors (2024)

The system size was calculated in order to supply the necessary electricity for the 4 households and the industrial kitchen, taking into account the current compensation system, i.e. net metering, regulated by Law 14,300 [79].

The compensation system establishes that there is a value that must be paid regardless of the consumption and power generation, which is called “minimum tariff”. The value of the minimum tariff varies according to the types of electricity distribution/connection: if it is single-phase, two-phase or three-phase, and the values are 30 kWh, 50 kWh

and 100 kWh, respectively.

The consumer units involved in this case study are all under single-phase connections, and the industrial kitchen will be connected to one of the consumer units, thus, this results in 120 kWh of electricity that will be charged every month (30 kWh x 4 consumer units), regardless of the PV generation associated with their electricity bills. The electricity consumption, production and the minimum tariffs are disposed in Table 21

Table 22 – Average energy consumption of the industrial kitchen

Description	Value	Unit
Average electricity consumption (per month)	1889,2	kWh
Average electricity generation (per month)	1767,3	kWh
Minimum tariff for the 4 consumer units (per month)	120	kWh
[Electricity consumption – electricity production]	122	kWh

Source: Elaborated by authors (2024)

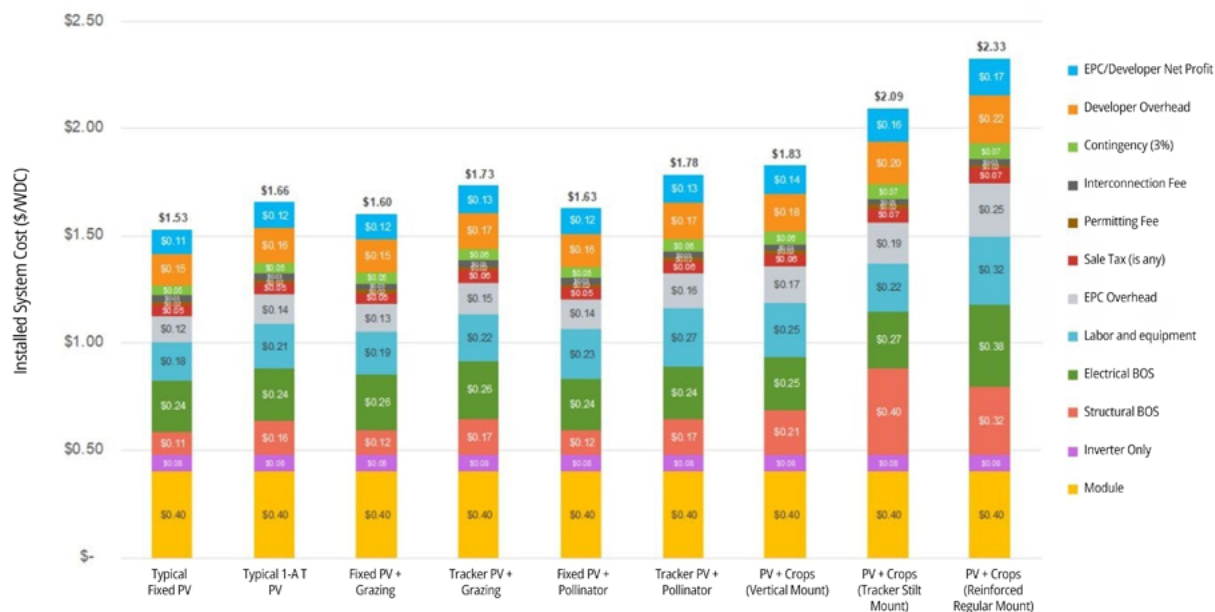
It is important to emphasize that this economic viability study was developed to verify the viability of the project in a wide perspective, and the electricity credits distribution among the households were not considered individually. If the project is to be implemented, different scenarios of proportional investment from each family and the amount of electricity credits that would go to each consumer unit would have to be further analyzed.

5.4.3 CAPEX of the proposed systems

The agrivoltaic greenhouse/shadehouse proposed in this case- study was designed to attend to their needs without

adding much complexity to the structure. Thus, the structure of the greenhouse/shadehouse is wooden, similar to the existing ones, and the PV metallic structure and PV modules considered in the design are the conventional ones. The cost data for the standard PV system in Brazil was sourced from the 2024 (the year the study was conducted) Greener study [177].

In order to estimate the CAPEX of the proposed elevated system, data from the NREL Report “Capital Costs for Dual-Use Photovoltaic Installations: 2020 Benchmark for Ground-Mounted PV Systems with Pollinator-Friendly Vegetation, Grazing, and Crops”⁷ [23] were used (Figure 63).

Figure 62 – Typical PV installed costs compared to different agrivoltaic configuration costs

Source: [23]

The percentage of additional value obtained from both the standard PV system and the alternative elevated agrivoltaic system (last column in Figure 62) was utilized to calculate the additional cost associated with the elevated agrivoltaic system when compared to a standard PV system in Brazil (Table 22).

7 <https://www.nrel.gov/docs/fy21osti/77811.pdf>

Table 23 – Estimated elevated agrivoltaic cost

Description	Value	Unit
Regular PV cost 6kWp Greener (Brazil) – Greenhouse/Shadehouse	4.15	R\$/Wp
Additional cost (normal PV system -> elevated agrivoltaic)	52.29%	
Regular PV system cost 8kWp, Greener (Brazil)	3.92	R\$/Wp
Estimated agrivoltaic system cost (Brazil)	5.97	R\$/Wp

Source: Elaborated by authors (2024)

The CAPEX for each of the proposed systems and the total CAPEX for the project is available in Table 23.

Table 24 – CAPEX of the different proposed PV system configurations

	Power (kWp)	Unit	CAPEX (R\$)	
Greenhouse/shadehouse system	6.60	kWp	R\$ 27.423,00	Total
Elevated agrivoltaic system	8.8	kWp	R\$ 52.533,12	R\$ 79.956,12

Source: Elaborated by authors (2024)

5.4.4 OPEX of the proposed systems

The operational costs considered in the project are the ones related to the maintenance of the PV systems. The maintenance cost of the PV system was considered 1% py. of the total initial investment value of the system in the first year, the same value adopted in other research studies on the economic feasibility of PV systems in Brazil [178]. Also, since the inverters usually have a shorter lifespan when compared to PV modules, the substitution of the two inverters of the proposed systems was considered in the year 10 and year 20 of the economic analysis. The cost for the inverter replacement was obtained considering data of the proportion of the inverter costs from Figure 62 [23], and the CAPEX of each system, shown in Table 23. Also, in the analysis, an inflation rate of 3.16% was considered for estimating future maintenance costs.

5.4.5 Potential agricultural productivity loss scenarios and electricity savings associated with the agrivoltaics

In many cases, especially in shade resistant crops, the presence of an agrivoltaic structure might benefit the crops and increase agricultural productivity. A study from 2016 reported that agrivoltaic farms planting shade-resistant crops could benefit from a 30 percent higher economic value than conventional farms, according to their simulations [179]. Even though the agricultural production can increase, a possible yield reduction might also occur. Regulations in France, Japan, and Germany have established the maximum permissible yield reduction levels achievable [138].

In this study, three productivity loss scenarios were considered, in order to compare an estimated income loss due to the possible productivity loss, to the energy savings

associated to the PV and agrivoltaic systems proposed. In this analysis, the CAPEX was not considered, only the operational values: productivity loss, energy savings and PV system OPEX.

In order to estimate the productivity loss in R\$, it was considered that the elevated agrivoltaic installation and Greenhouses would cover approximately 5% of the productive land of the farmers. Also, to find the equivalent income reduction associated to the productivity loss, the number and price of vegetable baskets were considered. The four families supply 82 families with organic vegetable monthly baskets, which are available in two sizes (small and large). Considering that half of them would be small size (R\$ 140) and half large (R\$ 200), the total monthly income of the selling of the baskets would be R\$ 13,940.00 per month. The results of the analysis are in Table 24.

Table 25 – Productivity loss and energy savings scenarios

Estimated productivity loss (%)	Productivity loss per year (R\$)	Energy savings (R\$) in year 1 considering maintenance PV costs
5%	R\$ 418,20	R\$ 15.127,95
10%	R\$ 836,40	R\$ 15.127,95
15%	R\$ 1.254,60	R\$ 15.127,95
20%	R\$ 1.672,80	R\$ 15.127,95

Source: Elaborated by authors (2024)

5.4.6 Economic indicators: NPV, IRR and discounted Payback period

In this economic analysis the NPV (Net Present Value), IRR (Internal Rate of Return), and discounted Payback period were calculated to investigate if the agrivoltaic systems proposed in the case-study were viable. It is relevant to note that the cost of implementation of the industrial kitchen will be covered by the Amazon Fund, and does not enter in this analysis.

The MARR (Minimum Attractive Rate of Return) use in

the calculations was 13.5%, which corresponds to the Selic Rate at the moment of the study, therefore representing a minimum rate of return that an investment must generate to be considered attractive or viable. An increase rate of 9.2% for the electricity tariff was considered in this analysis, according to data from the study developed by Montenegro et al. (2020).

The NPV, IRR, and discounted Payback were calculated for three different subsidy scenarios: 100% farmers investment; 80% farmers investment and 60% farmers investment. The results of the economic indicators are available in Table 25.

Table 26 – NPV, IRR and discounted payback period

Farmers investment	NPV	IRR	Discounted Payback
100%	R\$ 98.232,76	24,41%	7 years 10 months
80%	R\$ 114.223,99	29,01%	5 years 10 months
60%	R\$ 130.215,21	36,59%	4 years 1 month

Source: Elaborated by authors (2024)

All the scenarios analyzed in this study show attractive economic results, with positive NPVs, IRRs higher than the MARR and discounted Payback periods under the period of 25 years of the project.

5.5 Recommendations on operation and maintenance

In Brazil, there are no regulations that provide guidelines for the characterization and maintenance of agrivoltaic systems, however, documents from other countries suggest that ensuring the continuity of crops throughout the project period and maintaining soil quality after the construction and dismantling of the PV system should be a priority. Therefore, it is recommended to plan the implementation and maintenance of the crops associated with agrivoltaics.

In this chapter some maintenance guidelines are suggested, based on documents from other countries and existing practices for regular PV systems, which were adapted to agrivoltaic systems.

5.5.1 PV system maintenance guidelines

Modern PV system inverters have the alternative of monitoring power generation through applications. Through the application, individuals can access general system information and the daily, monthly, and annual generation of each linked system.

Additionally, the application also allows the viewing of an error history. It is necessary to designate a responsible individual to monitor monthly generation and, also, the energy bills associated with the system, in order to ensure that generation is occurring as expected and that credits are being generated and distributed correctly.

5.5.2 Problem identification and types of maintenance

When monitoring power generation, attention should be paid to periods in which generation is significantly reduced compared to the expected yield. This could indicate a system error, and once an error is identified, it is recommended to hire a specialized company to perform maintenance and identify the existing problem.

In addition, other indicators of issues in the plant that can be easily identified through visual inspection may include:

- Checking for abnormal or electrical noises;
- Observing cracks in the modules or modules that are crooked or loose;
- Noticing breaks or twists in the mounting structures.
- It is important to emphasize that cables should not be disconnected by untrained individuals to prevent electrical shocks or the creation of electrical arcs, which can lead to accidents. Furthermore, walking on or applying strong pressure to PV modules should be avoided to prevent damage to the PV cells.

5.5.2.1 Corrective maintenance

Corrective maintenance of PV systems aims to repair defects or failures in the PV system after they occur and also aims to prevent them from recurring. Corrective maintenance also includes the replacement of parts and equipment with manufacturing defects.

This type of maintenance should only be carried out by employees of specialized third-party companies in the field, with appropriate safety equipment. Among the actions of corrective maintenance, there are:

- Current measurement of the strings;
- General maintenance of the string boxes;
- Voltage and polarity;
- Insulation resistance;
- Inspection and replacement of operated SPDs (Surge Protective Devices);
- Evaluation of the integrity of DC fuses;
- MC4 connector crimping;
- Replacement of damaged PV modules.

5.5.2.2 Preventive maintenance

Preventive maintenance of the systems involves a set of actions aimed at ensuring the proper operation and longevity of the equipment and the PV system as a whole, as well as preventing system malfunctions. These actions are carried out in accordance with the equipment maintenance manuals, following the manufacturer's guidelines and recommendations to ensure their warranty. As part of preventive maintenance, some farmers may be responsible for activities such as observing dirt on the PV modules and electrical board.

It is not necessary to clean the system frequently; it is recommended to be done annually or in moments such

as when a thick layer of dirt and a decrease in generation efficiency are observed (Figure 64). In locations with frequent rainfall, like the case study area, it is often unnecessary to clean the modules as rain, combined with the PV module tilt, naturally removes accumulated dust.

Figure 63 – Example of dirty PV modules and clean modules



Source: Elaborados pelos autores (2024)

In order to clean the PV modules, it is advisable to hire a specialized third-party company. During the cleaning process, it is essential to ensure that the system is not in operation, the strings are open-circuited, and cleaning should not be conducted during rain or lightning storms. Cleaning can potentially damage the modules and other system components. The encapsulation material and glass that compose PV modules provide protection against electrical shock when they are intact. However, if cracked or broken, the module's integrity is compromised, leading to a loss of electrical insulating properties and posing a risk of electrical shock. Additionally, when cleaning the modules, care should be taken with the cleaning products to prevent spillage onto the ground, which could impact the crops below.

Another component that may require preventive maintenance is the electrical board. Insects, small rodents, and bird droppings can enter the boards, so periodic cleaning is necessary to maintain their good condition. Cleaning can be performed every six months or as determined by assessments and need.

Initially, a visual inspection of the boards should be conducted, and if only surface dirt is observed, farmers can perform the cleaning themselves using a soft brush or sponge. However, if more serious damage is identified or modifications to electrical connections or components are required during maintenance, these procedures should be carried out by a specialized company. Maintenance should preferably be conducted at dawn or dusk to avoid disrupting production. It is recommended not to perform this procedure during rain, drizzle, or lightning storms. To minimize the risk of electrical shock, electrical boards cleaning should be carried out with the systems de-energized.

5.5.2.3 Other safety guidelines

Regarding agricultural activities beneath the system, an important note is to avoid working beneath the system during extreme weather events. Also, during PV module cleaning, there should be caution regarding the use of cleaning agents to prevent any impact on the crops.

5.6 Conclusions

The agrivoltaic project in this case-study would directly support 4 riverside families and impact 82 consumer families, as well as it would support organic production and agroforestry practices in the Amazon region. Also, the project would financially support the operation of the industrial kitchen, which will enhance and add value to these families' production.

In this study, the primary focus was on the implementation of small-scale agrivoltaic systems tailored to the specific needs of small-scale farmers. While it is evident that the initial cost of these systems is slightly higher than that of conventional PV setups, the design of the systems was proposed in order to align with the economic realities of these farmers, as well as their resource availability. In this context, wooden structures were employed as a cost-effective and locally accessible solution.

In total, the 2 topologies proposed in the study consist in 15.4 kWp and would generate 21.2 MWh of electricity yearly. One of the key findings of this study is that the final capital expenditure (CAPEX) for agrivoltaic systems, although higher than that of conventional PV systems, remains within a reasonable range. This suggests that the financial barrier of adopting agrivoltaics may not be significantly greater for small-scale farmers, especially when considering the long-term benefits.

In the economic analysis, productivity loss scenarios were considered, and even in the one that considered 20% loss in agricultural production, the results would be considerably lower than the energy savings with the implementation of the project. The economic indicators, such as the discounted Payback period of 7 years and 10 months for the scenario of 100% farmers investment, resulted in numbers that closely resemble those of conventional PV systems, reinforcing that agrivoltaic systems can be an economically feasible choice for small farmers looking to integrate renewable power generation with agricultural activities.

The positive results of the study show that the agrivoltaic systems have synergy with "shared energy" business models, which can benefit from the existing association structure. In Brazil, this model refers to the practice of multiple consumers collectively generating renewable energy, often through PV modules, and the surplus being distributed back to the grid for others to use; in this case,

in the occasion of expansion of the project in future years, the future agrivoltaic system's surplus energy could benefit the individual energy expenses of other families from the association.

One relevant topic for further investigation is the quantification of the impact of agrivoltaic systems on agricultural productivity. Future studies should seek to determine whether these systems positively contribute to crop yields or, conversely, if there are any related productivity loss in association with specific crops. This would provide important insights into the implications of agrivoltaics on the small-scale farmers ecosystem and the sustainability of their agricultural practices.

6. Conclusions and recommendations for agrivoltaic systems within the Brazilian context

This section provides recommendations for best practices in future agrivoltaic systems. It encompasses technical and agricultural recommendations for large- and small-scale agricultural practices highlighting the main potentials of each national macro region, highlighting the most suitable designs for agrivoltaic systems. It also presents recommendations on best agricultural practices and policies incentives to promote agrivoltaic systems in Brazil.

Considering large-scale agricultural systems, these are led in Brazil by soybeans, corn, sugarcane, rice, coffee and beans. These six agricultural products accounted for over 70% of the total cultivated land in Brazil from 1985 to 2017 and are mainly located in the regions of Central-West, and some in the Southern and Southeastern regions. Large-scale agriculture is one of the main contributors to the Gross Production Value of the country. However, only few benefit from the income generation of the so-called modern agriculture as that 8% of rural establishments are responsible for generating 85% of the agricultural value. As large-scale agriculture occupies a considerable extension of land for agricultural and livestock production, it is understood that for this context, when considering business models, agrivoltaic systems for generating energy for the energy's free market might be more suitable. However, the open market is complex and usually only big players from the electricity market get involved. Furthermore, with the electrification of transport and eventually all machinery involved in agriculture (trucks, tractors, etc.), energy demands in agriculture are expected to increase and energy self-production and self-sufficiency will be an important aspect in the agricultural landscape in the near future.

Agrivoltaic systems applied to the large-scale agriculture should be more robust and consist of taller structures to allow large machinery to pass underneath the system, or the rows of PV modules should be spaced farther apart—with a greater pitch—so that machinery can pass between the rows of modules. In addition, increasing the spacing between PV modules to allow greater distribution of irradiation in the crop can be also a good practice when applying the agrivoltaic technology large-scale agriculture and monocultures like soy and sugarcane. See Figure 65 for an example.

Large-scale agriculture also encompasses the beef cattle industry, and it is widely developed across all states and ecosystems, particularly in the Central-West and Southeast regions. The beef cattle industry is directly related to the increase in deforestation in some regions of the country, and, besides that, it can cause soil degradation and it is

responsible for high fractions of CO₂ emissions to the atmosphere. Agrivoltaic applications for livestock production could become an option to increase animal welfare and support the promotion of more sustainable practices in this branch of large-scale agriculture. PV vertical applications for animal fencing should also be considered as a potential PV application for livestock production (Figure 66).

Figure 64 – Bifacial, vertically installed PV modules for fencing applications



Source: [23]

On the other side of the spectrum, small-scale and family farming represents 77% of agricultural establishments in Brazil, supplies approximately 70% of the food consumed by the Brazilian population, and plays a significant role in job creation as it employs about 10.5 million people, representing over 70% of the workforce in the Brazilian agricultural sector. Establishments characterized as family farming are prevalent in the Northern and Northeastern regions, where rural poverty presents the highest levels in the country. Considering the proven benefits of agrivoltaic systems, such as protection from extreme heat and irradiation, reducing evaporation and the need for irrigation, these systems show a potential match with the climate and social characteristics of the Northeast region.

For small-scale farmers, the current legal framework for distributed generation provides them means to generate their own energy through the electricity compensation system, adapting the solar energy technology to an agrivoltaic application. Therefore, agrivoltaic systems present social

and economic opportunities for family farmers by offering greater autonomy in power generation for self-consumption and the potential to create them an income aggregation through leasing or generating energy credits through the distributed generation system.

Another topic of discussion in Brazil is the impact on the distribution grid caused by the integration of power generation systems that use DG. Power flow reversal occurs when the energy generated locally by a grid-connected system (for example, a PV system) exceeds the instantaneous consumption of the consumer unit or the section of the grid to which it is connected. In this situation, the electricity flow no longer follows the traditional direction (from the substation to the consumer) but begins to flow in the opposite direction. In technical terms, this is a change in the direction of active power flow within the system, which can result in increased voltage in feeders, transformer overloads, miscoordination of protection systems, limitations on new DG connections, and difficulties in serving other households in the same area. Agrivoltaic systems tend to be implemented predominantly in rural areas, which have certain characteristics, such as long feeders, low installed capacity, and, consequently, a lower capacity to absorb surplus generation.

As a result, medium- and large-scale agrivoltaic systems may face technical constraints related to power flow reversal, especially when generation occurs during periods of low local demand. Finding ways to mitigate these impacts is a topic of discussion and should be taken into account when installing grid-connected agrivoltaic systems, such as the possibility of energy storage systems; strategies to increase local self-consumption, such as using energy for irrigation, pumping, or cooling; active power control (curtailment); integration with cooperatives or rural microgrids; and, finally, joint planning with the utility, taking into account studies on grid access and hosting capacity. Finally, in areas with high PV system penetration, especially in rural regions with low load density, reverse power flow can become a limiting factor for the expansion of generation.

In terms of the next steps for the development of the agrivoltaic technology in Brazil, some recommendations include:

- Conducting regional research to test different agricultural and production configurations, as well as providing financing opportunities for R&D project, taking into account the nation's regional diversity and seeking to identify the potential and specific characteristics of each region;
- Elaborating a national guideline and/or legal framework that regulates the agrivoltaic technology in the country. Within this scope, a definition of an agrivoltaic system should be established, taking into account the diverse range of beneficiaries and the national agricultural and

livestock production landscape. This guideline/legal framework should be aligned with the Law 14,300;

- Establishing credit lines for family farming focused on agrivoltaics (including electrification, transportation, and machinery used in agriculture, as well as equipment for processing byproducts);
- Promoting training programs on agrivoltaic technology at federal institutes and other educational institutions.

References

- [1] C. A. Brandão, “Espaços da destituição e as políticas urbanas e regionais no Brasil: uma visão panorâmica,” *Nova econ.*, vol. 26, no. spe, pp. 1097–1132, 2016, doi: 10.1590/0103-6351/3961.
- [2] FAO, IFAD, UNICEF, WFP, and WHO, **The State of Food Security and Nutrition in the World 2022 - Repurposing food and agricultural policies to make healthy diets more affordable**. Rome, 2022. doi: 10.4060/cc0639en.
- [3] GOVBR, “Brasil volta ao menor patamar de fome da história,” *Notícias*. Accessed on: 04 Feb. 2026. [Online]. Available: <https://www.gov.br/secom/pt-br/acompanhe-a-secom/noticias/2025/10/brasil-volta-ao-menor-patamar-de-fome-da-historia>
- [4] IBGE, “PNAD Contínua - Insegurança Alimentar 2024.” 2025. Accessed on: 04 Feb. 2026. [Online]. Available at: https://agenciadenoticias.ibge.gov.br/media/com_mediaibge/arquivos/724f23c52823528787ba0ef28b7940e3.pdf
- [5] A. Nunes, C. Schmitz, S. Moura, and M. Maraschin, “The use of pesticides in Brazil and the risks linked to human health / O uso de pesticidas no Brasil e os riscos associados à saúde humana,” *BJDV*, vol. 7, no. 4, pp. 37885–37904, Apr. 2021, doi: 10.34117/bjdv7n4-311.
- [6] C. Guzowski, M. M. I. Martin, and M. F. Zabaloy, “Energy poverty: conceptualization and its link to exclusion. Brief review for Latin America,” *Ambient. soc.*, vol. 24, p. e00272, 2021, doi: 10.1590/1809-4422asoc20200027r2vu202112de.
- [7] E. B. Pereira et al., “Atlas Brasileiro de Energia Solar 2a. Edição Revisada e Ampliada,” São José dos Campos: INPE, 2017.
- [8] EPE, “Observatório Brasileiro de Erradicação da Pobreza Energética.” 2018. Accessed on: 04 Feb. 2026. [Online]. Available at: <https://dashboard.epe.gov.br/apps/OBEPE/>
- [9] G. Masson, A. Van Rechem, M. De l’Epine, and A. Jäger-Waldau, “Snapshot of Global PV Markets 2025,” *International Energy Agency Photovoltaic Power Systems Programme*, Apr. 2025. doi: 10.69766/PBHV9141.
- [10] M. Trommsdorff et al., “Agrivoltaics: Opportunities for agriculture and the energy transition,” *Fraunhofer Institute for Solar Energy Systems ISE*, Freiburg, Germany, Third edition, 2024.
- [11] M. Trommsdorff, I. S. Dhal, Ö. E. Özdemir, D. Ketzer, N. Weinberger, and C. Rösch, “Agrivoltaics: solar power generation and food production,” in *Solar Energy Advancements in Agriculture and Food Production Systems*, Elsevier, 2022, pp. 159–210. doi: 10.1016/B978-0-323-89866-9.00012-2.
- [12] Fraunhofer ISE, “Agrivoltaics: Opportunities for Agriculture and the Energy Transition,” *Fraunhofer Institute for Solar Energy Systems ISE*, Freiburg, Germany, 2022.
- [13] A. Goetzberger and A. Zastrow, “Kartoffeln unter dem Kollektor,” *Sonnenenergie*, 1981.
- [14] J. Macknick et al., “The 5 Cs of Agrivoltaic Success Factors in the United States: Lessons from the InSPIRE Research Study,” *National Renewable Energy Laboratory (NREL)*, Golden, CO (United States), NREL/TP-6A20-83566, 1882930, MainId:84339, Aug. 2022. doi: 10.2172/1882930.
- [15] C. Toledo and A. Scognamiglio, “Agrivoltaic Systems Design and Assessment: A Critical Review, and a Descriptive Model towards a Sustainable Landscape Vision (Three-Dimensional Agrivoltaic Patterns),” *Sustainability*, vol. 13, no. 12, p. 6871, Jun. 2021, doi: 10.3390/su13126871.
- [16] DIN, “DIN SPEC 91434 - Agri-photovoltaic systems Requirements for primary agricultural use,” Berlin, Germany, 2021.
- [17] S. Schindele et al., “Implementation of agrophotovoltaics: Techno-economic analysis of the price-performance ratio and its policy implications,” *Applied Energy*, vol. 265, p. 114737, May 2020, doi: 10.1016/j.apenergy.2020.114737.
- [18] P. Jae-hyuk, “Agrivoltaics emerge as new income source for aging Korean farmers - The Korea Times.” Accessed on: 17 Feb. 2026. [Online]. Available at: <https://www.koreatimes.co.kr/business/companies/20220904/agrivoltaics-emerge-as-new-income-source-for-aging-korean-farmers>
- [19] Fraunhofer ISE, “Agrivoltaics: Opportunities for Agriculture and the Energy Transition,” *Fraunhofer Institute for Solar Energy Systems ISE*, Freiburg, Germany, 2020.
- [20] I. Ademe, “Caractériser les projets photovoltaïques sur terrains agricoles et agrivoltaïques - État de l’art bibliographique,” 2021.

- [21] M. J. J. Parra, Legal Counsel, and DVP Italia S.r.l., “Italy publishes new national guidelines for agrovoltaic plants,” *pV magazine International*. Accessed on: 16 Feb. 2026. [Online]. Available at: <https://www.pv-magazine.com/2022/07/05/italy-publishes-new-national-guidelines-for-agrovoltaic-plants/>
- [22] J. F. Weaver, “Vertical bifacial solar seeking greenhouse albedo, deployment space.” Accessed on: 26 Feb. 2026. [Online]. Available at: <https://www.pv-magazine.com/2023/07/31/vertical-bifacial-solar-seeking-greenhouse-albedo-deployment-space/>
- [23] K. Horowitz, R. Vignesh, J. Macknick, and R. Margolis, “Capital Costs for Dual-Use Photovoltaic Installations: 2020 Benchmark for Ground Mounted PV Systems with Pollinator-Friendly Vegetation, Grazing, and Crops,” National Renewable Energy Laboratory, Golden, CO, NREL/TP-6A20-77811, 2020. [Online]. Available at: <https://www.nrel.gov/docs/fy21osti/77811.pdf>
- [24] India Agrivoltaics Alliance, “Business Models of Agrivoltaics and its Potential Socio-economic Impacts,” New Delhi, 2024.
- [25] F. Ise, “Agrivoltaics: Opportunities for Agriculture and the Energy Transition,” 2024, [Online]. Available at: <https://www.ise.fraunhofer.de/en/publications/studies/agrivoltaics-opportunities-for-agriculture-and-the-energy-transition.html>
- [26] WRI China, “Agrivoltaics in China: Status, Potential and Pathways for Synergistic Energy– Agriculture Development,” 2025. [Online]. Available at: <https://wri.org.cn/en/research/agrivoltaics-china-status-potential-and-pathways-synergistic-energy-agriculture>
- [27] I. Todorović, “Enerjisa launches first agrivoltaic pilot project in Turkey,” *Balkan Green Energy News*. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://balkangreenenergynews.com/enerjisa-launches-first-agrivoltaic-pilot-project-in-turkey/>
- [28] SolarPowerEurope, “Agrisolar Policy Map.” Accessed on: 01 Feb. 2026. [Online]. Available at: https://api.solarpowereurope.org/uploads/Agrisolar_Policy_Map_Final_34d0583fc4.pdf?updatedat=2025-10-21T08:23:58.227Z
- [29] IEA, “Dual Land Use for Agriculture and Solar Power Production: Overview and Performance of Agrivoltaic Systems,” 2025. [Online]. Available at: <https://iea-pvps.org/wp-content/uploads/2025/03/IEA-PVPS-T13-29-2025-REPORT-Dual-Land-Use.pdf>
- [30] BayWa r.e., “BayWa r.e. wins smarter E AWARD for ‘fruitvoltaic’ system.” Accessed on: 26 Feb. 2026. [Online]. Available at: <https://www.baywa-re.com/en/news/baywa-re-wins-smarter-e-award-for-fruitvoltaic-system>
- [31] vattenfall, “Tützpätz, Germany’s largest combined solar and agricultural farm has been inaugurated.” Accessed on: 01 Feb. 2026. [Online]. Available at: <https://group.vattenfall.com/press-and-media/newsroom/2025/vattenfall-commissions-germanys-largest-agri-pv-park>
- [32] A. Ademollo, N. Ulivi, L. Ferretti, F. Serafini, C. Carcasci, and C. Pacini, “Policy-constrained agrivoltaics in Italy: a potato case study linking shading, crop and economics,” *Applied Energy*, vol. 405, p. 127225, Feb. 2026, doi: 10.1016/j.apenergy.2025.127225.
- [33] IEA, “TRENDS IN PHOTOVOLTAIC APPLICATIONS,” 2024. [Online]. Available at: <https://iea-pvps.org/wp-content/uploads/2024/10/IEA-PVPS-Task-1-Trends-Report-2024.pdf>
- [34] reNEWS, “Cero Generation finances 48MW solar farm in Italy,” *reNEWS – Renewable Energy News*. Accessed on: 26 Feb. 2026. [Online]. Available at: <https://renews.biz/79524/cero-generation-finance-48mw-solar-farm-in-italy/>
- [35] A. Petroni, “The Italian farmers saving an ancient fruit with solar power.” Accessed on: 17 Feb. 2026. [Online]. Available at: <https://www.bbc.com/future/article/20230424-how-agrivoltaics-helped-save-italys-citron-and-lemon-trees>
- [36] M. Maisch, “Croatia adopts legal framework for agrivoltaics,” *pV magazine International*. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://www.pv-magazine.com/2023/07/28/croatia-adopts-legal-framework-for-agrivoltaics/>
- [37] PV Europe, “Innovative 500 kW agrophotovoltaic installation in Croatia.” Accessed on: 26 Feb. 2026. [Online]. Available at: <https://www.pveurope.eu/solar-modules/innovative-500-kw-agrophotovoltaic-installation-croatia>
- [38] M. Hrabanski, S. Verdeil, and A. Ducastel, “Agrivoltaics in France: the multi-level and uncertain regulation of an energy decarbonisation policy,” *Rev Agric Food Environ Stud*, vol. 105, no. 1, pp. 45–71, Aug. 2024, doi: 10.1007/s41130-024-00204-1.
- [39] AFNOR, “Agrivoltaism: crops first.” [Online]. Available at: <https://www.afnor.org/en/news/renewable-energy/agrivoltaic-label-crops/>

- [40] République française, Décret n° 2024-318 du 8 avril 2024 relatif au développement de l'agrivoltaïsme et aux conditions d'implantation des installations photovoltaïques sur des terrains agricoles, naturels ou forestiers. 2024. [Online]. Available at: <https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000049386027>
- [41] Makoto Tajima, "Global Overview I - Pioneer Countries," presented at the Agrivoltaics World Conference, Freiburg - Germany, Jul. 01, 2025.
- [42] Sun Agri, "Projet agrivoltaïque de Sun'Agri à Tresserre." Accessed on: 26 Feb. 2026. [Online]. Available at: <https://sunagri.fr/realisations-agrivoltaiques/projet-agrivoltaïque-tresserre>
- [43] X. Zhang and X. Ma, "Vectorized Agrivoltaics Dataset in China from 2010 to 2022," *Sci Data*, vol. 13, no. 1, p. 116, Jan. 2026, doi: 10.1038/s41597-025-06305-w.
- [44] Z. Hu, "Politics over photovoltaics: unpacking the politically directed deployment of agrivoltaics in China," *Sustain Sci*, vol. 20, no. 4, pp. 1313–1328, Jul. 2025, doi: 10.1007/s11625-025-01659-x.
- [45] E. Bellini, "Giant agrivoltaic project in China," *pV magazine International*. Accessed on: 16 Feb. 2026. [Online]. Available at: <https://www.pv-magazine.com/2020/09/03/giant-agrivoltaic-project-in-china/>
- [46] Solar Energy Technologies Office, "The Potential of Agrivoltaics for the U.S. Solar Industry, Farmers, and Communities," *Energy.gov*. Accessed on: 26 Feb. 2026. [Online]. Available at: <https://www.energy.gov/eere/solar/articles/potential-agrivoltaics-us-solar-industry-farmers-and-communities>
- [47] P. Akbari, R. P. Hall, and J. Ignosh, "Agrivoltaics Policy Frameworks in the United States: Selected Policies and Programs through 2024," *Virginia Tech, Blacksburg*, 2026. [Online]. Available at: <https://hdl.handle.net/10919/141096>
- [48] A. Macy, T. Swanson, C. Seay-Fleming, A. K. Gerlak, and G. A. Barron-Gafford, "Designing for dual-use solar: An examination of the agrivoltaic policy landscape in the United States," *Energy Policy*, vol. 205, p. 114682, Oct. 2025, doi: 10.1016/j.enpol.2025.114682.
- [49] NREL, "Clean Energy to Communities Agrivoltaics 101 Resources Provide a Guide Toward Implementation." [Online]. Available at: <https://www.nrl.gov/news/detail/program/2024/clean-energy-to-communities-agrivoltaics-101-resources-provide-a-guide-toward-implementation>
- [50] DOE, "Agrivoltaics Pathway," 2024. [Online]. Available at: <https://docs.nrel.gov/docs/fy25osti/91671.pdf>
- [51] DOE, "Foundational Agrivoltaic Research for Megawatt Scale (FARMS) Funding Program," U.S. Department of Energy. [Online]. Available at: <https://www.energy.gov/eere/solar/foundational-agrivoltaic-research-megawatt-scale-farms-funding-program>
- [52] AFT, "Policy Recommendations to Increase Agrivoltaic Development," *American Farmland Trust*, 2025. [Online]. Available at: https://farmland.org/files/aft_final_policy_recommendations_to_increase_agrivoltaic_development_definition_and_incentives_final-2.27.25.pdf
- [53] Jack's Solar Garden, "Solar energy Colorado | Jack's Solar Garden, LLC | United States," Jack's Solar Garden. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://www.jacksolargarden.com>
- [54] AES, "Grafton Solar." Accessed on: 17 Feb. 2026. [Online]. Available at: <https://www.aes.com/sustainability-impact/people-communities/projects/grafton-solar-aes>
- [55] M. Kim, S.-Y. Oh, and J. H. Jung, "History and legal aspect of agrivoltaics in Korea," presented at the AGRIVOLTAICS2021 CONFERENCE: Connecting Agrivoltaics Worldwide, Freiburg, Germany, 2022, p. 050001. doi: 10.1063/5.0127822.
- [56] IEA, "Korea - 2024 Country Update." [Online]. Available at: <https://iea-pvps.org/about-iea-pvps/members/korea/>
- [57] PVKnowHow, "South Korea agrivoltaics: Unique Law Set for 2026 Rollout." [Online]. Available at: <https://www.pvknowhow.com/news/south-korea-agrivoltaics-unique-law-set-for-2026-rollout/>
- [58] Hanwha, "Hanwha's Year in Review 2022." Accessed on: 26 Feb. 2026. [Online]. Available at: https://www.hanwha.com/en/news_and_media/stories/sustainability/hanwhas-year-in-review-2022.html
- [59] S.-H. Chae, H. J. Kim, H.-W. Moon, Y. H. Kim, and K.-M. Ku, "Agrivoltaic Systems Enhance Farmers' Profits through Broccoli Visual Quality and Electricity Production without Dramatic Changes in Yield, Antioxidant Capacity, and Glucosinolates," *Agronomy*, vol. 12, no. 6, p. 1415, Jun. 2022, doi: 10.3390/agronomy12061415.
- [60] Clean Energy Council, "AUSTRALIAN GUIDE TO AGRISOLAR FOR LARGE-SCALE SOLAR: For proponents and farmers," 2021.

- [61] Renew Economy, “Lots of solar and lots of sheep, but Australia still too slow on agrivoltaics.” Accessed on: 26 Feb .2026. [Online]. Available at: <https://reneweconomy.com.au/lots-of-solar-and-lots-of-sheep-but-australia-still-too-slow-on-agrivoltaics/>
- [62] Iberdrola, “Iberdrola pone en marcha en Toledo la primera planta agrovoltaica inteligente de España.” [Online]. Available at: <https://www.iberdrola.com/sala-comunicacion/noticias/detalle/iberdrola-pone-en-marcha-en-toledo-la-primeraplanta-agrovoltaica-inteligente-de-espana>
- [63] Torres, “Familia Torres launches agrivoltaic pilot installation in the Penedès as part of the SOLARWINE project.” [Online]. Available at: <https://www.torres.es/en/news/beyond-sustainability/familia-torres-launches-agrivoltaic-pilot-installation-penedes-part>
- [64] Statkraft, “Agrivoltaics: Combining solar panels and agriculture into a win-win result.” [Online]. Available at: <https://www.statkraft.com/newsroom/explained/agrivoltaics-combining-solar-panels-and-agriculture>
- [65] Ministry of Agriculture, Forestry and Fisheries, “Status of Installation of Agrivoltaic Facilities.” [Online]. Available at: www.maff.go.jp/j/nousin/noukei/totiriyo/einogata.html
- [66] M. Tajima and T. Iida, “Evolution of agrivoltaic farms in Japan,” presented at the AGRIVOLTAICS2020 CONFERENCE: Launching Agrivoltaics World-wide, Perpignan, France, Online, 2021, p. 030002. doi: 10.1063/5.0054674.
- [67] Ryo Hagiwara, “Understanding the Foundation of Agrivoltaics: The Agricultural Land Act and Latest Guidelines in Detail.” [Online]. Available at: <https://japan-agrivoltaics-insight.com/article/article6>
- [68] E. Bellini, “Novel plant design for agrivoltaics,” pv magazine International. Accessed on: 16 Feb. 2026. [Online]. Available at: <https://www.pv-magazine.com/2021/08/05/novel-plant-design-for-agrivoltaics/>
- [69] Next2Sun, “Luxor Solar KK is new exclusive partner of Next2Sun AG and realizes first Agri-PV project in Japan,” Next2Sun. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://next2sun.com/en/luxor-solar-kk-is-new-exclusive-partner-of-next2sun-ag-and-realizes-first-agri-pv-project-in-japan/>
- [70] D. Jung, F. Schönberger, and F. Spera, “Effects of Agrivoltaics on the Microclimate in Horticulture: Enhancing Resilience of Agriculture in Semi-Arid Zones,” AgriVoltaics Conf Proc, vol. 2, May 2024, doi: 10.52825/agripv2i.1033.
- [71] P. Gese, F. Mancilla Martínez-Conde, G. Ramírez-Sagner, and F. Dinter, “Agrivoltaic in Chile – Integrative Solution to Use Efficiently Land for Food and Energy Production and Generating Potential Synergy Effects Shown by a Pilot Plant in Metropolitan Region,” in Proceedings of the ISES Solar World Congress 2019, Santiago, Chile: International Solar Energy Society, 2019, pp. 1–9. doi: 10.18086/swc.2019.19.04.
- [72] GIZ, “MANUAL PARA EL DESARROLLO DE PROYECTOS AGRIVOLTAICOS EN CHILE,” Energy Partnership Chile– Alemania, 2025. [Online]. Available at: https://energypartnership.cl/fileadmin/chile/media_elements/Studies/2025_Manual_para_elDesarrollo_de_Proyectos_Agrivoltaicos_en_Chile.PDF
- [73] NSEFI, “Agrivoltaics in India: Overview of projects and relevant policies,” National Solar Energy Federation of India (NSEFI), New Delhi, 2023.
- [74] India Agrivoltaics Alliance, “Business Models of Agrivoltaics and its Potential Socio-economic Impacts,” NSEFI, New Delhi, 2024.
- [75] M. Rithiga, “BUSINESS MODELS FOR AGRIVOLTAICS IN INDIA,” JINAGRI, vol. 12, no. 4, pp. 1–9, Dec. 2025, doi: 10.37446/jinagri/ra/12.4.2025.1-9.
- [76] NSEFI, “Agrivoltaics in India Overview of projects and relevant policies,” 2023. [Online]. Available at: https://energyforum.in/fileadmin/india/media_elements/Photos_And_Gallery/20201210_SmarterE_AgroPV/20201212_NSEFI_on_AgriPV_in_India_1.pdf
- [77] ABSOLAR, “Energia Solar Fotovoltaica no Brasil Infográfico ABSOLAR.” [Online]. Available at: <https://www.absolar.org.br/mercado/infografico>
- [78] L. C. Vidotto, K. Schneider, R. W. Morato, L. R. Do Nascimento, and R. Rütther, “An evaluation of the potential of agrivoltaic systems in Brazil,” Applied Energy, vol. 360, p. 122782, Apr. 2024, doi: 10.1016/j.apenergy.2024.122782.
- [79] Brasil, “Lei No 14.300, de 6 de Janeiro de 2022,” 2022.
- [80] Solargis, “Global Solar Atlas 2.0.” [Online]. Available at: <https://globalsolaratlas.info>
- [81] R. A. Ferreira Junior et al., “Agrophotovoltaic systems in sugarcane crop – A Brazilian case study,” Energy Conversion and Management, vol. 344, p. 120307, Nov. 2025, doi: 10.1016/j.enconman.2025.120307.
- [82] ANEEL, “Resolução Normativa no 482, de 17 de abril de 2012,” 2012.

- [83] A. M. F. Gomes, G. X. de A. Pinto, D. O. dos Santos, F. G. Antonioli, H. F. Napolini, and R. Rüther, "Uncovering the beneficiaries: exploring the impact of new distributed solar energy legislation in Brazil," *Renewable Energy*, vol. 251, p. 123474, Oct. 2025, doi: 10.1016/j.renene.2025.123474.
- [84] Greener, "Estudo estratégico – Geração Distribuída – Mercado Fotovoltaico – 1º Semestre de 2023," 2023.
- [85] Japan, "MAFF." [Online]. Available at: <https://www.maff.go.jp/j/shokusan/renewable/energy/einou.html>
- [86] ADEME, "Caracteriser les projets photovoltaïques sur terrains agricoles et agrivoltaïsme - Etat de l'art bibliographique," 2021.
- [87] TSEEnergy, "The regulatory framework for agrivoltaics to preserve French agriculture." [Online]. Available at: <https://www.tse.energy/en/articles/le-cadre-reglementaire-de-lagrivoltaïsme-pour-preserver-lagriculture-francaise>
- [88] DOE, "Agrivoltaics: Solar and Agriculture Co-Location." [Online]. Available at: <https://www.energy.gov/eere/solar/agrivoltaics-solar-and-agriculture-co-location>
- [89] AFT, "Smart Solar." [Online]. Available at: <https://farmland.org/smart-solar>
- [90] MINISTERO DELLA TRANSIZIONE ECOLOGICA, "Linee Guida in materia di Impianti Agrivoltaici," Jun. 2022. [Online]. Available at: https://www.mase.gov.it/portale/documents/d/guest/linee_guida_impianti_agrivoltaici-pdf-1
- [91] M. Martinez, "Sistema que combina produção de comida e energia solar pode ajudar famílias no semiárido," *Mongabay*. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://brasil.mongabay.com/2022/06/sistema-que-combina-producao-de-comida-e-energia-solar-pode-ajudar-familias-no-semiarido/>
- [92] F. F. Lacerda, F. M. Neves, L. X. C. Canel, and G. M. Lopes, "Conceito de sistemas agrovoltáicos no Nordeste: uma solução de desenvolvimento ecossustentável para o Semiárido nordestino," *Rev. Dep. Geogr.*, vol. 42, p. e189543, Sep. 2022, doi: 10.11606/eISSN.2236-2878.rdg.2022.189543.
- [93] Atmosfair, "Brazil: Agriphotovoltaics in the village of the indigenous Pankará," atmosfair. Accessed on: 17 Feb 2026. [Online]. Available at: <https://www.atmosfair.de/en/climate-protection-projects/solar-energy/brazil-agriphotovoltaics-in-the-village-of-the-indigenous-pankara/>
- [94] M. L. Aragão, "Sistemas agrofotovoltaicos e o papel fundamental do povo Pankará junto à comunidade científica em Itacuruba, PE – Agrega." Accessed on: 26 Jan. 2026. [Online]. Available at: <http://www.agrega.org.br/2023/06/13/sistemas-agrofotovoltaicos-e-o-papel-fundamental-do-povo-pankara-junto-a-comunidade-cientifica-em-itacuruba-pe-%ef%bf%bc/>
- [95] I. J. Bueno, R. A. F. Junior, I. C. Torres, M. A. dos Santos, and J. L. de Souza, "AVALIAÇÃO DO AMBIENTE DE CULTIVO DA CANA-DE-AÇÚCAR PROPORCIONADA PELO SISTEMA AGROFOTOVOLTAICO EM ALAGOAS," ANAIS DO XXII CONGRESSO BRASILEIRO DE AGROMETEOROLOGIA, 2023.
- [96] T. Gonzaga, "Pesquisa vai avaliar sistema agrofotovoltaico em plantação de cana-de-açúcar," *Notícias*. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://noticias.ufal.br/ufal/noticias/2022/6/pesquisa-vai-avaliar-sistema-agrofotovoltaico-em-plantacao-de-cana-de-acucar>
- [97] PVMagazineBrasil, "Nextracker quer liderar o mercado AgriPV de grande escala." [Online]. Available at: <https://www.pv-magazine-brasil.com/2025/01/21/nextracker-quer-liderar-o-mercado-agripv-de-grande-escala/>
- [98] PVMagazineBrasil, "Nextracker amplia Centro de Excelência Solar em Sorocaba (SP)." [Online]. Available at: <https://www.pv-magazine-brasil.com/2024/11/14/nextracker-amplia-centro-de-excelencia-solar-em-sorocaba-sp/>
- [99] MME, "Webinário Explorando o Potencial Agri-PV: Agricultura e Energia Sustentável no Brasil," Canal do Youtube do MME. [Online]. Available at: <https://www.youtube.com/watch?v=96vlayWuP2s>
- [100] M. Chanes De Souza, R. Nery De Castro, B. Azambuja Possato, M. B. Krause, and S. Hutson, "Feasibility of AgriVoltaic Wheat Farming with Standard-Height, Utility-Scale Tracking Systems," *AgriVoltaics Conf Proc*, vol. 3, May 2025, doi: 10.52825/agripv3i.1355.
- [101] M. Chanes De Souza, R. Nery De Castro, B. Azambuja Possato, M. B. Krause, and S. Hutson, "A Study of Agrivoltaics Peanut Production With Single-Axis Tracking Systems," *AgriVoltaics Conf Proc*, vol. 3, Jul. 2025, doi: 10.52825/agripv3i.1356.
- [102] CEMIG, "Com projeto inovador da Cemig, Epamig e CPQD, produtores rurais poderão cultivar embaixo de usinas solares," Cemig. Accessed on: 26 Feb 2026. [Online]. Available at: <https://www.cemig.com.br/noticia/com-projeto-inovador-da-cemig-epamig-e-cpqd-produtores-rurais-poderao-cultivar-embaixo-de-usinas-solares>

- [103] Agência Minas, “Projeto sobre uso de energia solar na agricultura avança em Minas Gerais.” Accessed on: 26 Jan. 2026. [Online]. Available at: <https://www.agenciaminas.mg.gov.br/noticia/projeto-sobre-uso-de-energia-solar-na-agricultura-avanca-em-minas-gerais>
- [104] CenarioEnergia, “EDP Lança Projeto BeeVolt para Preservação das Abelhas e Sustentabilidade em Usinas Solares.” [Online]. Available at: <https://cenarioenergia.com.br/2024/10/04/edp-lanca-projeto-beevolt-para-preservacao-das-abelhas-e-sustentabilidade-em-usinas-solares/>
- [105] EDP, “EDP multiplica abelhas nativas em usina solar em Roseira.” [Online]. Available at: <https://edp.com/pt-br/america-do-sul/brasil/imprensa/noticias/edp-multiplica-abelhas-nativas-em-usina-solar-em-roseira>
- [106] Agrovoltáicos Sin Fronteras, “Webinar Livestock and Solar Grazing.” [Online]. Available at: <https://www.youtube.com/live/aMjgkfGlnk>
- [107] CDSA, “Mutirão de plantio em produção agrofotovoltaica e formação em solos integram diferentes projetos do CDSA e comunidade camponesa.” [Online]. Available at: <https://www.cdsa.ufcg.edu.br/index.php/noticias/1720-mutirao-de-plantio-em-producao-agrofotovoltaica-e-formacao-em-solos-integram-diferentes-projetos-do-cdsa-e-comunidade-camponesa>
- [108] Vitrine do Cariri, “Sócia da Vênus Energia Regenerativa visita o Cariri para promover geração de energia solar fotovoltaica.” [Online]. Available at: <https://www.vitrinedocariri.com.br/2024/07/01/socia-da-venus-energia-regenerativa-visita-o-cariri-para-promover-geracao-de-energia-solar-fotovoltaica>
- [109] PVMagazineBrasil, “Agrivoltaico no Brasil: energia, alimento e uma nova lógica para o uso da terra.” [Online]. Available at: <https://www.pv-magazine-brasil.com/2025/05/14/agrivoltaico-no-brasil-energia-alimento-e-uma-nova-logica-para-o-uso-da-terra>
- [110] SunFarming, “Conclusão da construção do Centro de Pesquisa e Treinamento Agri-Solar da SunFarming no Ceará, Brasil.” [Online]. Available at: <https://sunfarming.com.br/conclusao-da-construcao-do-centro-de-pesquisa-e-treinamento-agri-solar-da-sunfarming-no-ceara-brasil/>
- [111] C. A. Alvares, J. L. Stape, P. C. Sentelhas, J. L. De Moraes Gonçalves, and G. Sparovek, “Köppen’s climate classification map for Brazil,” *metz*, vol. 22, no. 6, pp. 711–728, Dec. 2013, doi: 10.1127/0941-2948/2013/0507.
- [112] Embrapa, “Grãos.” [Online]. Available at: <https://www.embrapa.br/agropensa/agro-em-dados/agricultura/graos>
- [113] EMBRAPA, “A Embrapa - Portal Embrapa.” Accessed on: 26 Feb. 2026. [Online]. Available at: <https://www.embrapa.br/>
- [114] IBGE, “Censo agropecuário: resultados definitivos 2017,” 2017.
- [115] BGE CNA, “Panorama do Agro,” Portal CNA Brasil. Accessed on: 26 Feb 2026. [Online]. Available at: <https://www.cnabrasil.org.br/cna>
- [116] Estadão, “Agronegócio: veja os 10 principais Estados produtores do Brasil | Agro Estadão.” Accessed on: 26 Feb. 2026. [Online]. Available at: <https://agro.estadao.com.br/summit-agro/agronegocio-veja-os-10-principais-estados-produtores-do-brasil>
- [117] J. D. Coêlho, “Milho: produção e mercados,” Banco do Nordeste do Brasil, Fortaleza, 2021.
- [118] CONAB, “Portal de Informações Agropecuárias.” Accessed on: 27 Feb. 2026. [Online]. Available at: <https://portaldeinformacoes.conab.gov.br>
- [119] CEPEA/CNA, “MERCADO DE TRABALHO DO AGRONEGÓCIO BRASILEIRO,” 2023.
- [120] A. Miccolis et al., *Restauração ecológica com sistemas agroflorestais: como conciliar conservação com produção no cerrado e na caatinga*. Ispn, 2016.
- [121] Brasilagro, “Controversa, agricultura familiar abastece boa parte do Brasil.” Accessed on: 17 Feb 2026. [Online]. Available at: <https://www.brasilagro.com.br/conteudo/controversa-agricultura-familiar-abastece-boa-parte-do-brasil.html>
- [122] E. DSSBR, “Insegurança alimentar e Covid-19 no Brasil,” *Determinantes Sociais da Saúde*. Accessed on: 26 Feb. 2026. [Online]. Available at: <https://dssbr.ensp.fiocruz.br/inseguranca-alimentar-e-covid-19-no-brasil/>
- [123] L. Dierings, “Agricultura em Ascensão: Norte do Brasil se Consolida como Polo de Produção de Grãos e Enfrenta Desafios para Manter o Crescimento,” *eProdutor*. Accessed on: 17 Feb. 2026. [Online]. Available at: <https://eprodutor.com.br/norte-brasil-crescimento-agricola-desafios/>
- [124] InfoEscola, “Economia de Roraima - Atividades Econômicas de Roraima.” Accessed on: 27 Feb. 2026. [Online]. Available at: <https://www.infoescola.com/economia/economia-de-roraima/>

- [125] EMBRAPA, “Perguntas e respostas Matopiba – Portal Embrapa.” Accessed on: 27 Feb. 2026. [Online]. Available at: <https://www.embrapa.br/tema-matopiba/perguntas-e-respostas>
- [126] A. A. Rodrigues et al., “Cerrado deforestation threatens regional climate and water availability for agriculture and ecosystems,” *Global Change Biology*, vol. 28, no. 22, pp. 6807–6822, Nov. 2022, doi: 10.1111/gcb.16386.
- [127] Embrapa, “Coleção 500 Perguntas 500 Respostas – Portal Embrapa.” Accessed on: 27 Feb. 2026. [Online]. Available at: <https://www.embrapa.br/publicacoes-e-bibliotecas/colecao-500-perguntas-500-respostas>
- [128] SYNGENTA, “Regiões agrícolas do Brasil: descubra quais são as principais.” Accessed on: 27 Feb. 2026. [Online]. Available at: <https://blog.syngentadigital.ag/regioes-agricolas-brasil/>
- [129] o A. C. Wendell and Y. C. Lima, “Análise da Agricultura do Nordeste no Início do Século XXI,” 2017.
- [130] M. Martinez, “In Brazil’s semiarid region, agrivoltaics show promise for food, energy security,” *Conservation news*. Accessed on: 27 Feb. 2026. [Online]. Available at: <https://news.mongabay.com/2022/07/in-brazils-semiarid-region-agrivoltaics-show-promise-for-food-energy-security/>
- [131] PASI, “Portal de acompanhamento e informações dos sistemas isolados.” Accessed on: 21 Jan. 2026. [Online]. Available at: <https://app.powerbi.com/>
- [132] Next2Sun, “AgriPV” Accessed on: 27. Feb 2026. [Online]. Available at: <https://next2sun.com/en/agripv/>
- [133] SandBoxSolar, “SandBox Solar” Accessed on: 27. Feb 2026. [Online]. Available at: <https://sandboxsolar.com/>
- [134] PVMagazine, “Agrivoltaics prevail in Frances tender for innovative PV technologies” Accessed on: 27. Feb 2026. [Online]. Available at: <https://www.pv-magazine.com/2021/01/05/agrivoltaics-prevail-in-frances-tender-for-innovative-pv-technologies/>
- [135] ConnexionFrance, “France imposes regulation on use of solar panels on farms” Accessed on: 27. Feb 2026. [Online]. Available at: <https://www.connexionfrance.com/practical/france-imposes-regulations-on-use-of-solar-panels-on-farmscade/156720>
- [136] AES, “Grafton Solar” Accessed on: 27. Feb 2026. [Online]. Available at: <https://www.aes.com/sustainability-impact/people-communities/projects/grafton-solar-aes>
- [137] Hanwha, “From sun to soil, agrivoltaics takes root to transform the energy landscape” Accessed on: 27. Feb 2026. [Online]. Available at: <https://www.hanwha.com/newsroom/news/a-stories/from-sun-to-soil-agrivoltaics-takes-root-to-transform-the-energy-landscape.do>
- [138] Fotovoltaica UFSC, “Sistema piloto Agrivoltaico FV UFSC”, comunicação pessoal, UFSC, 2026.
- [139] EDP, “Livestock and Solar Grazing” [Online]. Available at <https://www.youtube.com/watch?v=aMjgkfGlnk>
- [140] R. Zilles, “Sistemas Piloto IEE USP”, comunicação pessoal, USP, 2026.
- [141] M. Diniz, “Sistema Piloto FMVZ Unesp Botucatu”, comunicação pessoal, UNESP, 2026.
- [142] R. Morato. “Foto de propriedade da APOI”, comunicação pessoal, 2026.

www.energypartnership.com.br