MAURITIUS AGRIVOLTAICS STUDY

TECHNICAL ASSISTANCE FOR THE IMPLEMENTATION OF SUNREF III PROGRAMME - MAURITIUS

APRIL 2024

Consultants :
FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE
PSE PROJECTS GMBH

Developed by
With the financial participation of
In partnership with
Implemented by

MAURITIUS AGRIVOLTAICS STUDY

April 2024

Karim Fahmy
Brendon Bingwa
Susanne Wolf
Charlotte Gudat
Nicolas Travieso Perez

Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstraße 2, 79110 Freiburg, Germany

Werner Warmuth

Project partner: PSE Projects GmbH

Version	Date [dd/mm/yyyy]	Issued by	Description
1.0	30/03/2024	Karim Fahmy	First draft
1.1	03/04/2024	Werner Warmuth	Review and economic analysis added
1.2	16/04./2024	Karim Fahmy	Final review

Table of contents

List of Figures

List of Tables

Abbreviations

AMB *Agricultural Marketing Board*
BIPV *Building Integrated Photovoltaics*
BOS *balance of system*
CEB *Central Electricity Board*, *The Central Electricity Board*
CPV *Concentrating Photovoltaics*
C-Si *crystalline silicon*
EPBT *Energy Payback Time*
EU *European Union*
FAO *Food and Agricultural Organization of the United Nations*
FAREI *Food and Agricultural Research and Extension Institute*
GCR *Ground Cover Ratio*
GDP *Gross Domestic Product*
GHI *Global horizontal irradiation*
GM-PV *Ground-mounted PV*
GWp *Gigawatts peak*
IEA *International Energy Agency*
IPP *Independent Power Producers*
km *Kilometers*
LCA *Life Cycle Assessment*
LCOE *Levelized cost of electricity*
LER *Land Equivalency Ratio*
LSC *luminescent solar collector*
Mm^3 *Cubic megameters*
mono-Si *monocrystalline silicon*
MSDG *Siehe* Medium Scale Distributed Generator
multi-Si *multicrystalline silicon*
MWp *Megawatts peak*
NDCs *National Determined Contributions*
OPV *Organic solar cells*
PV *photovoltaic*
SFWF *Small Farmers Welfare Funds*
SIDS *Small Island Developing State*
SSDG *Small-Scale Distributed Generators*
TES *Total energy supply*

1
Executive Summary

This study explores the potential of agrivoltaics as a multifaceted solution to address Mauritius' challenges stemming from climate change, particularly focusing on increased extreme weather events, rising sea levels, and declining agricultural productivity. With ambitious targets to reduce greenhouse gas emissions by 40% and increase renewable energy production to 60% by 2030, Mauritius aims to harness agrivoltaics to optimize land use, bolster agricultural resilience, and bolster sustainable energy production.

Agrivoltaics represent a dual land-use approach, allowing for the simultaneous generation of electricity and cultivation of crops. By deploying photovoltaic (PV) modules over agricultural land, agrivoltaics can drastically enhance land use efficiency, reaching up to 84%, while delivering a range of benefits such as shading for crops, enhanced rural electrification, and income diversification opportunities for farmers. Additionally, agrivoltaic systems can facilitate rainwater harvesting, mitigate groundwater depletion, and reduce heat stress and evapotranspiration, potentially leading to irrigation water savings of up to 20%.

Internationally, agrivoltaics have witnessed rapid development, with significant installations in countries like China, Japan, France, and the USA. These systems have demonstrated increased land productivity, with some studies reporting productivity gains of up to 73% and offer various ancillary benefits including reduced levelized cost of electricity, income diversification for farmers, and enhanced resilience against extreme weather events.

In Mauritius, where agriculture plays a pivotal role in ensuring food security and economic stability, agrivoltaics present an opportunity to fortify agricultural resilience, decrease reliance on food imports, and contribute to achieving energy self-sufficiency. The favorable climatic conditions, ample land availability, and renewable energy goals of Mauritius provide a conducive environment for the deployment of agrivoltaic systems.

1.1 Objectives of the Agrivoltaics study for Mauritius

The objectives of this study were to:

- Develop an efficient agrivoltaics system by **combining solar energy and agricultural cultivation** and identify potential obstacles and barriers.
- Conduct an **agricultural analysis**, including assessing the compatibility and requirements of different crops in the target region and analysing current and potential agricultural practices.

- Evaluate factors such as climate crisis impact on crop selection, **shading tolerances**, synergy possibilities with agrivoltaics, **location suitability**, export potential, and **food security considerations**.
- Evaluate diverse **water management concepts**, taking into account local conditions and system operation requirements.
- Technology screening for **monitoring** sensors compatible with the site's demands.
- Develop a detailed **testing protocol for crops** identified as suitable during the agricultural analysis.
- Formulate a **Request for Proposal (RFP)** outlining the technical framework of the most fitting agrivoltaics solution.
- Elaborate a **cost calculation tool** and perform an **economic analysis.**

1.2 Key Findings and Recommendations

1. **Crop Selection**: Identify crops suitable for agrivoltaic systems in Mauritius, considering factors such as shade tolerance, economic viability, and market demand. Focus on both food and non-food crops to maximize agricultural and economic benefits.
    a. **Nonfood crops**: While sugar cane is the major cultivated crop in Mauritius, its full sun requirements, height, and mechanization requirements may hinder an economically feasible implementation within an agrivoltaic system. Tea's potential for agrivoltaics lies in its shade tolerance, manual labor-intensive cultivation, and international success stories, especially in Japan. Although, due to its cultivation in the central, super humid part of Mauritius, electrical yield may be comparably lower.
    b. **Food crops**: The major produced food crops in terms of quantity in Mauritius are potato, banana, pumpkin, onion, tomato, cabbage, calabash, pineapple, cucumber, and carrot. For tomatoes, studies found that a shading rate between 25% to 35% seems to be beneficial for the yield, reducing sun scalding and fruit cracking as well. For cucumbers, shading can be beneficial, although cases have been observed, where a proportional increase of leave and stem biomass compared to harvestable fruits. Further crops investigated in this analysis include potato, onion, carrot, leafy greens, culinary herbs, ginger, banana, and pineapple.
    c. **Crop clusters:** The design of agrivoltaic systems is complex and influenced by local environmental factors, crop types, farming practices, and socio-economic contexts. For interspace ground-mounted PV, the spacing between rows is critical, ensuring sufficient room for agricultural activities and preventing shading on PV modules. Overhead systems, on the other hand, require careful arrangement to optimize sunlight for underlying crops, considering solar radiation and crop shade tolerance. According to the different agrivoltaic system types, crops can be clustered:

i. Crop Cluster I: This cluster comprises shade-tolerant horticultural crops like leafy greens, some root crops, and high-value crops and small fruit trees that benefit from the additional protection by the PV modules. For Crop Cluster 1, overhead agrivoltaic systems are deemed suitable.
ii. Crop Cluster II: This cluster includes crops that tolerate less shade, such as certain C4 crops like maize, sugar cane and sorghum. Due to the dual use of the land, the overall productivity of the land will still increase, but as they are expected to have a lower yield in the shade, interspace and vertical PV systems can be considered with a lower CAPEX.

d. **PV Greenhouses:** Greenhouses can be combined with PV electricity generation, either by a retrofitting of PV modules or by completely new greenhouse installations. The checkerboard pattern (placement of PV modules in a checkerboard manner) can be used to improve light homogeneity compared to straight light conditions, thereby improving growing conditions for crops.

Food security should have highest priority. This can be verified by means of evidence of sales of agar products, purchase of seeds (or young animals) or unannounced inspection visits.

2. **Water Management:** The analysis of precipitation patterns across different regions of Mauritius highlights the varying potential for rainwater harvesting. Coastal areas generally receive less precipitation compared to inland regions, with the highlands, particularly Inland Regions 2 and 3 (see Figure 44: Spatial distribution of precipitation in Mauritius), identified as attractive locations for implementing integrated agrivoltaics and rainwater harvesting systems. Rainwater harvesting should be an important consideration while implementing agrivoltaics.

3. **System Design**: Carefully assess system types and configurations to optimize energy production and crop yield while minimizing interference with agricultural activities. Consider factors such as module tilt angle, table height, row distance, and overall system orientation.
   a. Two System designs were selected for testing one with Rooftop configuration in an East-West Orientation and a tracked system. In two different sites on the West coast near Port Louis and a second site in the highlands.
   b. Simulation results show higher installed capacity and energy production in the fixed system than the tracked system.

4. **Cost-Benefit Analysis**: Conduct a thorough evaluation of costs and benefits associated with agrivoltaic implementation, considering factors such as capital expenditure, energy generation potential, agricultural productivity, and long-term sustainability.
5. **Research and Collaboration**: Foster collaboration among government agencies, private sector entities, academic institutions, and local communities to develop and implement agrivoltaic projects effectively. Invest in research to address uncertainties regarding crop response in Mauritius' specific climate.
6. **Policy Support**: Develop supportive policies and incentives to encourage the adoption of agrivoltaics including: streamlined permitting processes, financial incentives, and subsidies for farmers and developers. Ensure that regulatory frameworks facilitate the deployment of agrivoltaic systems. All supporting schemes should be transparent and predictable. Communication campaigns can increase acceptance.
7. **Incentive**: The economic analysis shows that the higher costs for agrivoltaic systems in Mauritius are not profitable without financial support. The multiple benefits for food security, solar power generation and biodiversity justify financial support from the state. Larger agrivoltaic systems have lower specific cost. Therefore, it is recommended that tariffs graduated according to performance classes are granted. The tariffs should be adjusted regularly to reflect changes in the market.

In conclusion, agrivoltaics offer a promising avenue for addressing the interconnected challenges of climate change, agriculture, and energy in Mauritius. Through strategic planning, investment, and stakeholder engagement; agrivoltaics can contribute significantly to sustainable development, resilience-building, and economic prosperity for the nation.

2 Introduction

Mauritius can be considered highly vulnerable to the impacts of climate change; with key sectors such as agriculture, water, marine environment, fisheries, and coastal zones at risk. In addition, the frequency of storms of at least tropical cyclone intensity have increased. Therefore, according to its updated National Determined Contributions (NDCs) to reduce its national emissions and adapt to climate change, Mauritius aims to reduce its greenhouse gas emissions by 40% and to increase its energy production from green sources to 60% by 2030. As well as phasing out coal and increasing energy efficiency by 10% (baseline 2019). To achieve the 60% target by 2030, the Central Electricity Board (CEB) has launched several renewable energy schemes and requests for proposals, with an anticipated creation of approximately 7000 green jobs.[1–3]

Further, Mauritius is a net food importer, and import-dependent on most of its staple food (such as wheat flour and rice) and importing around 77% of its total food requirements. While about 40% of the countries surface is used for crop cultivation, about 90% of crop land is used for sugarcane cultivation, which is the major export earner. As a complement to diversifying away from sugar cane, which's cultivation area has steadily decreased since 2016, and to increase the countries food sovereignty and security, the government of Mauritius has been promoting self-sufficiency in foods that can be produced locally.[4,5]

To tackle the intertwined challenges of climate change, agriculture, and limited land resources in Mauritius, agrivoltaics - a combination of agriculture and photovoltaic systems - offer a potential solution. This approach enables the dual use of land by installing PV modules above agricultural land, generating electricity while cultivating crops. Implementing agrivoltaics can yield various benefits, including increased land use efficiency (up to 84% depending on the crop), positive shading effects, and improved rural electrification. It is a resource-efficient method of enhancing land productivity, contributing to agricultural resilience against extreme weather events, and facilitating the generation of sustainable electricity from renewable sources, reducing reliance on fossil fuels. Moreover, agrivoltaics provide farmers with income diversification through simultaneous production of electricity and crop yields. Additionally, these systems allow for the integration of rainwater harvesting, mitigating ground-water depletion. The shading provided by PV modules reduces heat stress and decreases evapotranspiration, leading to potential irrigation water savings of up to 20%, which is expected to be even more critical in the future. Given the diverse benefits of agrivoltaics, there is significant potential in implementing these systems.[6]

This report aims to analyze the proposal for implementing agrivoltaics in Mauritius. It will examine the potential of agrivoltaics for land-use optimization and power generation, considering the country's climate zones, agricultural practices and conditions, and the current status of PV technology. Suitable crops for Mauritius' agriculture will be identified, and potential agrivoltaic system types and technologies, as well as their costs, will be outlined.

2.1 Agrivoltaics Overview

2.1.1 Agrivoltaic Development and Land Efficiency Ratio

In addressing the conflicting interest of land-use, agrivoltaics, which is a combined land-use for food and electricity production, offers not only the advantage of a multiple land use system but introduces an environment which can boost the output performance for both systems (reduction in system losses due to lowered temperature for PV and protected biomass from harsh environmental conditions) when optimally designed. Alternative terminologies frequently characterizing the same and similar technological approaches are agrophotovoltaics, solar sharing or agri-solar. The concept, first proposed in 1982 by Adolf Goetzberger and Armin Zastrow, contributes to resource efficiency, through dual land-use via energy and crop production on the same area of land.[7]

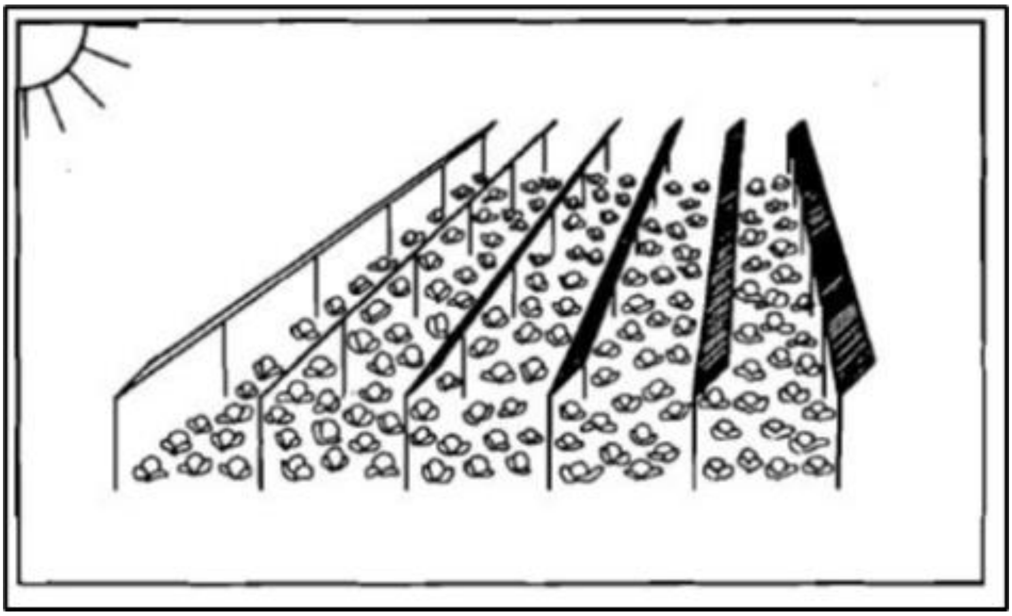


Figure 1: Illustration of Agrivoltaics.[7]

The resource efficiency gained by agrivoltaics is more specifically quantified through applying the concept of the Land Equivalency Ratio (LER), adapted from agroforestry (the practice of combining cultivation of trees and food crops). LERs are indicators of the productivity of the land, used to assess the value of mixed cropping systems. The approach allows the comparison of productivity of mixtures of crops on the same land area versus monocultures.[8]

$$LER = \frac{Yield_a(dual)}{Yield_a(mono)} + \frac{Yield_b(dual)}{Yield_b(mono)}$$

Equation 1: Land Equivalency Ratio (LER). [8]

Where a and b represent the cultivated crop and the electricity, respectively. The dual yields refer to agrivoltaic yields and mono yields to productivity of conventional agrivoltaic and ground-mounted PV (GM-PV).
By extending LER to any system that mixes two (or more) types of production on the same land unit, Dupraz was able to measure the productivity of agrivoltaic systems. The results of the study showed that agrivoltaic systems had the potential to be efficient, with a 35-73% increase of land productivity for two agrivoltaic systems with different PV module densities (ground cover).

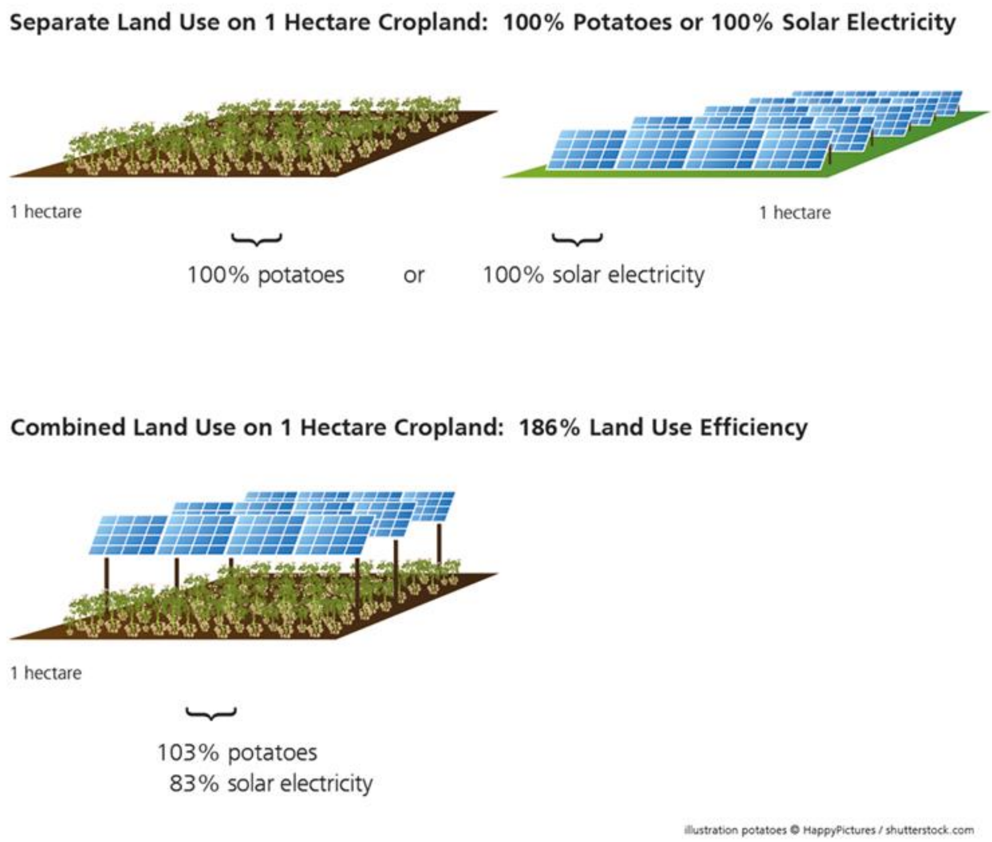


Figure 2: Illustration of increase in land use efficiency.[9]

2.1.2 International Development

The development of the agrivoltaic technology in recent years has been highly dynamic. Today it is prevalent in almost all regions throughout the globe with the installed capacity having increased exponentially, from around 5 megawatts peak (MWp) in 2012 to at least 14 gigawatts peak (GWp) in 2021. This was possible thanks to government funding programs in Japan (since 2013), China (around 2014), France (since 2017), the USA (since 2018), and most recently Korea. Between 2017 – 2018, China, the world leader in agrivoltaic installation, commissioned 1.7 GWp of agrivoltaic systems, including several large-scale utility facilities. Beside these power stations, agrivoltaics has seen proliferation only on smaller scale of up to 2 MWp, rarely over 5 MWp.

Table 1: Overview of global installed agrivoltaic capacity.[9]

Country	Installed capacity	Trend	Remarks
China	> 2 GWp	Uncertain, decreased installation pace from 2018 onwards.	Knowledge and experiences made with large scale agrivoltaics applications made in China are not sufficient diffused to Western/ South Asian scholars and industry.
Japan	>200 MWp	Increasing	New policy allows preferential treatment of "Solar Sharing," no minimum of self-consumption is required to get PV FiT.
France	15 – 30 MWp	Increasing	At least 120 MWp will start construction in 2021 and 2022.[10]
Germany	10 – 15 MWp	Increasing	Agrivoltaics is likely to be included in tenders as the new renewable energy policy is being negotiated.
Italy	>8 MWp	Increasing	Thereof 6.7 MWp dual axis tracking agrivoltaics by RemTec.
USA	>5 MWP	Increasing	New megawatt sized agrivoltaic system upcoming in Massachusetts, high interest in the technologies by states like Arizona and California.
India	6 MWp	Increasing	Large programme for solarization of agriculture with potential to include provisions for agrivoltaics.
South Korea	~ 2 MWp	Increasing	New policy on supporting farmers with agrivoltaics along Japanese policy learnings. 19 demonstration sites up to 100 kWp [11].
South America	>100 kWp	Increasing	Initiatives in Chile [12] and Brazil [13].
Africa	n.A.	Increasing	Demonstrators planned in Algeria, Mali, Gambia [15] as well as Kenya and Uganda [17].

2.1.3 Benefits of Agrivoltaics

In summary, agrivoltaic systems have been found to have the following benefits and effects[8,18–24]:

- Harmonious combination of GM-PV systems with agriculture
- Lower levelized cost of electricity (LCOE) compared to small rooftop PV systems.
- Diversification of source of income on farms
- Higher module efficiency through better convective cooling (elevated, overhead PV modules)
- Higher efficiency of bifacial modules due to larger distances to the ground and adjacent module rows (for elevated, overhead PV modules)
- Potential additional benefits for agriculture e.g., protection against damage from hail, frost, and drought

Agrivoltaics offers further potential for synergies between photovoltaics and agriculture such as:

- Reducing the need for irrigation by up to 20 percent (for elevated, overhead PV modules)
- Possibilities of rainwater collection for irrigation purposes
- Reduction in wind erosion
- Use of the PV mounting structure for protective nets or foils (for elevated, overhead PV modules)
- Optimizing light availability for arable crops, e.g., PV tracking systems (for elevated, overhead PV modules)

The use of agrivoltaics can create additional value in the region, benefiting rural development. Furthermore, agrivoltaics offers the chance to generate renewable electricity for self-consumption on farms. Solar electricity used directly onsite lowers electricity costs by reducing the need to purchase expensive power from the grid and allows farms to establish a second financial base.

2.2 Rationale for Agrivoltaics Implementation in Mauritius

The Republic of Mauritius is located in the Southwest of the Indian Ocean and comprises several islands, including Mauritius itself, Rodrigues, Agalega, Tromelin, Cargados Carajos, and the Chagos Archipelago. Mauritius faces significant challenges due to climate change, which threaten its socio-economic development and environmental stability, despite its picturesque landscapes and cultural richness.

Over the past 70 years (1951-2020), the country has experienced increasingly severe climatic events that jeopardize infrastructure, agriculture, and human

lives. The mean annual temperature has increased by 1.39 ºC. Projections indicate that the temperature may rise by up to 2 °C by 2061-2070, which could worsen heat-related health issues and harm ecosystems. Mauritius has also experienced a decline in mean annual rainfall of 104 mm, with a further reduction of 7.7% during the last decade (2011-2020) compared to the period 1951-1960. Projections suggest that water availability may decrease by 13% by 2050, which could have negative impacts on agriculture, water resources, and biodiversity. Furthermore, the island is experiencing accelerated sea level rise, averaging 5.6 mm/yr over the last decade, which is higher than the global average of 3.4 mm/yr. This phenomenon poses significant threats to coastal communities, infrastructure, and ecosystems, particularly in low-lying areas. The island is also facing significant beach erosion, with certain coastal areas experiencing a reduction in beach width by up to 20 meters over recent decades. Several beaches have lost approximately 18,500 m^2 of beach area, which poses a threat to tourism, coastal communities, and ecosystems.[25]
Mauritius is vulnerable to climate change due to its exposure to various climate-related hazards and limited capacity to mitigate and adapt to these impacts. As a Small Island Developing State (SIDS), it faces unique challenges because of its small land area, limited resources, and dependence on vulnerable sectors such as agriculture, fisheries, and tourism. Additionally, the geographic layout of Mauritius, with a large portion of its population and infrastructure situated along the coast, increases the dangers related to rising sea levels, severe weather events, and beach erosion.[25]

Agrivoltaics, including PV greenhouses, offer a solution to mitigate the impacts of climate change while enhancing agricultural productivity and economic resilience in Mauritius. Agrivoltaics aim to increase land use efficiency and encompass various applications, particularly addressing the Water-Energy-Food nexus. PV modules can provide shading and physical protection that can benefit Mauritian agriculture, especially considering decreased precipitation and unpredictable rainfall patterns. These systems reduce evapotranspiration, maintain soil moisture, and facilitate rainwater harvesting systems, thereby improving crop irrigation, and aiding in water conservation. Moreover, PV modules can improve crop growth conditions by moderating temperatures and reducing water stress through shading, which can lead to increased yields and improved crop quality. Additionally, agrivoltaics can provide smallholder farmers with additional sources of steady income, contributing to economic resilience and added value in rural areas. Integrated agrivoltaic systems generate carbon-free energy, supporting climate change mitigation efforts while aiding in climate change adaptation in Mauritius.

3 Technology Screening

3.1 PV Module Technologies

According to the DIN SPEC 91434, various PV module technologies and designs can be used in agrivoltaic systems. However, the planning of the module technology, cell gaps and encapsulation materials, as well as the orientation of the modules shall be adapted to the light availability and thus to the agricultural use of the land. The modules shall be distributed evenly over the agricultural land to ensure the highest possible light homogeneity." Accordingly, in currently deployed agrivoltaic systems, various module technologies are used. Monofacial and bifacial modules make up the majority share, but experiments and demonstrations have been conducted with emerging module technologies, including semi-transparent materials, giving promising results. This section provides an overview on PV modules for agrivoltaic use cases.

3.1.1 PV Market Development

The International Energy Agency (IEA) highlighted that solar energy is going to take the largest share of the next decades electricity's mix expansion[26], resulting in even higher demand for PV modules. During the last decades module prices have been reduced significantly, due to the technological development and economies of scale. PV module prices underlie a steep price learning curve: a doubled PV production led to a price reduction of 23.3% in the past 42 years, as can be seen in Figure 3.[27]

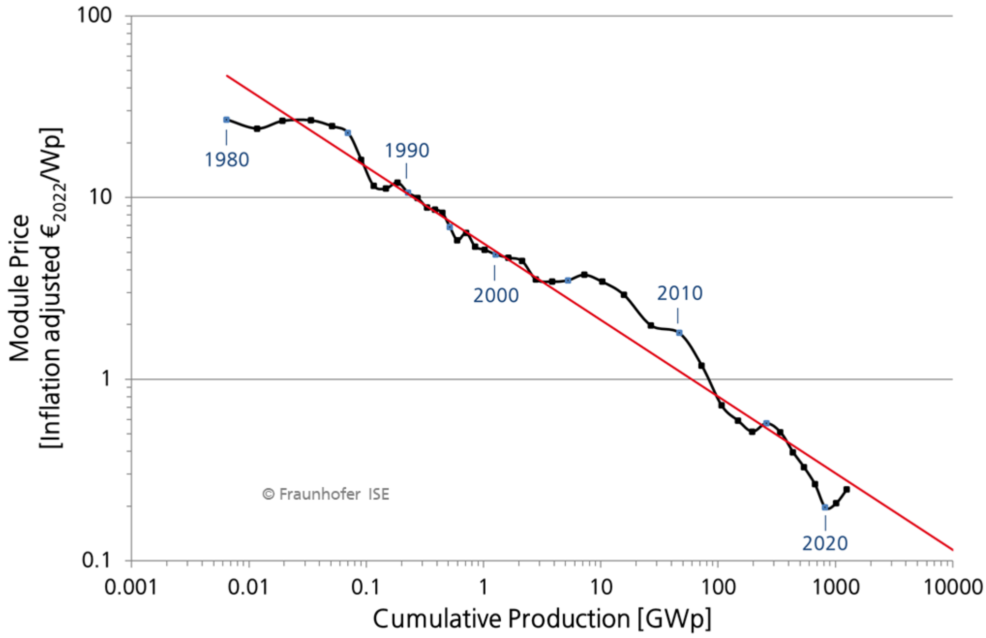


Figure 3: Price learning curve of commercially available PV technologies.[6]

Data: from 1980 to 2010 estimation from different sources: Strategies Unlimited, Navigant Consulting, EUPD, pvXchange; from 2011: IHS Markit; from 2022: ISE; Graph: PSE 2024.

However, Fortune Business Insights reported a negative global market growth rate of - 77.7%, compared to 2018-2019 for PV modules. This trend is driven by COVID-19- related supply chain complications and rising commodity prices, leading to increasing PV module prices. PV module prices climbed from July 2020 to April 2021, erasing a 25% price reduction achieved between January and June 2020. The increasing price trend for PV modules is expected to be of relevance in the African marked until 2024.[28]

Crystalline silicon modules

With a global market share of 97%, crystalline silicon (C-Si) modules dominate the PV market. C-Si modules are divided in two technology clusters: (i) monocrystalline silicon (mono-Si) and (ii) multicrystalline silicon (multi-Si) cells[9]. Mono-Si cells were dominant with a 97% share of the total c-Si modules manufactured in 2022. Figure 4 further depicts the development of the percentual annual production of mono-Si, multi-Si and thin film cells between 1980-2022. [9]

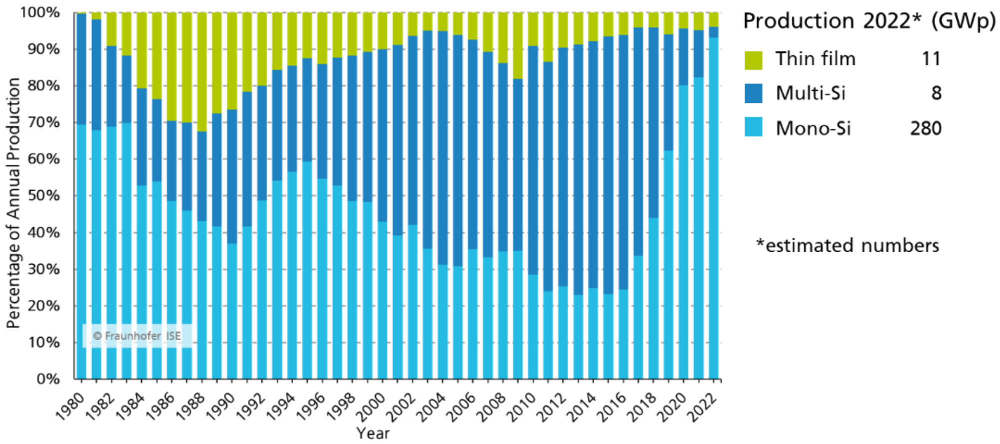


Figure 4: Share of PV production by technology.[9]

The vast majority of Agrivoltaic systems is based on c-Si modules, including opaque monofacial, opaque bifacial and semi-transparent (bifacial or monofacial) modules (Figure 5). These module types will be introduced in the following sections.

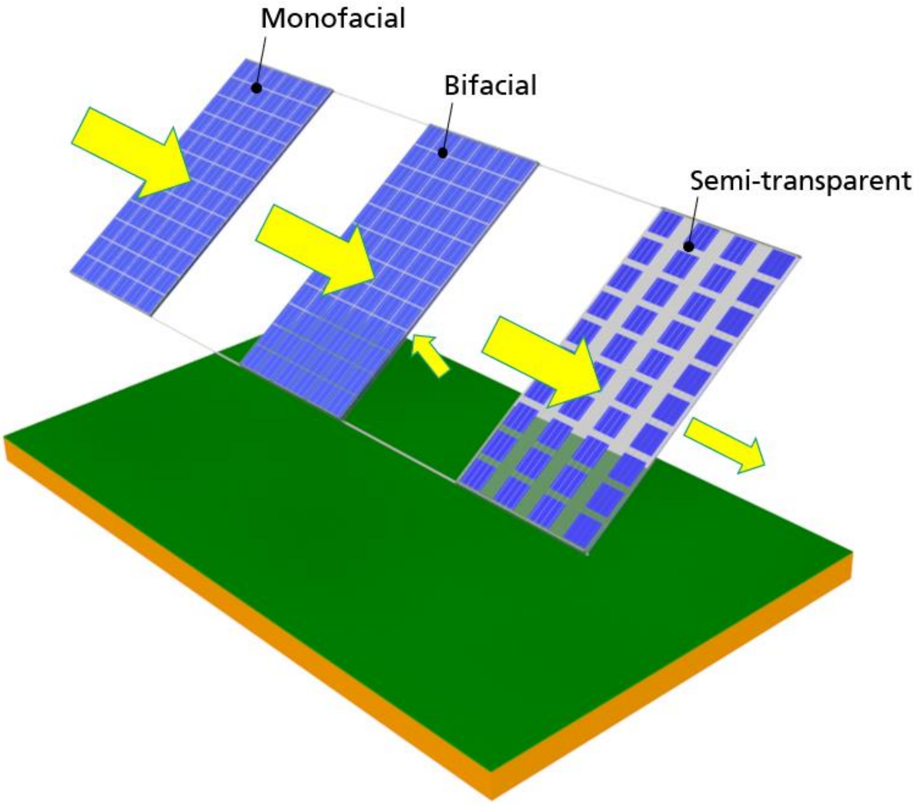


Figure 5: Illustration of the three main c-Si module types used in agrivoltaic system.[9]

Opaque monofacial modules

By now the majority of implemented agrivoltaic systems is based on opaque modules, where light management is made possible through the adaption of the system (e.g., lower Ground Cover Ratio (GCR), deviation from South, tracking mechanism).[22]

Currently the market is dominated by Passivated Emitter and Rear Contact (PERC) solar cells based on p-type mono-Si wafers. The dominance of mono-Si over multi-Si cells is increasing, especially for high efficiency modules. The module efficiency based on PERC cells is around 20% in STC conditions as per 2020. STC conditions refer to Standard Testing Conditions where Temperature = 25°C, Irradiance GSTC = 1000 W/m² and spectrum AM1.5G, which is the spectrum generally used in terrestrial solar cell research. In Figure 6, the efficiency and power of selected modules is given. The efficiency of a solar cell is highly affected by the temperature and the light intensity. An increase in the temperature and a reduction in the light intensity cause a reduction of the module efficiency in comparison to the nominal values.

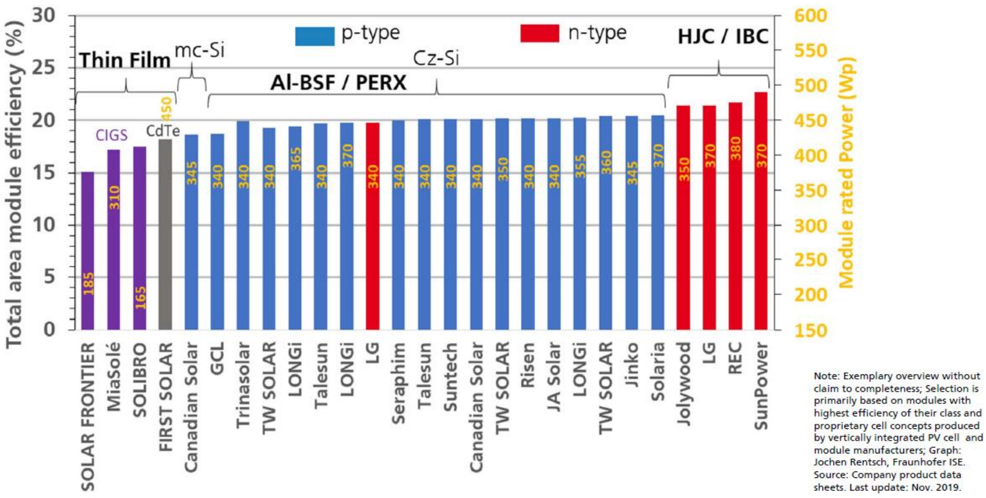


Figure 6: Efficiency and power of currently available commercial modules based on their cell type.[9]

Bifacial modules

Bifacial modules utilize the solar irradiation from both module sides. As a result, the irradiance reaching the rear side of the module can add additional electrical power. In 2020, bifacial modules had a market share of around 20%. This is expected to reach 70% by 2030.[29] As shown in Figure 7, the rear irradiance can come from the direct sunlight after reflection in the ground or from the diffuse part of the irradiation (directly or after reflection).

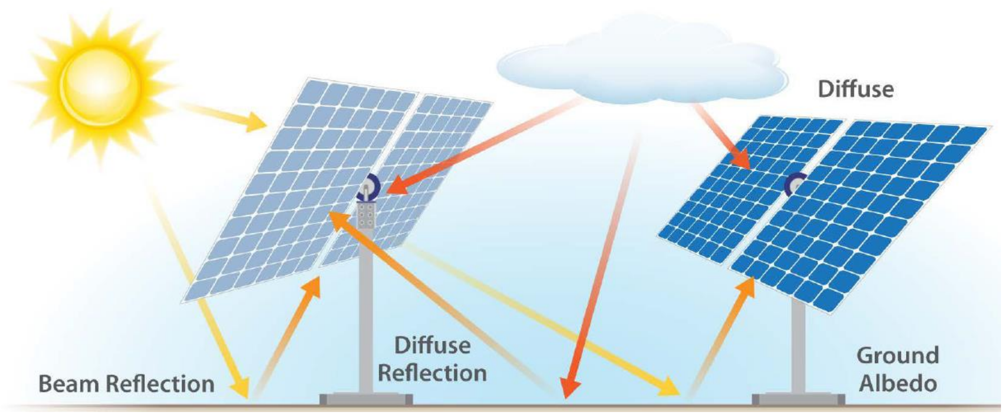


Figure 7: Illustration of the rear irradiance in bifacial systems. (Deline et al., 2019.

Semi-transparent modules

Semi-transparent c-Si modules are constructed with the same cells as the opaque modules, with the difference that the cells are spatially segmented. As a result, the total cell area is smaller than the module area, allowing part of the sunlight to pass through (Figure 8).

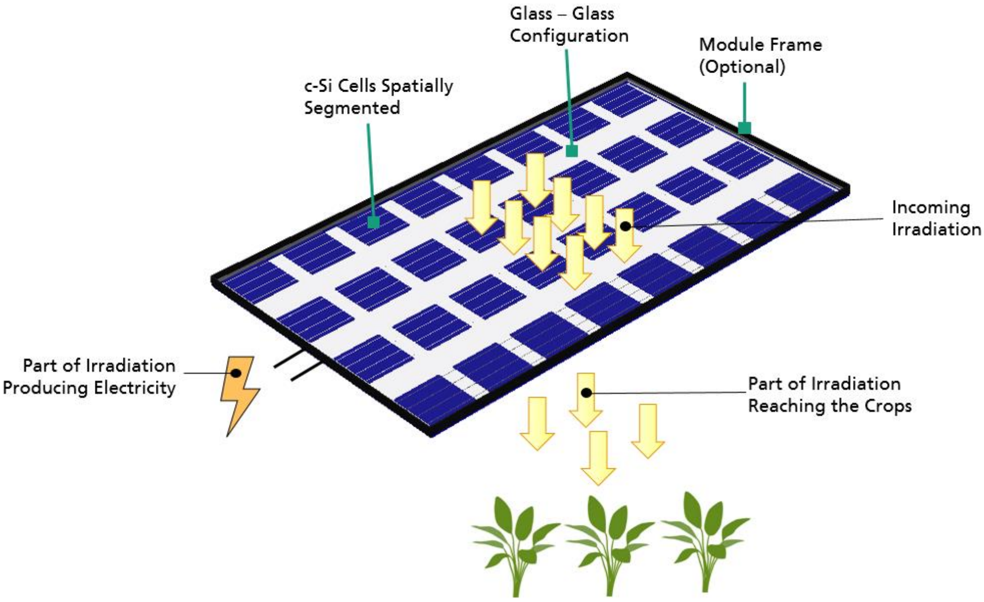


Figure 8: Illustration of the main parts and the working concept of a semi-transparent c-Si module..[9]

As the demand for semi-transparent modules is low, manufacturers avoid including these in their portfolio. The only active areas requiring these types of modules are Building Integrated Photovoltaics (BIPV), greenhouses and only recently open APV systems over orchards, which represent in total a very small market. Moreover, the various possible transparencies make it difficult to offer standardized products.

3.1.2 Environmental Assessment of Relevant Modules

Regarding the environmental footprint, Life Cycle Assessment (LCA) analysis conducted by Fraunhofer ISE showed that the PERC modules produced in Europe lead to a lower Energy Payback Time (EPBT) in a system and module level (Figure 9). However, currently more than 90% of the modules are produced in Asia. In comparison, semi-transparent modules are expected to have a higher carbon footprint than the opaque ones. This results from the higher energy and material consumption during the construction phase and the lower energy production during the usage phase. Module recommendations are highly depended on a light assessment on plant level, giving the possibility to optimize agrivoltaic systems for use cases in Mauritius on plant and PV yield level.

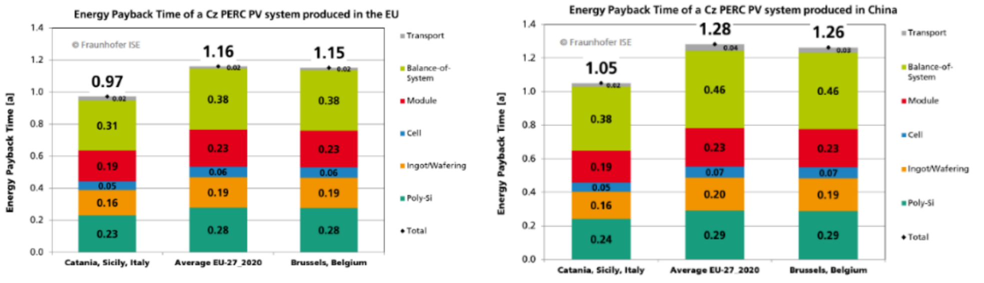


Figure 9: Energy Payback Time for a module produced in EU (left) and in China (right).[9]

3.1.3 Emerging Cell Technologies

Numerous other cell technologies exist, **most however are only in development stage**.

- Soliculture commercialized a semi-transparent luminescent solar collector (LSC), where low density crystalline cells are arranged on a solar glass, allowing light to be transmitted in-between. The glass is coated with a luminescent material which converts the green spectrum to the more efficient for photosynthesis red spectrum[30]
- Wavelength-selective Concentrating Photovoltaics (CPV), is an approach where the concentrator is coupled with a dichroic mirror, which reflects the near infrared region and allows the transmission of the visible spectrum. A group of scientists in China built and tested a CPV module based on this idea, reaching a total system efficiency of 8% and demonstrating very good crop growth.[31]
- The Swiss start-up Insolight developed a CPV module based on lenses which concentrate the sunlight on highly efficient multijunction solar cells. The novel feature is that no module external sun-tracking system is required, while shifting lenses concentrate the sunbeams either directly on the solar cells or beneath. A module efficiency of 29% was confirmed by Fraunhofer ISE testing. Moreover, most diffuse light passes through the module, making it partially transparent. According to Insolight, a price of 150 EUR/m^2 could be achieved if economies of scale were realized[32]. Since the modules only convert direct sunlight, efficiency gains are higher in less cloudy regions.
- Organic solar cells (OPV) are a transparent solution which have a unique feature of narrow absorption spectrum, allowing wavelength selective transparency. Fraunhofer ISE has elaborated a feasibility study on OPV for horticulture in Germany, concluding that a 5% efficiency and 60% average visible transmittance is realistic in short term, with significant benefits for the crops. The study also highlighted the need of further research to solve remaining challenges concerning durability and efficiency[9].

3.2 System Types and Key Characteristics

The design of an agrivoltaic system is influenced by local environmental and climatic conditions, crops, farming systems, and socioeconomics. Commonly, agrivoltaic systems are differentiated between overhead systems, with modules elevated and above crops and interspace systems, with agricultural activities taking place in between the PV module rows. Additionally, greenhouses can be either retrofitted with PV modules or a new PV greenhouse structure can be installed.

3.2.1 Overhead Agrivoltaics

For overhead systems, the layout of the PV modules needs to be optimized to allow sufficient sunlight to reach the underlying crops. The optimal PV module layout for an agrivoltaic system depends on the amount of solar radiation at the location and the shade tolerance of the crops. In areas with high solar radiation and Photosynthetically Active Radiation (PAR), a denser PV module layout can be used for shade-tolerant crops. However, in areas with less shade-tolerant crops and higher latitudes, a less dense layout is recommended. The height of the PV modules should be determined based on the planned crops and cultivation methods.
For taller crops or mechanized farming, a taller module mounting structure is required compared to shorter, hand-picked crops. Even if large agricultural machinery is not used, the PV modules should still be mounted high enough to prevent damage. The modules can be either tracked, or fixed.

Figure 10 shows possible overhead systems, Figure 11 shows a tracked overhead agrivoltaic system.

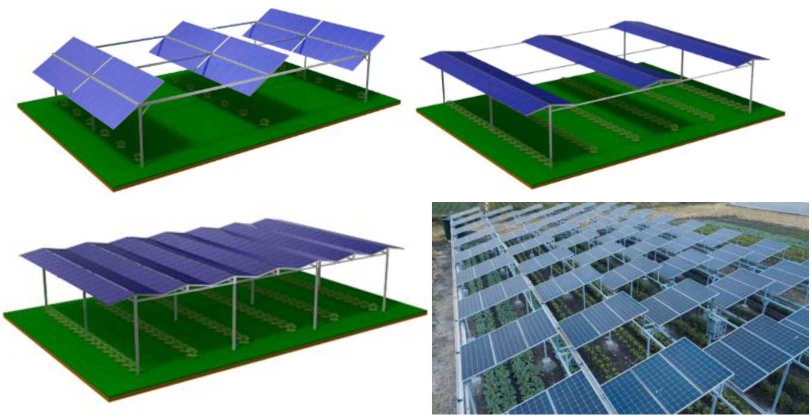


Figure 10: Various overhead agrivoltaic designs and concepts.[9,33]

Figure 11: Tracking agrivoltaic system[6]

Orientation: Regarding the overall system, the orientation of the system affects both the energy yield and light distribution below PV modules. Generally, fixed tilt PV systems in Mauritius are installed facing north (or north-northeast) to maximize energy yield, however, for overhead agrivoltaic systems, this orientation results in an uneven distribution of sunlight to the crops below the PV modules. Deviating to an orientation of either north-west, north-east, or east-west further improves light distribution below the PV modules and thus, homogeneity of light at crop level. To improve the energy yield while orienting systems east-west, single axis tracking can be implemented. Furthermore, systems can be oriented due north in the checkerboard PV layout.

Ground cover ratio (GCR) and pitch distance: GCR is the primary factor to consider as it influences the irradiation incident on the crops and ground beneath the PV modules. The GCR is defined as the ratio of the photovoltaic array area to the total ground area. The GCR required by overhead agrivoltaic systems is typically 20%-40% more than that of ground-mounted PV systems. It is a factor of the PV module layout and/or the pitch distance, which defines the PV module row to row distance. The distance between module rows additionally contributes to the GCR and subsequently the shading rate. The larger the pitch distance, the higher the irradiation (lower the shading) at crop and ground level. In terms of the PV module layout and pitch distance, several options exist and a decision on the layout can only be defined per specific installation site. Pitch distance can be between 5 and 20 m. Row spacing should be chosen according to the light requirements of the crop and the width of the farm machine. This means that, depending on the type of system, a conventional ground-mounted PV system can achieve 700 to 1,100 kWp per hectare, while an overhead agrivoltaic system can achieve 500 to 800 kWp per hectare. Interspace agrivoltaic systems, on the other hand, only manage 250 to 400 kWp per hectare, meaning that they require about three times as much land as ground-mounted PV systems.

System height: The combination of the wide variety of agrivoltaic systems and project-specific aspects (soil conditions, country-specific regulations, etc.) makes it difficult to standardize agrivoltaics substructures. Reducing material consumption is key to reducing costs and environmental impact and improving landscape integration. This aspect is even more important in the case of agrivoltaic, as the systems reach heights of up to 6 m. The main factors in determining the clearance height of the system are the height and size of the agricultural machinery used (if any) and the height of the crops/ trees cultivated under the PV modules. The clearance height should offer sufficient space for undisturbed crop/tree growth, development, and cultivation, and allow for optimal conditions during operations, maintenance activities, agricultural management, and crop harvest.

PV Module Technology: Technically, any module technology can be used for overhead agrivoltaics. Currently, the competitive price of bifacial PV modules, combined with the higher energy yield through increased height and higher rate of reflection of sunlight make the application in overhead agrivoltaics more suitable. High market value crops enable the possibility of the use of more expensive semi-transparent PV modules to increase the light distribution to the area below. However, this needs to be assessed on a case-by-case basis, with the overall site economics determining the eventual selection of module technologies and other balance of system (BOS) components.

3.2.2 Interspace ground-mounted Agrivoltaics

Interspace ground-mounted agrivoltaic systems integrate agriculture between rows of PV modules (Figure 12). Unlike overhead PV approaches, ground-mounted systems have limited vertical clearance, restricting the use of agricultural machinery to the spaces between module rows which have a distance of typically 6-15m. This distance varies depending on row height.[34] It is important to determine the appropriate pitch distance or spacing between rows. This distance should allow for effective agricultural activities to take place, ensuring enough room for machinery to move unhindered between the rows and preventing potential damage to the PV infrastructure.

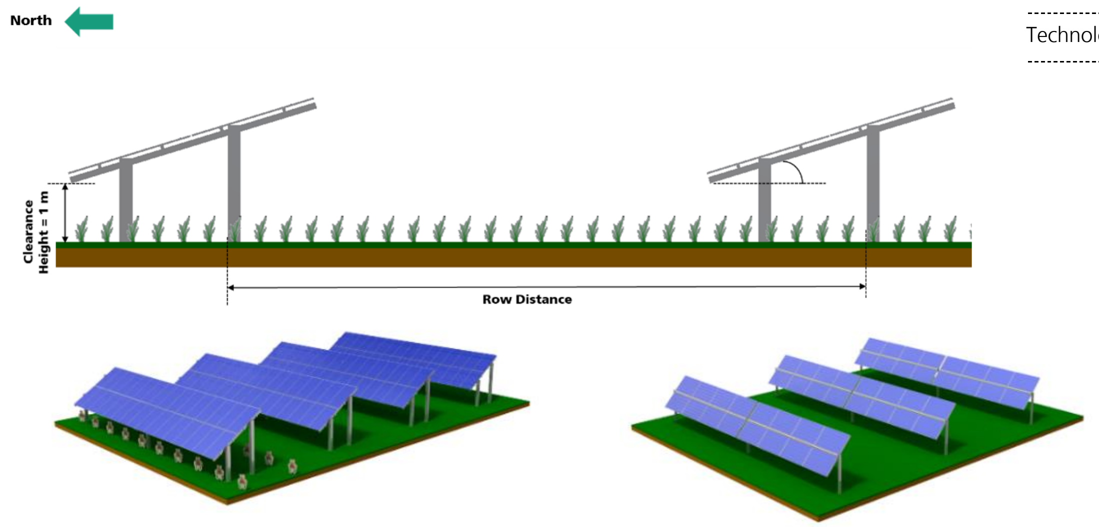


Figure 12: Interspace ground-mounted Agrivoltaic system with machinery.[9]

Vertical agrivoltaic system, a specialized form of interspace ground-mounted agrivoltaics, uses bifacial modules with an east-west orientation, generating electricity primarily in the morning and evening (Figure 13). Despite uneven light distribution causing heterogeneous crop growth, interspace PV can act as a windbreak in windy areas, potentially reducing soil erosion and evapotranspiration. Specific applications of interspace agrivoltaics include grassland and arable farming, excluding horticultural activities typical of overhead PV systems. These differences underscore the need for tailored design considerations in the implementation of interspace agrivoltaics.[34]

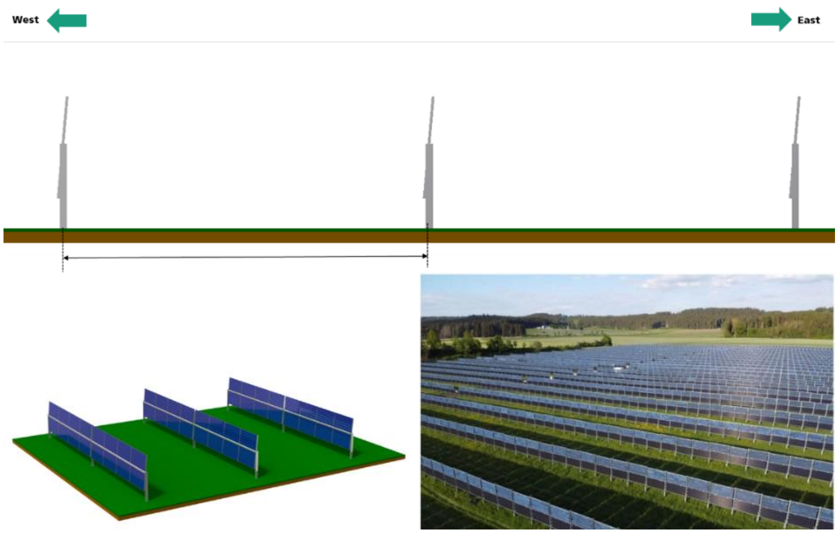


Figure 13: Vertical ground-mounted PV system schemes and 4.1 MWp vertical plant in Donaueschingen-Aasen.[6]

Orientation: As crops will be grown between and only in particular cases under the PV module rows, the orientation of a tilted system would be according to the conditions for standard GM PV, to maximize energy yield. In Mauritius, this would be north/north-northeast facing. For horizontal or vertical PV, the common E-W orientation used in installations in Germany should as well be applied in Mauritius.

Pitch Distance: For interspace GM PV systems, the main variable that defines the distance between the PV module rows is the cropping area and the subsequent unobstructed passage of agricultural machinery through the modules.

System Height: Standard heights used in GM PV installations can be applied to interspace GM PV agrivoltaics. The height may be slightly raised to allow some productive use of the area directly below the PV modules, for either grazing by sheep or growing more shade tolerant crops that can be harvested by hand (e.g., leafy greens).

PV Module Technology: Standard mono- or bifacial modules used in traditional GM PV installations can be used in interspace GM PV systems, while bifacial modules are typically used for vertical agrivoltaics.

3.2.3 Greenhouse PV

Greenhouse system production is a cultivation method that optimizes the interior environment to promote crop growth and development. Greenhouses have transparent walls and roofs made of glass or plastic, allowing cultivation even in cold temperatures that hinder open field crop growth. To enhance crop yields and quality, fuel and electricity are utilized to regulate the greenhouse environment, although the increasing costs of energy reduce profits for growers. Consequently, growers aim to improve production efficiency and minimize energy consumption. Greenhouses extend the growing season and offer a wider range of crop choices. They can also reduce cultivation time, increase the number of crop cycles, and significantly improve annual crop yields. By maintaining favorable conditions within the greenhouse, crop quality is enhanced. Growers can adjust the timing of crop harvest to meet market demands and ensure profitability.[35]

Greenhouses are typically constructed in sunny locations on open fields, as sunlight is crucial for crop photosynthesis. These locations are ideal for PV electricity production as well. The integration of greenhouses and PV systems on the same land unit holds the potential for an innovative and energy-saving crop production system (Figure 14). However, it is important to strike a delicate balance between crop cultivation and PV electricity generation to effectively utilize sunlight for both crop growth and electricity production.[35]

Figure 14: PV greenhouse[6]

Sunlight penetrates easily into a greenhouse because of the roof and wall transparency. The cover materials block thermal leakage. Consequently, the internal temperature becomes higher than outside. By exploiting this thermal property, various technologies related to nighttime heating have been applied. Heating assisted with fuel and grid electricity inputs enables the extension of the cultivation period to colder seasons. It allows the location of greenhouses even in colder areas, with consequent improvement of crop quality during winter. Accordingly, consumption of fuel and electricity increases in cold and lower-insolation regions during winter. By contrast, greenhouse internal temperatures increase excessively during summer in high-insolation regions. Transitory or constantly high temperatures cause a range of morpho-anatomical, physiological, and biochemical changes in plants. They affect plant growth and development and might engender drastic reduction in their economic yield.[35] To regulate temperatures during the summer, greenhouses use artificial shading, evaporative or AC cooling systems, depending on the technology level of the greenhouse and local conditions. There are also greenhouses where no agricultural activity takes place during the summer because of the high heat.

The PV system should be designed to use only the excess sunlight and protect the crops from it. It is vital to consider the requirements of crops to tailor PV greenhouses to their needs, e.g., shade tolerance, water requirements and temperature.

The implementation of PV greenhouses at a farm site could follow two pathways. The first is using the existing greenhouse infrastructure and retrofitting it with PV modules; the second is the new installation of a PV greenhouse structure. Each approach has different design considerations.

For the first case, the existing infrastructure essentially defines the overall design, system orientation, module tilt and sub-structure materials. The existing infrastructure needs to be fully analyzed to assess the capability to accommodate the installation of PV modules (e.g., orientation, gutter height, cover material and current light transmission, structural integrity - i.e., location of support beams and compatibility with PV module dimensions, weight bearing capacity of the structure, etc.).

As with open agrivoltaic systems, the installation of new PV greenhouses can be complex and a single system type cannot be defined for a single AEZ, let alone for an entire country. However, previous research provides enough evidence to give a potential guidance of suitable basic parameters such as the orientation, PV module configuration and PV module type.

Orientation: The orientation of the greenhouse is the first important parameter that also indicates the position of PVPs. The E-W oriented greenhouses with the installation of modules on a North facing roof would ensure the optimum conditions for energy generation. However, it increases the heterogeneity of the light distribution and the shading rate which could harm the agricultural activities.[36] Gupta et al. (2012) investigated the effect of orientation on light distribution for an initially E-W oriented conventional greenhouse (without PV integration). They rotated (clockwise) the single-span greenhouse (even-span roofs) 30°, 45°, 60°, 90° (N-S) in a virtual environment and conducted simulations. It was concluded that there is not much difference of orientation on solar fraction. However, it was stated that 45° rotation has slightly better conditions for a small greenhouse and 30° for a bigger greenhouse because these angles ensure a higher irradiation in winter and lower in summer, which is the preferred condition.[37] The orientation effect becomes more crucial for the multi-span and PV greenhouses. Kozai/Kimura (1977) studied spatial light distribution for a 4-span greenhouse for the E-W and N-S orientations. It was found that the N-S orientation has better light homogeneity, particularly when the elevation angle of the sun is low. For the E-W orientation the southern span shows uniform light, however, heterogeneity increases on northern spans due to the shade of the neighbor spans.[38]

However, the orientation of the greenhouse is not only determined by the sunlight conditions but also the wind direction of the land to ensure natural ventilation. Therefore, wind direction should also be considered.

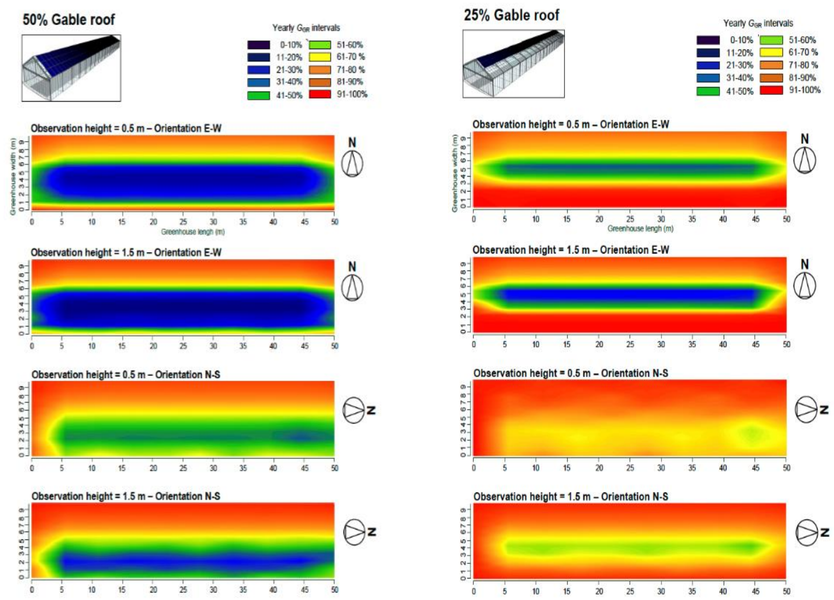


Figure 15: Examples of light distribution maps for different orientations and GCR (percentages shows the irradiation levels with respect to conventional greenhouse).[39]

Gutter height: The gutter height of a greenhouse is also a determinant factor for the PV integration. Higher gutter height means more side wall area which can transmit the light without any blockage. Therefore, particularly in the winter months where the elevation angle of the sun is low, more light transmits through the side walls and more irradiations can be received. According to a study, each one meter of additional gutter height improves the light availability by 3.8% for a PV integrated greenhouse.[40] However, higher gutter height means higher initial investment and higher greenhouse volume which increases the heating and cooling loads. Therefore, even though the higher gutter height contributes the light availability and could help to in-crease installed power, the economic analysis should be done to determine the most feasible dimensions.

3.2.4 Solar Tracking Systems

Several agrivoltaic systems worldwide use tracked PV modules. Tracked systems have the advantage of controlling both electricity generation and biomass production. For example, if certain crops require more sunlight during early growth stages but significantly less during maturation, tracking can increase overall electricity yield while promoting crop growth. The modules can be tilted throughout the day to increase electricity yields or adjust shading levels based on crop growth requirements. France and Italy have made significant progress in researching dynamic agrivoltaics.[41] This technique has the potential to provide substantial benefits for crop adaptation to climate change, such as vine grapes. Research interest has been sparked in the field of artificial intelligence and machine learning to track crop growth data and meteorological forecasts in real-time. Fraunhofer ISE is currently investigating this.

However, there are economic challenges ahead. The cost of tracking mechanisms adds to the elevated mounting structure, while a crop-oriented tracking regime might decrease electrical yields and prohibit offsetting the tracker investment. Although some may view higher operation and maintenance requirements as a major disadvantage, dual-axis systems also offer unique advantages. According to a recent LCA, innovative tensile structures can significantly reduce the amount of steel required, and the tracking mechanism can increase electrical yields by up to 35%. Single-axis tracking may also enable the implementation of robotic cleaning solutions at greater heights. These cleaning robots can autonomously clean PV modules when module arrays are positioned horizontally.[42]

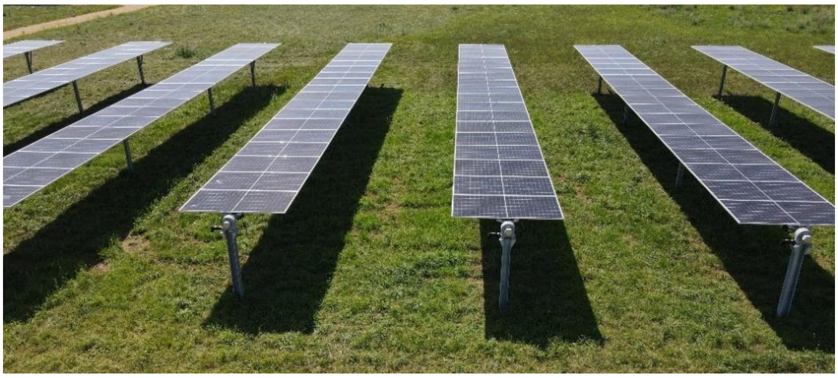


Figure 16: Single axis solar tracking system.[6]

3.3 Rainwater Harvesting

The rain gutter system is comparable to the standard rainwater collection system commonly installed on residential buildings. It can be attached to the existing substructure or directly to the lower end of the PV modules (Figure 17). The rain gutters can be installed at any stage or included in the substructure design. This flexibility allows for the retrofitting of the RWH system if necessary.[43]

Figure 17: Ground-mounted agrivoltaic system with integrated rain gutter. [44]

Fraunhofer has developed a technique and applied for a German patent (application: 10 2020 122 843.0) for an apparatus and method that allows for simultaneous crop cultivation and energetic use of sunlight. The agrivoltaic system integrates rainwater collection and utilizes a V-shaped substructure that can be adjusted to meet individual needs and module requirements (Figure 18).

To ensure proper drainage, maintain a 1.25 cm per 3 m (approx. 0.25° angle of inclination) slope towards the downspout. It is also recommended to install a downspout every 10 m to prevent overloading and standing water in the gutter.[45]

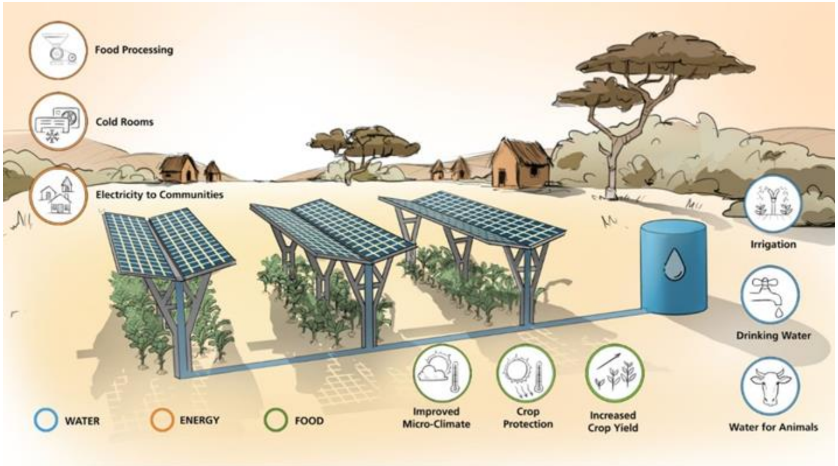


Figure 18: Schematic diagram of an agrivoltaic system for rainwater harvesting that explains the triple land use of agrivoltaics. [46]

Water storage options fall into two categories:

- Natural, which includes the use of already existing water bodies (such as ponds or aquifers)
- Man-made, which includes above and below ground storage (e.g., in tanks).

The water storage system should align with the project objectives, such as aesthetics or reducing visual impact on the environment. To optimize the water reservoir size, analyze the water demand in the area, including detailed requirements for plant irrigation and other water needs. Consider existing water sources as well. After clarifying the relationship between supply and demand and determining the difference, the storage size can be appropriately determined. It should be based on the demand and expected quantity to be collected, without being over or under-sized.

To efficiently distribute water for irrigation and other non-potable uses, good water quality is important. This requires filtering rainwater to remove particles and foreign bodies that can accumulate in the tank and damage pumps and glands. To prevent accumulation of leaves and debris, gutters should be kept clean either by using a wire mesh or by cleaning them at least every six months. For drinking, cooking, cleaning, and other similar uses, a water purification system must be used to guarantee good water quality.

On-site irrigation can be differentiated between:

- Drip irrigation: a highly efficient irrigation system where water is directly applied to the roots of plants. This method is advantageous because it requires lower pressure levels to operate the system, resulting in reduced energy demand for pumping.[47]
- Sprinkler & pivot irrigation: systems that alternate between longer non-irrigated periods and shorter, irrigated periods. Although they can achieve high water efficiencies, they are not as efficient as drip irrigation. However, flood irrigation methods require significantly more water than other irrigation methods.[47]
- Surface and flood irrigation: a system where the entire soil surface of the field is covered by ponded water. This method requires a higher amount of water compared to sprinkler or drip irrigation, making it the least water-efficient irrigation system.[47]

3.4 Substructure, Foundation and Inverters

3.4.1 Load-bearing Structures

The load-bearing structure is a crucial component of the agrivoltaic system. Due to the wide variety of agrivoltaic systems and project-specific aspects such as soil conditions and country-specific regulations, standardizing agrivoltaic load-bearing structures is challenging. Nonetheless, various companies across Europe are involved in designing load-bearing structures for different agrivoltaic projects and gaining experience.

Reducing material consumption is crucial for cost reduction, minimizing environmental impact, and improving landscape integration. This aspect is particularly important, especially for agrivoltaic systems that can reach a height of up to 6 meters. Environmental analysis has revealed that the load-bearing structure and substructure significantly contribute to the ecological footprint of the system. To reduce material consumption, one solution is to use a tensile system (as shown in Figure 20). According to Agostini et al. (2021), traction systems (a setup of rotors that change the angle of the PV modules to follow the sun) have the potential to reduce greenhouse gas emissions. The report states that using a traction system instead of a classic elevation with concrete foundations can reduce greenhouse gas emissions by almost 99%. In a classic elevation, approximately 95% of emissions come from the substructure, while a traction system reduces this to just under 50%.[24]

Figure 19: Tensile structures of (a) the tracked agrivoltaic system (Agostini et al., 2021) and (b) a static overhead system © Krinner Carport

When using special modules, it is important to consider specific aspects of module assembly. For instance, for bifacial or semi-transparent modules, it is recommended to avoid structural elements on the back of the modules to allow higher irradiance at the plant level. Similarly, for frameless modules, a suitable design of the module overlap must also be considered to ensure proper installation.

One open research question is investigating alternative materials, particularly wood. Wood is being considered to be a more suitable material because of its better integration into the landscape. Also, this increases the social acceptance. Currently, researchers are investigating the long-term stability, shadow cast by the columns, costs, and ecological footprint of wooden structures.

3.4.2 Foundation

The anchoring or foundation of the agrivoltaic system ensures its structural stability. When constructing the system, it is necessary to provide proof of compliance with safety requirements. To protect valuable agricultural soil, a permanent concrete foundation is not recommended. Instead, alternatives such as driven foundations, Spinnanker foundations, or ground screws can be used. These approaches allow for the dismantling of the systems without compromising soil quality, as no concrete is poured into the surface.[42]

To ensure the safety and stability of the structure, it is important to find a balance between cost, wind load resistance, and soil protection. This requires a careful assessment of wind loads, which are typically higher in stilted systems compared to ground-mounted ones.[42]

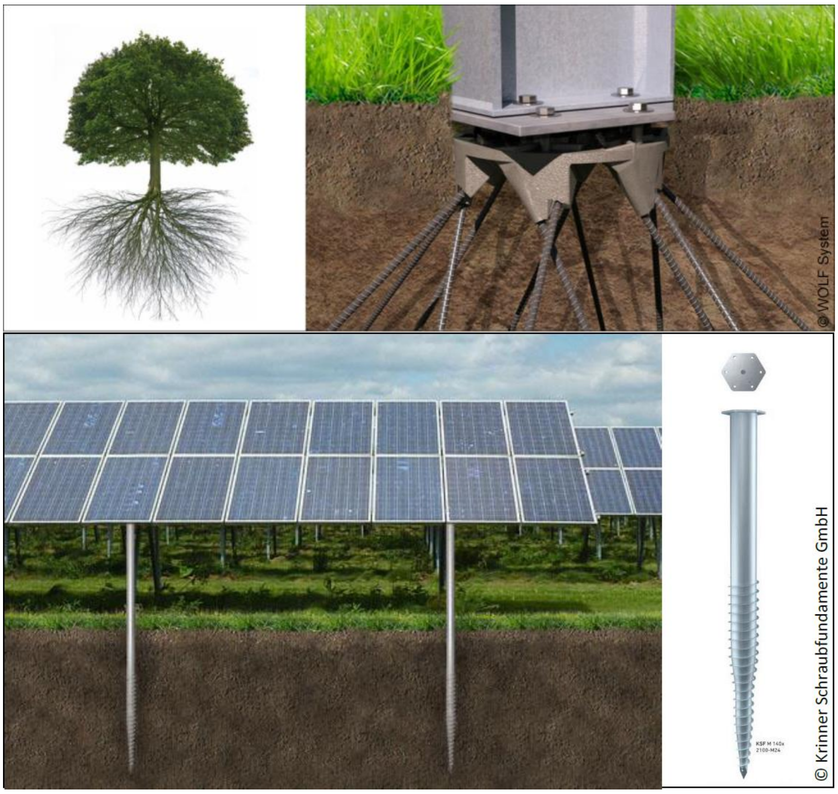


Figure 20: Concept and display of Spinnanker foundation (top), and foundation using ground screws (bottom).

3.4.3 Inverters

Utility scale PV plants can be installed with central or string inverters. Each inverter has its advantages and disadvantages, and the final selection of inverter type needs careful consideration of the main influencing factors of cost and serviceability. Central inverters "centralize" the systems power into one place. String combiners connect wires from each row of PV modules together, then recombiners combine the output of the string combiners together to feed into the central inverter. Central inverter units are physically much larger than string inverters, use longer wires and can convert more power per unit.

String inverters are a distributed architecture for solar systems. They're small, and each unit converts a much smaller amount of power than a central inverter. There's an inverter sited at each row of PV modules, so the 10-20 input strings leading from the modules to the inverters can be much shorter. Since string inverters are converting less power for fewer modules, if one string fails, the whole array's energy is not lost, just the power from that string. In contrast to a central inverter, where much more power is lost if one goes down. Central inverters are less expensive than string overall for large utility-scale installations because fewer are required per site. But for smaller utility-scale projects, string inverters could win out for their easier serviceability. Serviceability is how easily an inverter can be repaired in case of failure. Power electronics are the aspect inherently most prone to failure in a solar installation, so inverters are likely to need servicing throughout their lifespan.

Figure 21: Comparison of String (top) & Central inverter (bottom).

String inverters have several advantages for the medium size of utility scale of agrivoltaic system. The following points are the main advantages of string inverters compared to central inverters, for agrivoltaic system.

- MPPTs (Maximum Power Point Trackers) allow the output of multiple strings to be optimized.
- Installation, maintenance, and repair does not require specialist knowledge while fixing central inverters requires technical expertise that many O&M technicians don't have. Thereby, the replacement of single inverters only affects the power output of the string connected to the inverter and thus, the energy from the whole array is not lost.
- Wiring losses can be reduced, as modules are installed near inverters.
- No agricultural land is sealed by installing central inverter stations.

4
Country Overview

Mauritius is an island nation in the Indian Ocean, located about 2300 kilometers (km) from the southern part of the African continent. In addition to the main island of Mauritius, the second largest island Rodrigues, which is 600 km away, the Cargados-Carajos Islands at a distance of 500 km, the Agalega Islands at a distance of 1000 km and various smaller islands belong to the official national territory.[48] However, only the main island of Mauritius is considered in this report. The location of the main island is shown in Figure 22 below:

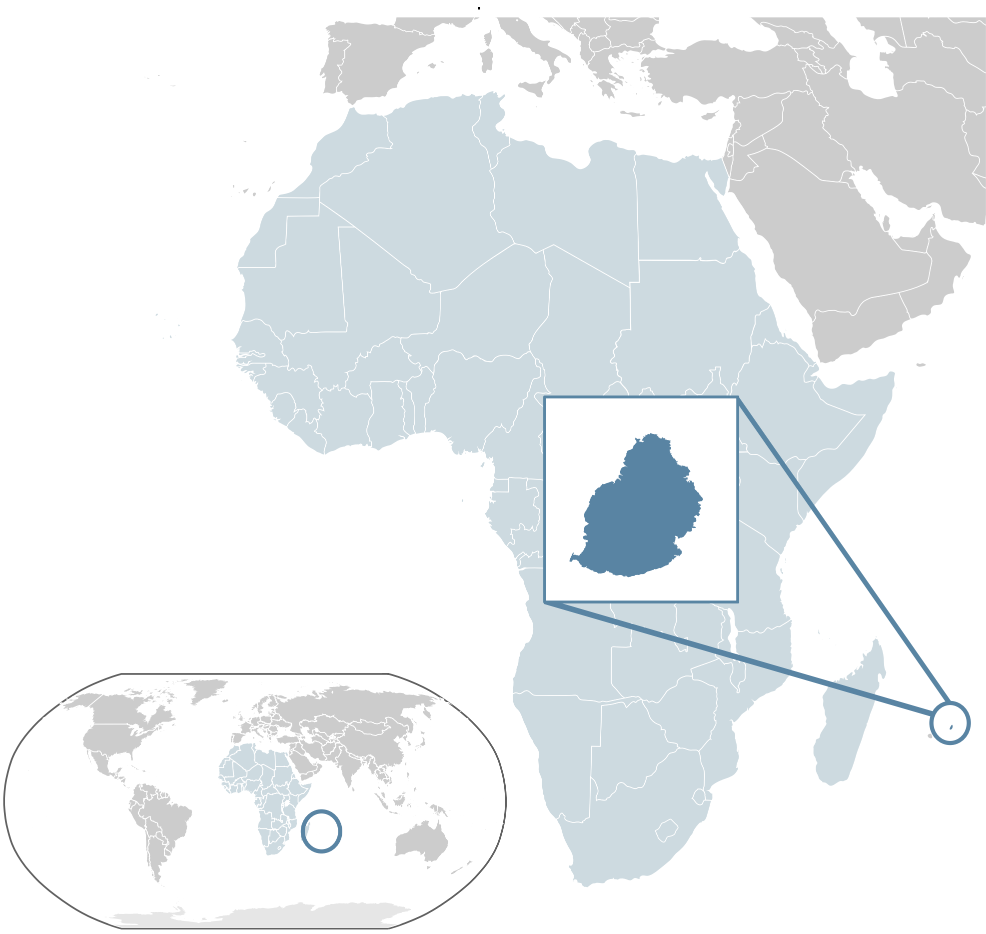


Figure 22: Location of Mauritius[49].

According to a ranking by the World Bank, Mauritius has been classified as a high-income country since 2020. This is due to an increase in income among the lower-income population and a decrease in gender inequality in terms of salary. As shown in Figure 23: Population development of Mauritius, the population of Mauritius increased steadily in the interval from 1950 to 2010; this growth stagnated from 2010 to 2023, when it stood at around 1.3 million inhabitants. A decline to around 850,000 inhabitants is forecast by the year 2100.[50]

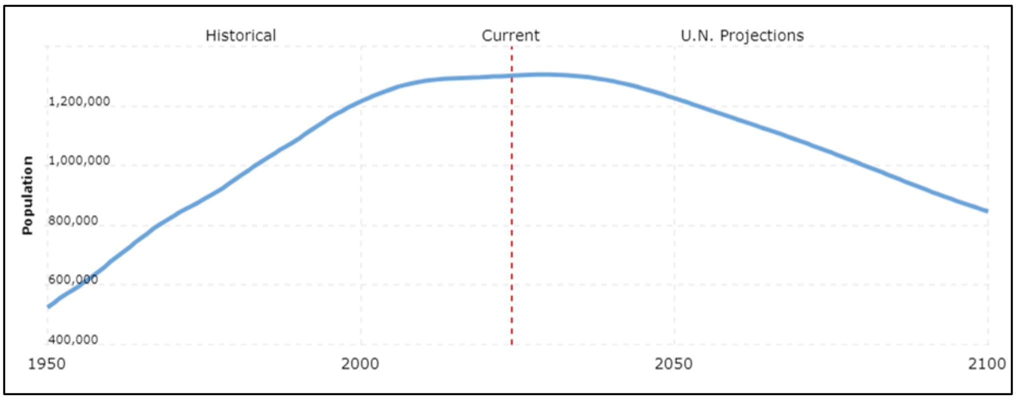


Figure 23: Population development of Mauritius.[50]

4.1 Climate

4.1.1 Temperature and Precipitation

The climate in Mauritius is classified as a mild tropical maritime climate. The months from June to September are characterized by low rainfall intensity and rainfall heights in the range of 10-20 mm per month as well as temperatures of 15°C to 24°C and are referred to as a cold, dry winter. The months of May and October, as well as November in some cases, are so-called transitional months. From November to April, the climate is warm and humid with rainfall of up to 120 mm per month and temperatures between 18°C and 28°C. While the seasonal differences in the amount of precipitation can vary by more than 100 mm, the variations in temperature are relatively small. In the following, Figure 24 shows the annual variation in minimum and maximum temperatures and precipitation levels in Mauritius. The data refer to the respective mean value from the period 1991-2020.[51] More information on the distribution of precipitation on Mauritius can be found in chapter 6 (Water Management Assessment).

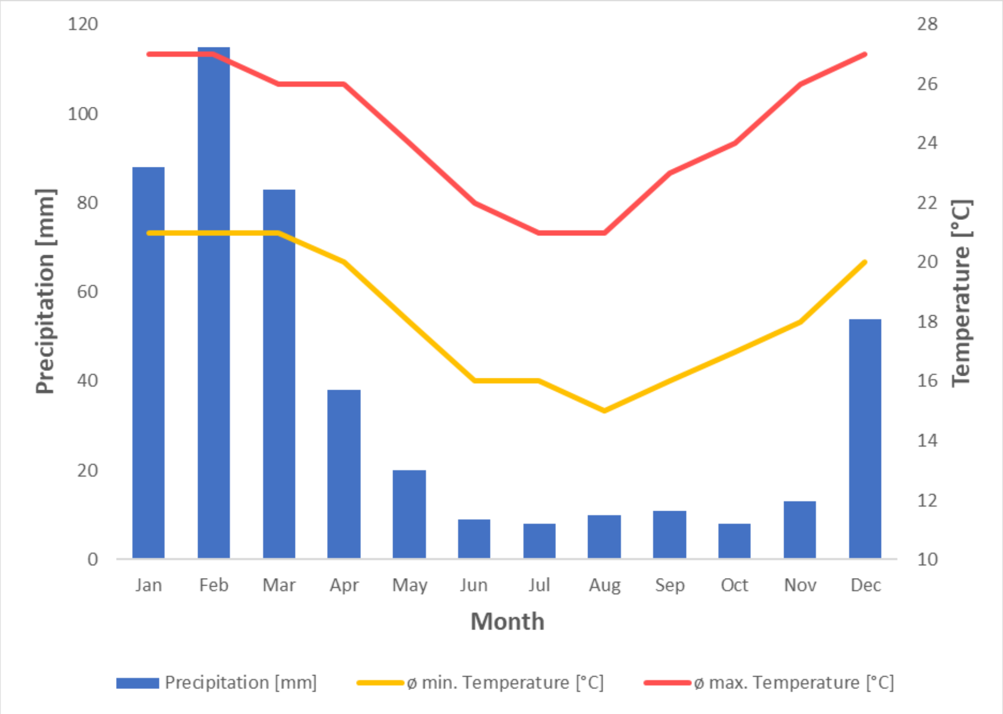


Figure 24: Climate chart of Mauritius[49]

As an island in the Indian Ocean, Mauritius is particularly vulnerable to climate change. In particular, an increase in extreme events and natural catastrophes such as cyclones, floods and droughts, as well as rising sea levels, pose enormous challenges for the country.[48]

4.1.2 Wind

Figure 25: Wind rose of Mauritius and Figure 26: Monthly wind speeds of Mauritius below show a wind rose with the relevant annual wind directions and average wind speeds. Mainly, the wind comes from East or East-South-East. The wind speeds range between 0 and 61 km/h, although in most cases they are between 12 and 28 km/h. All speeds above 61 km/h are termed as cyclones. These are caused by tropical depressions and can reach speeds of up to 260 km/h. Tropical storms are more frequent during the summer season, especially mid-December to mid-March, when the sea temperature gets warmer.[53,54]

Figure 25: Wind rose of Mauritius.[53]

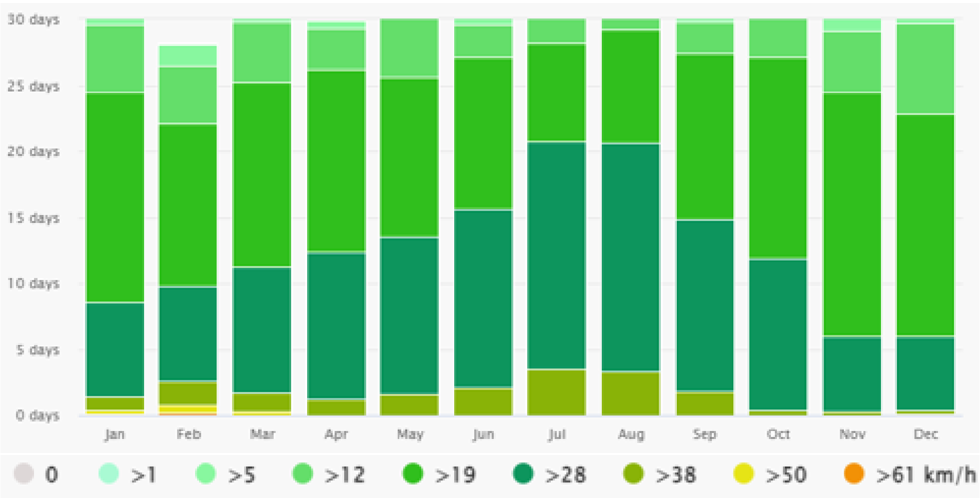


Figure 26: Monthly wind speeds of Mauritius.[53]

An increase in cyclones has already been observed in the northern part of the Indian Ocean, which is presumably linked to anthropogenic climate change. A further increase is also predicted for the future.[55,56] However, for the southern part, where Mauritius is located, there are no current measurements or modeling that indicate an increase, although an increase in events was recorded from 1960 to 2009.[57]

Nevertheless, Mauritius was affected by several highly intense and destructive cyclone events during the period of 2018-2023, nine of which had wind speeds of over 200 km/h. The Agulhas Current in particular provides the basic conditions for the formation of cyclones due to its warm waters, and the impact of the Coriolis force gives the current its characteristic rotational movement.[58] Figure 27 below shows all the cyclones that have formed in the southwestern Indian Ocean and their development from 1980 to 2005. Several of these events have also affected Mauritius.

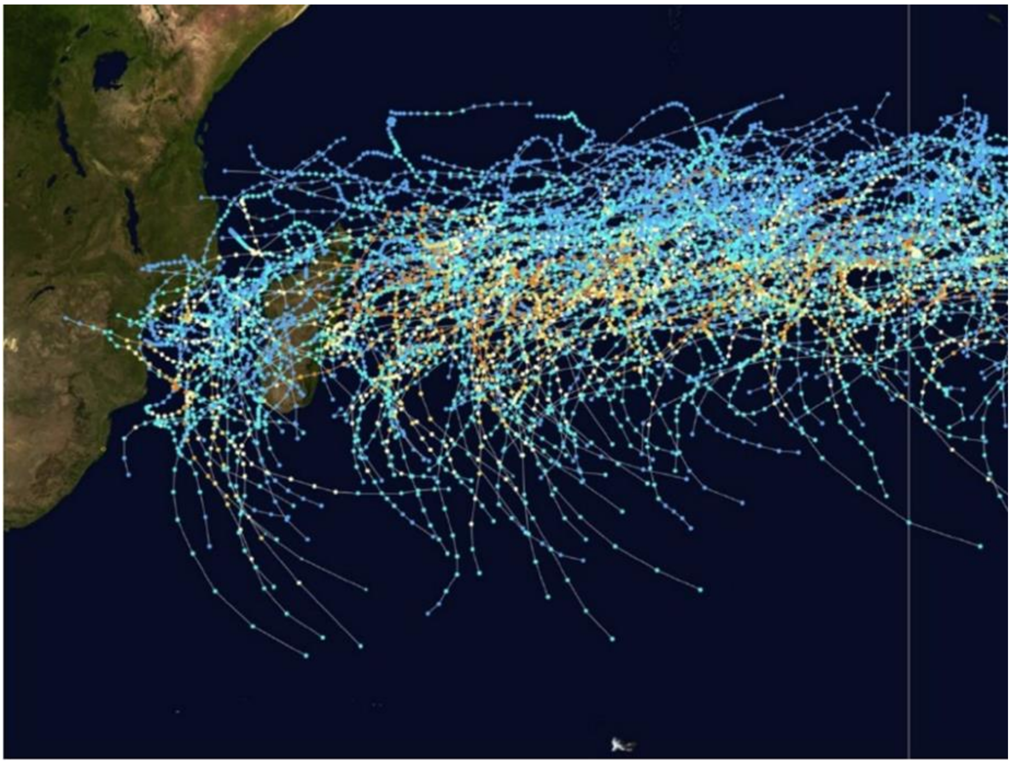


Figure 27: Cyclones in the Indian Ocean from 1985 to 2005.[58]

4.1.3 Solar Radiation

Referring to the long-term average of the global horizontal irradiation (GHI) from 1999 to 2018, the values vary from about 1600 kWh/m^2 per year at the central plateau to about 2100 kWh/m^2 in the north of the island. In terms of PV output, the yearly totals vary between around 1300 kWh/kWp to about 1750 kWh/kWp (Figure 28).[59]

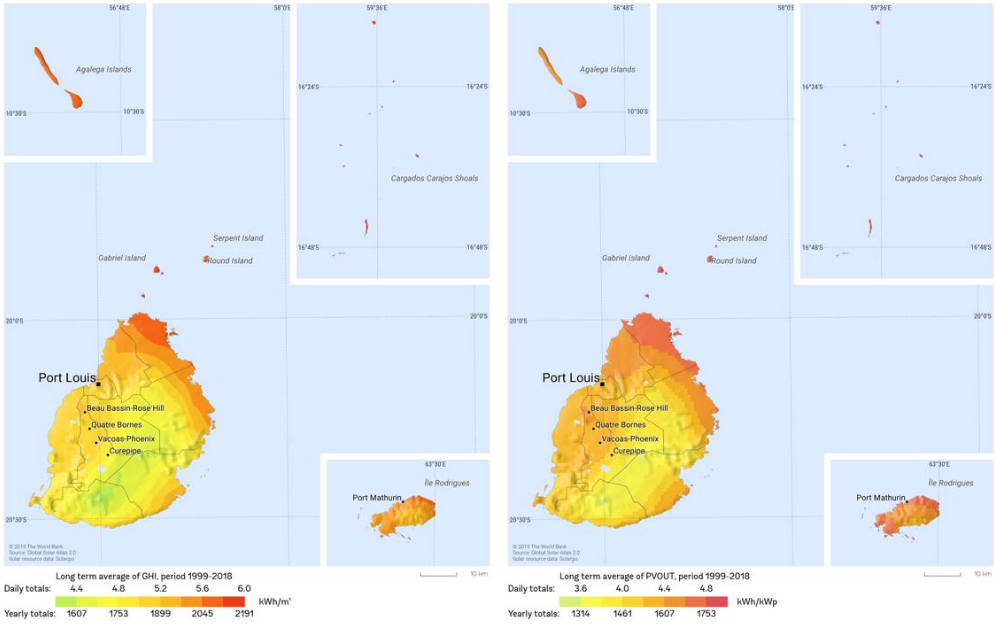


Figure 28: Global horizontal irradiation and potential photovoltaic output of Mauritius.[59]

4.2 Water Use

Mauritius is divided into 25 major and 21 minor river basins, which are varying in size between 3.9 to 172.7 km². Most of the rivers are perennial and have their origin in the Central Plateau, flowing radially to the sea. Further, there are five main groundwater basins in Mauritius that account for most of the ground water resources of the country.

In terms of water reservoirs, used as well for hydropower purposes, there are currently 11 reservoirs, mainly managed by the state and only few privately owned.[60,61]

According to the Water Resource Unit of the Ministry of Energy and Public Utilities, in 2020 most water was used for hydropower with 389 cubic megameters (Mm³), followed by agriculture (305 Mm³), and domestic/industrial/tourism use (294 Mm³). In total, about 997 Mm³ were utilized, mainly from river-run offtakes and storage reservoirs, while only to a lesser extend from ground water, mainly for the domestic/industrial/tourism use (see Table 2).[62]

Table 2: Water Utilization in Mauritius in 2020.[62]

Utilisation	Surface water		Ground water	Reuse of treated wastewater	Total
	River-run offtakes	Storage (Reservoirs)			
Domestic, Industrial & tourism	51 [1]	103	140	0	**294**
Industrial	2	1	6	0	**9**
Agricultural	234	66 [2]	4	1	**305**
Hydropower	175 [3]	214 [4]	0	0	**389**
Overall Utilisation	**462**	**384**	**150**	**1**	**997**
Total Water Mobilisation	**415**	**307**	**150**	**Napp**	**872**

4.3 Energy Collocation and Electricity System Overview

The Central Electricity Board (CEB), under the Ministry of Energy and Public Utilities, holds exclusive responsibility for electricity transmission, distribution, and sales in Mauritius. The island's installed capacity is 876.76 MW, with 498.47 MW from CEB units and 378.29 MW from Independent Power Producers (IPPs), Medium Scale Distributed Generators (MSDG), and Small-Scale Distributed Generators (SSDG). In 2018, total energy production reached 2,827.6 GWh. CEB generated 1,307.8 GWh (46.25%) from its thermal and hydroelectric plants, while 1,519.8 GWh (53.75%) was purchased from private producers. Private generators predominantly use bagasse during the sugarcane season and coal during off-season months. Primary energy sources include heavy fuel oil and coal. CEB utilizes heavy fuel oil for base and semi-base load plants, with kerosene for gas turbines during peak periods. IPPs use bagasse during crop seasons and coal during off-seasons. CEB's thermal plants are strategically located near Port Louis for efficient fuel handling.

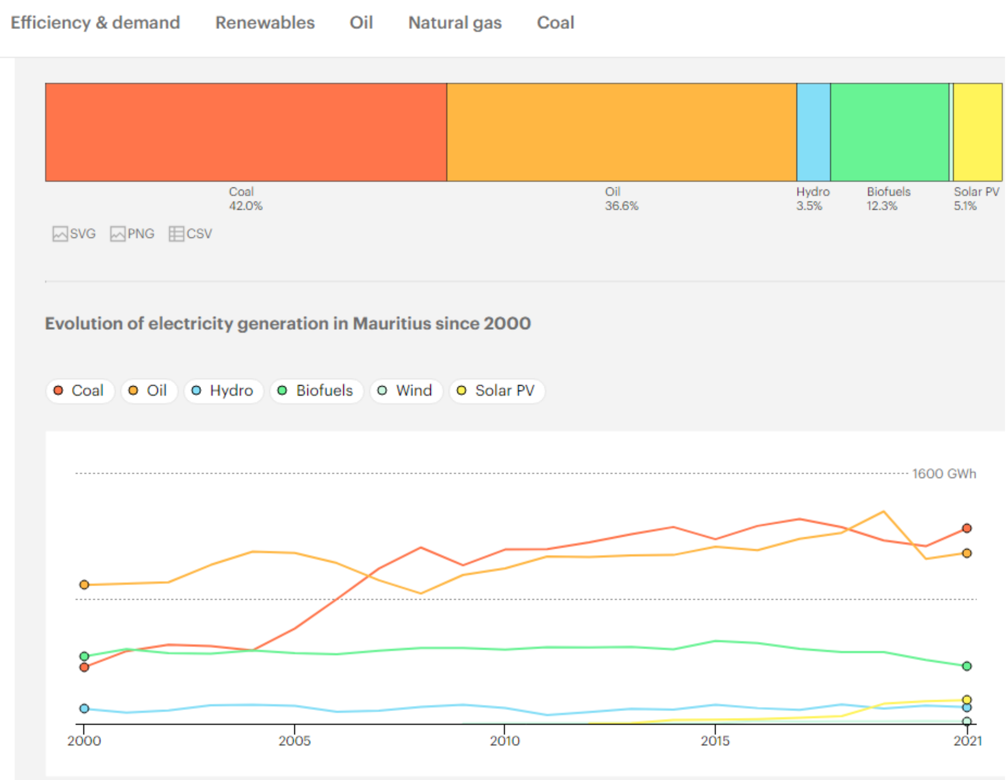


Figure 29: Electricity generation, Mauritius, 2021.[63]

Total Energy Supply

Total energy supply (TES) includes all the energy produced in or imported to a country, minus that which is exported or stored. It represents all the energy required to supply end users in the country. Some of these energy sources are used directly while most are transformed into fuels or electricity for final consumption.

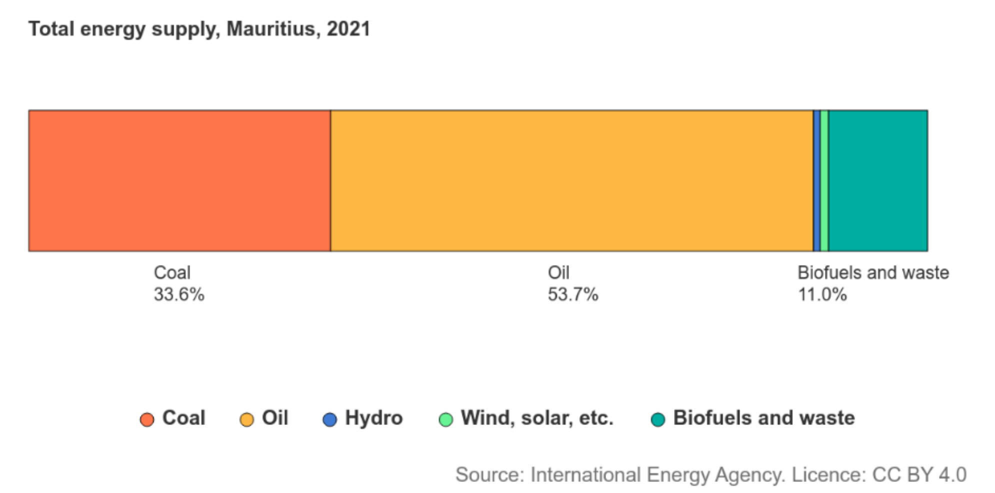


Figure 30: Total Energy Supply in Mauritius in 2021[63]

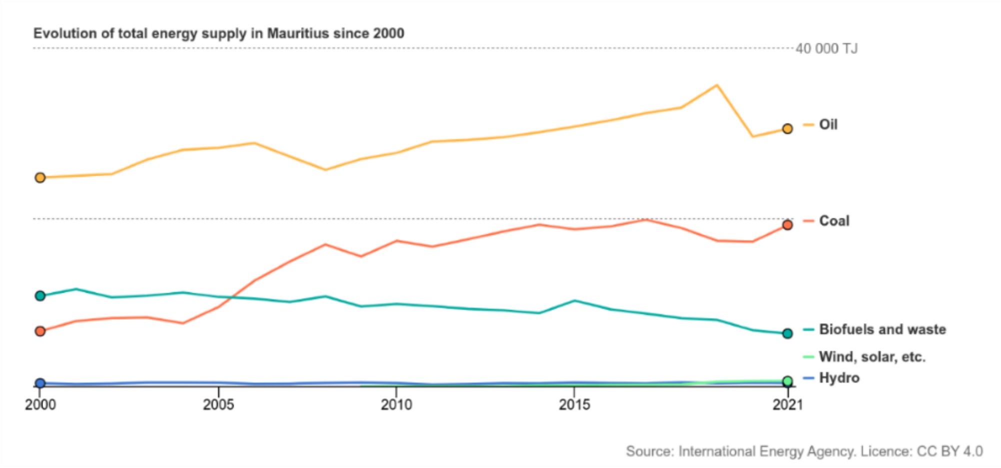


Figure 31: Evolution of total energy supply in Mauritius since 2000.[63]

Domestic energy production

Energy production includes any fossil fuels drilled and mined, which can be burned to produce electricity or used as fuels, as well as energy produced by nuclear fission and renewable power sources such as hydro, wind and solar PV. Bioenergy - which here includes both modern and traditional sources, including the burning of municipal waste - is also an important domestic energy source in many countries.

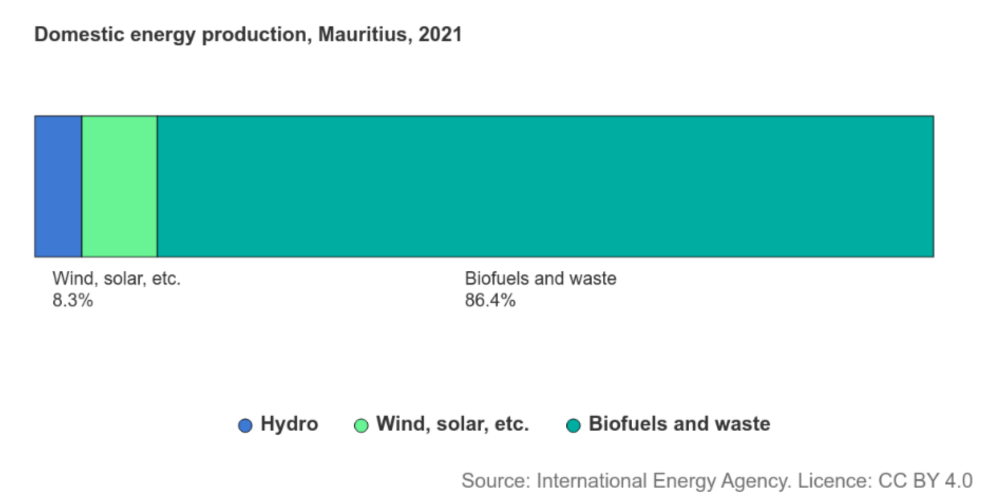


Figure 32: Domestic Energy production in Mauritius in 2021.[63]

Renewable Energy Status and Outlook

The government's energy policy prioritizes renewable and clean energy to reduce fossil fuel dependence and lower greenhouse gas emissions. In 2020, renewable electricity generation reached 23.9%, up from 21.7% in 2019. Plans outlined in the 2021-2022 budget aim to increase renewable energy's share to 60% by 2030, phase out coal, and improve energy efficiency by 10%. The Renewable Energy Roadmap 2030 has been revised to align with these goals, focusing on wind, solar, biomass, wave, and waste-to-energy projects. Bagasse remains the primary renewable energy source (13.3%), with other sources including hydro, wind, landfill gas, and solar.

Mauritius boasts favorable solar and wind conditions, with an average annual solar radiation of approximately 6 kWh/m²/day and wind speeds reaching 8.1 m/s at 30 meters above ground level in certain areas. However, the utilization of solar and wind energy is still in its early stages. Hydropower plants, totaling 60 MW in installed capacity, currently contribute around 4% to the overall energy production, while bagasse accounts for approximately 11% of the energy mix.

Solar Technology: With abundant year-round sunlight, Mauritius is poised for solar photovoltaic (PV) energy, aligning with its goal of achieving 35% renewable energy by 2025. Plans include commissioning six additional solar farms. By mid-2019, total committed solar capacity reached 125.5 MWp, predominantly owned by the private sector. The government's Home Solar Project, inaugurated in 2018, aims to install 10,000 rooftop solar panels. Funded by a $10 million loan from the Abu Dhabi Fund for Development and IRENA, the project successfully reached its first-year target of 2,000 households.

Wind and wave energy: The CEB has secured Energy Supply and Purchase Agreements with two foreign firms for wind farm projects. The first, a 9 MW project by French company Quadran in joint venture with a local partner, was completed in 2016. However, the second project, a 29 MW endeavor involving Indian firm Suzlon in joint venture with a local partner, faced legal issues and stalled.
Preliminary research by the Mauritius Research Council (MRC) indicates potential for offshore wind farms and wave energy in Mauritian and Rodriguan waters. In 2015, Carnegie Wave Energy Ltd. from Australia collaborated with MRC to explore commercial wave energy opportunities. Workshops, including one in 2016 with a U.S. expert from General Electric, have focused on offshore wind energy.

In 2017, MRC issued an Expression of Interest for offshore wind farm development consultants, attracting 40 interested bidders. Additionally, Italy signed a memorandum of understanding in 2018, pledging up to $2.3 million to support activities such as promoting tidal energy and establishing a pilot tidal energy project.

Agrivoltaics/ existing colocation

To date, the main actors that have been active in agrivoltaics and/or solar PV installations in the agricultural sector are as follows:

Akuo Energy
The Henrietta 17.5 MWp solar photovoltaic farm is developed by Akuo Energy, France's leading independent developer of renewable energy developed jointly with the local leader in real estate, Médine Ltd. Henrietta benefits from the industrial, administrative, and regulatory expertise of its two shareholders. Henrietta Solar is a mitigation project that combines the generation of renewable energy with agriculture in Mauritius. Through the construction of 53,700 solar panels, the project will supply sustainable energy to 40,000 people while preserving an agricultural land of 20 hectares. Solar panels will produce around 26,500 MWh, thus injecting renewable energy in the country energy mix. This will then dramatically reduce energy-related carbon emissions.

SUNFarming

A 200 kWp SUNfarming Food & Energy Agrisolar Training Centre was inaugurated, on 26 August 2023, over an area of 4,500 m at Gros Cailloux. The project was project selected for the National Scheme for Emerging/Innovative Renewable Energy Technologies (NSEIRET) by the MARENA, Mauritius Renewable Energy Authority and combines high quality photovoltaic electricity generation and food production facilities (bio-horticulture and vegetable production by drip irrigation).

4.4 Agriculture

4.4.1 Crops and Economy

Agriculture in Mauritius plays a significant role in the country's economy, despite its relatively small contribution of 3.4% to the overall Gross Domestic Product (GDP), compared to over 10% in 1970. Around 5.1% of total labor force is employed in agriculture, while the major labor force can be found in the sector of services (> 70%).[64,65] Figure 33: Share of agriculture in the economy of Mauritius.[60]34 shows the share of the different agricultural sectors in the economy for the year 2018 (Stat Rep 2018). In terms of trade, the European Union (EU) remains Mauritius main trading partner with 24.7% of the total trade, with the main product of export to the EU being sugar and isoglucose (64%).[66]

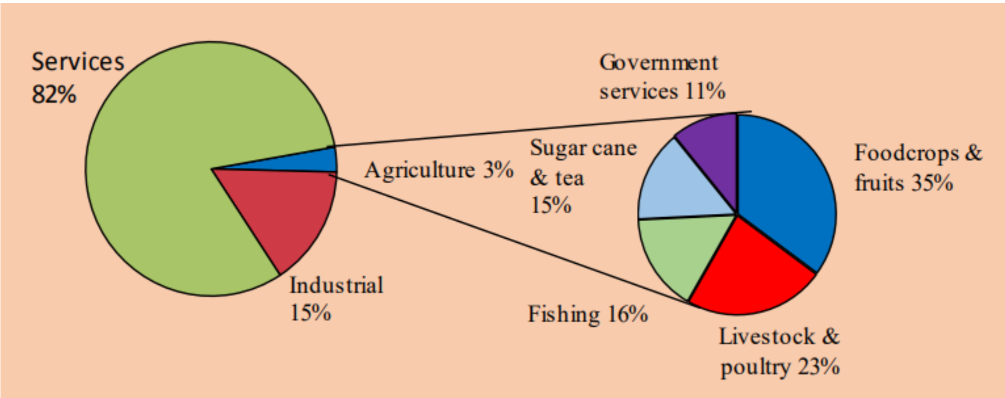


Figure 33: Share of agriculture in the economy of Mauritius.[60]

Thereby, sugar cane is a major contributor to agricultural production, which had an annual production of about 2.62 Mio tons and is being cultivated on about 42.154 hectares, relating to about 22.6% of the whole island surface. Although, as can be in seen in Figure 34: Area of sugar cane cultivation and the production of sugar cane for the years from 1985 to 2017[67], there is a decline cultivated area. It can be seen that the production area almost halved since 1985, while the sugar cane produced was reduced more drastically. Further, a decrease in the production per area has been observed over the years from 2014 to 2018 (Figure 35: Average yield of sugar cane from 2014 to 2018[67]). Other than the diversification within the sugar sector in terms of fairtrade, refined and special sugars, there has been observed a shift from sugar to sugar cane products, including the use of the sugar cane molasses for ethanol production and sugar cane bagasse bio-energy production, contributing to the sectors sustainability and resilience.[52]

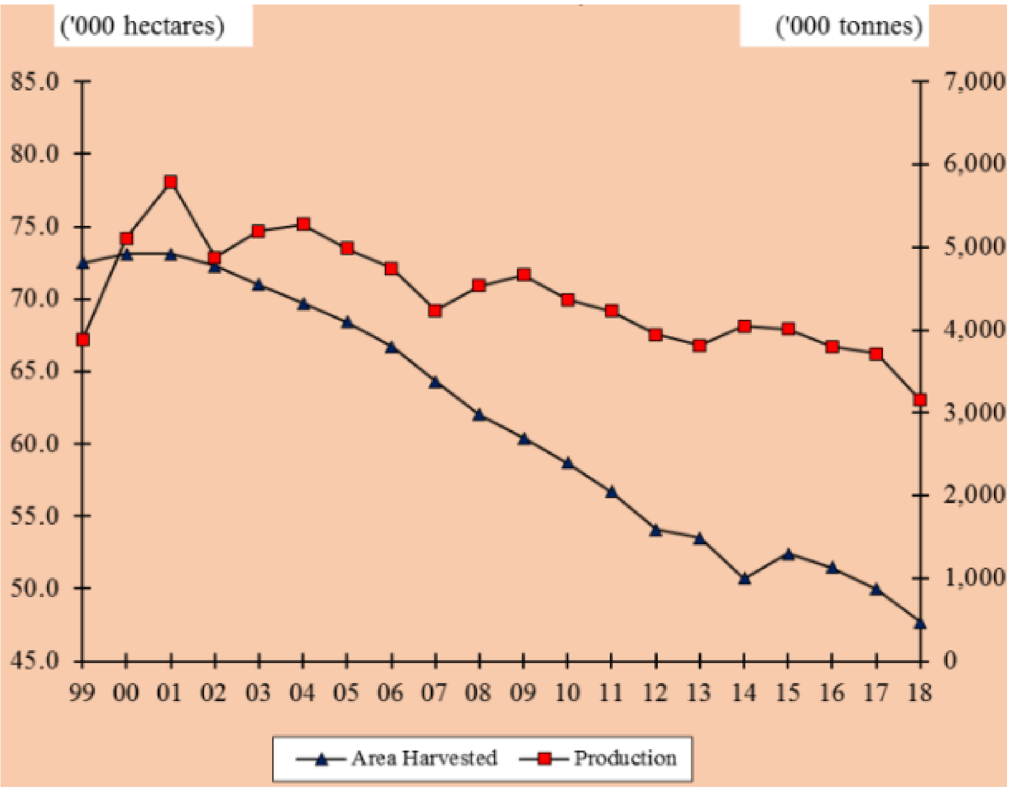


Figure 34: Area of sugar cane cultivation and the production of sugar cane for the years from 1985 to 2017[67]

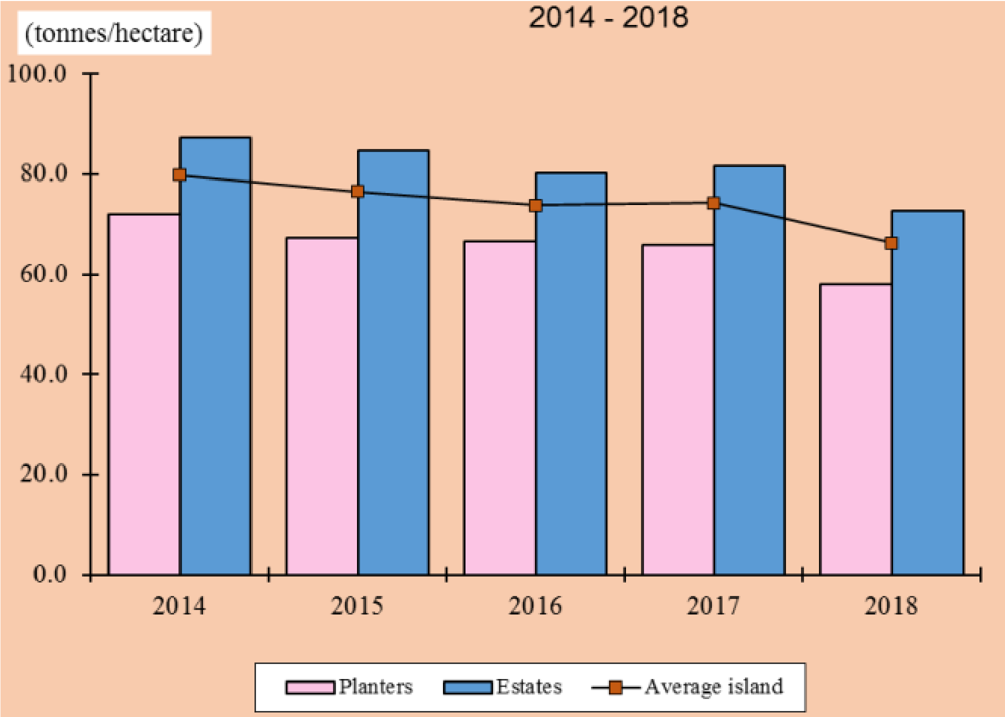


Figure 35: Average yield of sugar cane from 2014 to 2018[67]

In terms of production quantity, sugar cane is followed by food crops such as potatoes, tomatoes, pumpkin, and cucumber, as can be seen in Figure 36: Food crop production in Mauritius from 2009 to 2018[67]

37 for the years from 2009 to 2018. Thereby, the total quantity of food crops produced in 2022 were about 115 200 tons. In terms of fruits such as pineapple and banana, about 30 000 tons of fruits were produced in 2022, while tea leaves contributed about 6 400 tons on a total of 659 ha to the agricultural production in Mauritius.

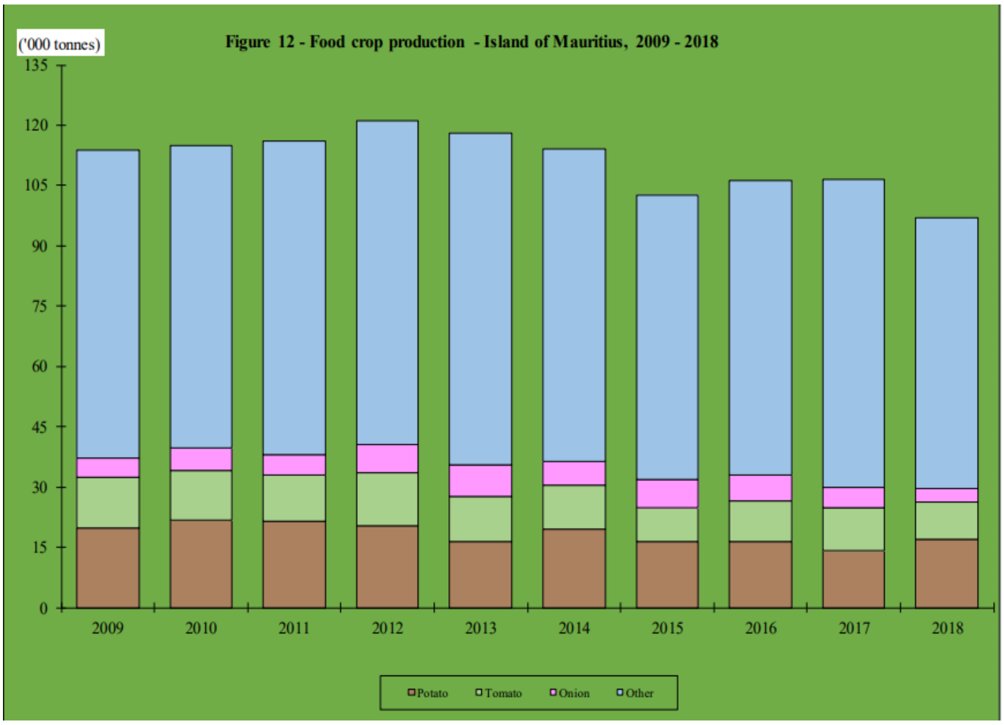


Figure 36: Food crop production in Mauritius from 2009 to 2018[67]

4.4.2 Institutions and Governmental Initiatives

In terms of governmental institutions, the **Ministry of Agro Industry and Food Security** aims on developing agriculture and promoting agro industry, especially in terms of safety, supply, quality innovation and new technologies. It is divided into the departments of agricultural service, forestry service and national parks a conservation service. Thereof, it is in charge of twelve para-statal bodies, with institutions such as the Food and Agricultural Research and Extension Institute (FAREI) (https://farei.mu/farei2021/), the Agricultural Marketing Board (AMB) (https://ambmauritius.mu/) and the Small Farmers Welfare Funds (SFWF) (https://sfwf.govmu.org/). Thereby, FAREI was established in 2014 and has the responsibility to conduct research in non-sugar crops, livestock, forestry and to provide an extension service to farmers in Mauritius including its outer islands. The objectives of FAREI are especially to promote and introduce research and technologies, and to promote and encourage agricultural and agri-business development. The AMB is a self-financed parastatal body operating under the aegis of the Ministry of Agro Industry and Food Security. The AMB was established in 1964 to implement food security strategies and to expand the local production of strategic crops like onions, potatoes, and garlic. The SFWS aims on promoting economic and social welfare of small farmers and their families.

The Mauritius chamber of agriculture is a non-profit association belonging to the private sector, regrouping agricultural farmers and stakeholder especially regarding the sugar sector, other agricultural productions, and related activities. According to their own information, about all agricultural producers of Mauritius (~70) are members of the chamber.[68] In terms of academic research, several academic institutions can be found in Mauritius. Thereby, the University of Mauritius holds a faculty of agriculture (dean: associate professor Daneshwar Puchooa), split into the department of Agricultural Production and Systems and the department of agricultural and food science.

Due to factors such as its limited land size, no economy of scale and the comparative economic advantage of sugar cane cultivation, Mauritius is a net food importer, with a self-sufficiency of about 25%, depending on essential foods as well. Thereby, the government plans to reduce its dependency on imported food by promoting smart agriculture, local crops and inputs, as well as agro processing.[69] According to Mauritius Strategic Plan (2016-2020) on the food crop, livestock and forestry sector, this shall be done by raising the national food security level by maintaining self-sufficiency in agricultural products were possible or generating an increase of local production, focusing especially on sustainable agricultural practices. Within the non-sugar sector, there is an almost 100% self-sufficiency of fresh vegetables and tropical fruits, except for off-season imports of vegetables such as onions, potatoes and garlic.[70]

Several public projects have been implanted within Mauritius, such as the DeSIRA project, which aimed on fostering innovations in agriculture by strengthening the research and development capacity of FAREI, and the Smart Agriculture project, aiming on the reduction in the use of chemicals while proposing sustainable alternatives.[71,72]

4.4.3 Challenges in the Agricultural Sector

There are several challenges that the agricultural sector is facing in Mauritius:

- **Climate change and natural disasters**. Mauritius can be considered as one of the most vulnerable countries to climate change and is highly exposed to natural hazards due to its geographical location in an active tropical cyclone basin. Thereby, extreme weather events are expected to become more frequent, such as heavy rains and flash floods, and the chances for cyclone occurrences will increase, impacting the agricultural sector heavily.[73] During the last decades, Mauritius experienced longer dry seasons, an increased intensity of droughts and shorter wet seasons.[74]
- **Dependence on imports**. Mauritius is a net importer of food, importing a high share of its essential food requirements and having a self-sufficiency ratio of 25%. Thereby, agricultural imports accounted for about 19.9% of total imports in Mauritius in 2021. Reasons for the high share

of food import thereby related to factors such as a small and isolated market, high production cost, limited arable land, the vulnerability to climate change and natural disasters, and limited storage/processing capacity leading in turn to an increased post-harvest loss.[69]

- **Sustainability and environmental concerns.** The local food production in Mauritius relies heavily on the use of agro-chemicals, especially pesticides and fertilizer. According to the Food and Agricultural Organization of the United Nations (FAO), Mauritius is one of the few countries in Africa, applying pesticide levels above the global average.[75] To tackle this challenge, the government has diverse strategies to promote Good Agricultural Practices and organic farming.[70]
- **Water scarcity**. The agricultural sector accounts for the highest water use, followed by an increasing demand of the domestic, tourism and industrial sectors. Thereby, Mauritius is classified as water stressed country and challenged by seasonal water scarcity, especially during the dry months of October to December. Thereby, half of the water supply in Mauritius is ground water, extracted from aquifers, while further sources of water are reservoirs (30%) and river off-take (20%).[74,77]
- **Labor shortage.** Mauritius faces the challenge of an ageing farming community, and an unwillingness of the newer generation start a career in agriculture.[70]

5
Agricultural Analysis

Within the first deliverable of the Mauritius pilot study (Deliverable 1a: Typologies of agrivoltaic solutions adapted to a local context), an agricultural analysis was conducted by Fraunhofer ISE Agrivoltaics team to provide insights into the potential challenges and opportunities for integrating specific crops into Mauritius' agrivoltaic landscape. In the following, after a short executive summary, crops are analyzed on their suitability to a changed microclimate, mainly regarding shading (Chapter 5.1), and further allocated to a specific agrivoltaic system type (Chapter 5.2).

5.1 Executive Summary of Agricultural Analysis

- **Nonfood crops**: While sugar cane is the major cultivated crop in Mauritius, its full sun requirements, height, and mechanization requirements may hinder an economically feasible implementation within an agrivoltaic system. Tea's potential for agrivoltaics lies in its shade tolerance, manual labor-intensive cultivation, and international success stories, especially in Japan. Although, due to its cultivation in the central, super humid part of Mauritius, electrical yield may be comparably lower.
- **Food crops**: The major produced food crops in terms of quantity in Mauritius are potato, banana, pumpkin, onion, tomato, cabbage, calabash, pineapple, cucumber, and carrot. For tomatoes, studies found that a shading rate between 25% to 35% seems to be beneficial for the yield, reducing sun scalding and fruit cracking as well. For cucumbers, shading can be beneficial, although cases have been observed, where a proportional increase of leave and stem biomass compared to harvestable fruits have been observed. Further crops investigated in this analysis include potato, onion, carrot, leafy greens, culinary herbs, ginger, banana, and pineapple.
- **Crop clusters:** The design of agrivoltaic systems is complex and influenced by local environmental factors, crop types, farming practices, and socio-economic contexts. For interspace ground-mounted PV, the spacing between rows is critical, ensuring sufficient room for agricultural activities and preventing shading on PV modules. Overhead systems, on the other hand, require careful arrangement to optimize sunlight for underlying crops, considering solar radiation and crop shade tolerance. According to the different agrivoltaic system types, crops can be clustered:

    - Crop Cluster I: This cluster comprises shade-tolerant horticultural crops like leafy greens, some root crops, and high-value crops and

small fruit trees that benefit from the additional protection by the PV modules. For Crop Cluster 1, overhead agrivoltaic systems are deemed suitable.
    - Crop Cluster II: This cluster includes crops that tolerate less shade, such as certain C4 crops like maize, sugar cane and sorghum. Due to the dual use of the land, the overall productivity of the land will still increase, but as they are expected to have a lower yield in the shade, interspace and vertical PV systems can be considered with a lower CAPEX.

- **PV Greenhouses:** greenhouses can be combined with PV electricity generation, either by a retrofitting of PV modules or by completely new greenhouse installations. The checkerboard pattern (placement of PV modules in a checkerboard manner) can be used to improve light homogeneity compared to straight light conditions, thereby improving growing conditions for crops.

5.2 Analysis of Crops for Agrivoltaics

In terms of area and total production, sugar cane is the major crop cultivated in Mauritius, which had a production of about 2,256,806 tons on about 39,199 ha in 2022. Tea, another nonfood crop, has been produced on about 659 ha with a total production of about 6,351 tons in 2022.[67] In terms of food crops, Figure 37 and Figure 38 show the production area and total production for the year 2022 in Mauritius. Most cultivation takes place on the open field, except for tomato, cucumber, and sweet pepper, which are also (or in the case of sweet pepper only) produced under cover. In terms of production quantity, it can be seen, that the ten most produced food crops in Mauritius in 2022 were potato, banana, pumpkin, onion, tomato, cabbage, calabash, pineapple, cucumber and carrot.[76]

Cereals, such as rice and wheat, are mostly imported to Mauritius. For the year 2022, there was no production of wheat, while about 165,000 tons were imported, and in terms of rice, there were 6,000 tons produced locally, while 60,000 tones were imported.[78] There have been experimental wheat cultivation projects in Mauritius, but constraints are numerous, such as high production cost, scarcity of labor and water, as well as attacks by predators such as mice, birds and hares.[79]

Depending as well on the location of the island, crops can be cultivated either in winter, summer or all year round. Crops, that can be cultivated all year round, include cabbage, bean (broad green), cucumber, tomato, pineapple, lettuce, and chili – although some of them perform better in one season. Seasonal crops (crops that are cultivated and harvested during specific times of the year, known as growing seasons) include potato, sugar cane, cauliflower, carrot, eggplant, and onions (see Crop Calendar, Table 15 in Annex).

In the following, crops, and their potential for cultivation in an agrivoltaic system will be discussed. Important parameters that define the suitability for a specific agrivoltaic system type, are, (1) the crop's need for protection from environmental hazards such as excessive irradiation and rain, (2) response to shading or shade tolerance, (3) the degree of mechanization and machinery used in the agricultural process, and (4) the height of the crops. International experience and research results for the specific crops and system types are also mentioned, where available.

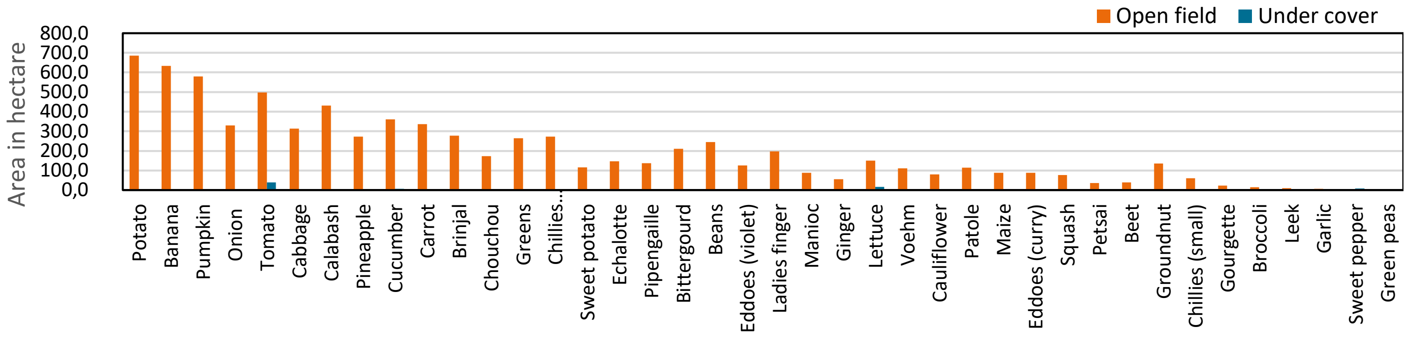


Figure 37: Cultivation area of crops cultivated in the year 2022[76]

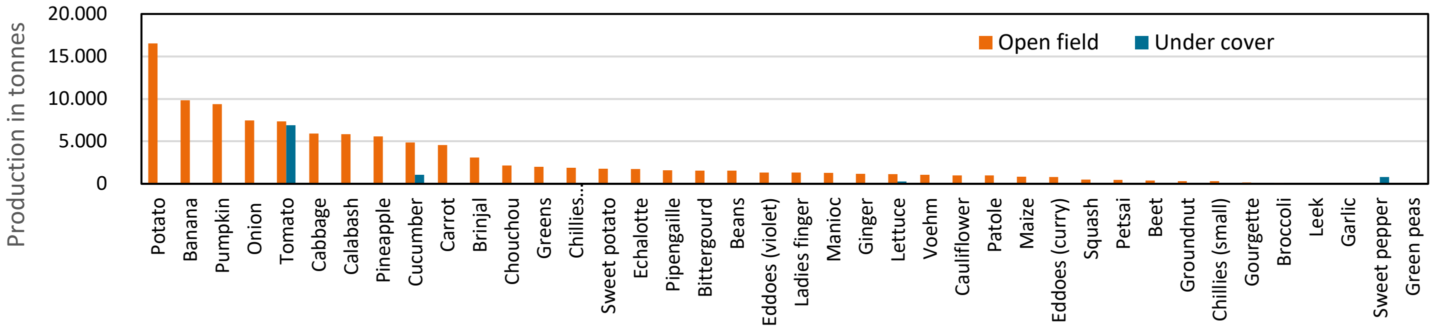


Figure 38: Production of crops in tonnes in 2022[76]

5.2.1 Nonfood Crops

In terms of nonfood crops, sugar cane and tea are some of the most cultivated crops within Mauritius, which are going to be analyzed for their suitability within the agrivoltaic system in the following. Ornamental crops are also produced in Mauritius and will be briefly investigated.

Sugar cane (Saccharum officinarum)
Sugar cane is the major agricultural crop in Mauritius, which had a production of about 2,256,806 tons on about 39,199 ha in 2022. Thereby, the districts in the East, such as Flacq, had the largest area harvested (in total 14,972 ha), followed by the districts in the South (12,736 ha) and North (11,491 ha). In general, the highest productivity in yield per hectare was observed for the northern region, accounting for 59.9 tons per hectare, compared to an average of 54.9 tons per hectare in the southern region. In terms of plantation size and ownership, owned plantations were prevalent with a number of 9,503 plantations and almost 21,000 ha, while there were only about 214 tenant planters on a total of 419 ha. Most plantations had a size of up to 10 ha, while less than 1% were cultivating on an area larger 10 ha. However, those plantations with a holding size of larger 10 ha accounted in sum for about half of the land cultivated with sugar cane[67].
Physiology: Sugar cane is a large, perennial grass belonging to the family of Graminaceae, producing multiple stems or culms. It is cultivated in the tropical and subtropical regions of the world, primarily due to its ability to store large concentrations of sucrose in its stem. The height of sugar cane is about 2 to 5 meters, with 5 to 20 upright stems ("tillers"), which have a diameter of 2 to 4 cm.[80]
Cultivation: The harvest season of sugar cane in Mauritius normally begins in June and ends toward the month of December. Sugar cane is reproduced by vegetative propagation, usually using two or three bud cuttings. The plant cane is then commonly harvested 8 to 24 months after planting, while the "ratoon" crop, which arises from the stalk of the plant cane, is usually harvested after 12 months. Commonly, sugar cane is cultivated with a plant cycle of seven years in Mauritius, and it prefers a well aerated soil with a depth of 1 to 1.5 m and a clayey or loamy texture. It is advised to do dual row planting for sugar cane, which consists of planting pairs of rows 0.5 m apart with 1.8 m between their centers, as it facilitates weed control, does not require additional fertilizers and potentially improves cane yield.[81–83]

Potential of sugar cane for agrivoltaics:

Physiology and shade tolerance: Sugar cane, as a cereals like corn, sorghum and millets, belongs to the C4 plants, which can make efficient use of available light compared to C3 plants.[84] Therefore, they often thrive under full sun conditions, making them more suited to interspace agrivoltaic system than to overhead systems. Although, due to height of sugar cane, shading effects on PV modules in an interspace system, need to be considered. In general, there is not much research being done in terms of how shade affects sugar cane.

Mechanization: In contrast to previous decades, the sugar cane sector has experienced a development from manual to a more mechanized cultivation, including agricultural machinery such as cane harvesters, as well as tractors for the application of fungicides and herbicides.[85] This needs to be considered when designing the agrivoltaic system (→ interspace system). Although, at isolated small fields and areas with steep slopes manual harvesting is still being practiced, further highly humid areas with more than 2,500 mm of rainfall impose challenges to heavy machinery such as harvesters, as they remove large quantities of soil in wet conditions.

Environmental hazards: Mauritius is hit frequently by cyclones, with the officially cyclone season being from November to March. The cyclones are characterized by high waves, strong winds and heavy rainfall and their effect on sugar cane production can be dramatic. It has been estimated that the average annual crop output is reduced by 5.6% due to cyclones, while for exceptional cyclones, crop yield can be reduced by up to 60%.[86] While the PV modules and substructure can provide a form of wind protection to prevent wind erosion and desiccation, as well as physically protecting the crops, cyclones need to be considered in the design from a statics point of view. Further, sugar cane can be considered as susceptible to drought, as it is a water loving plant, reacting with a reduced cane yield, especially when there is a water deficit in the early growth stages. The PV modules in an overhead agrivoltaic system thereby might reduce crop water use and the water evaporation from the soil.[86–89]

International experience: There has been a feasibility study been conducted for hypothetical agrivoltaic system for sugarcane cultivation, by Stefani and Felema (2021), for a central region of the State of Sao Paulo, although according to our best knowledge there has not yet been any implementation.[90]

Conclusion: Sugar cane is the most produced crop in Mauritius, with a well elaborated value chain, enabling the production of bioethanol and biogas as well, thereby contributing to the renewable energy goals of the country. Due to a limited shade tolerance as a C4 crop, its large size and the use of heavy machinery, overhead agrivoltaic systems most likely will not be economically feasible. In terms of interspace agrivoltaic systems, significant loss of area for sugarcane cultivation is expected as the PV modules are low to the ground and do not allow cultivation beneath and, when cultivated between module rows, sufficient space should be left between the crop and the PV modules as shading by the plant may affect PV yield.

Tea (Camellia Sinensis)

Tea had a production of about 6,351 tons on about 659 ha in 2022, and cultivation took mainly place on private plantations (492 ha), while factories had a lower share (167 ha). In terms of plantation size, almost all tea plantations (99.6%) have an area size of less than 2 hectares, relating to 70% of the total cultivated land by tea, with only few individual plantations above 2 hectares. The total production of green tea was 6,351 tons in 2022, while the production of black tea was smaller with 1,156 tons. Export was relatively low, with 34.5 tons making up less than 1% of total tea production. Thereby, in 2022 most tea was exported to Reunion and France.

In the Strategic Plan 2016-2020, the Ministry of Agro-Industry and Food Security identified tea as a priority crop which could contribute immensely to the Mauritian economy. While there was a large decrease in area cultivated due to the expansion of sugar cane during the 90s, there was a percentage increase in manufactured tea for the period 2015 to 2019 of 22.24%. Several measures were taken within the 2022/2023 budget to revitalize the tea sector, such as winter allowance, covering up for losses during the winter period, the release of agricultural state lands and the extension of financial and non-financial support to tea cultivators.[91]

Physiology: The tea plant (Camellia Sinensis) is a plant native to China and has been introduced to Mauritius about 250 years ago.[92] The plant can grow tall (3 to 4.6 m) but can be trimmed shorter or shaped as hedges, with a preferred height of 1 to 1.5 m in commercial operations to facilitate tasks such as the manual harvest of leaves. It has elliptic, leathery dark green leaves which are evergreen, and white fragrant flowers. Camellia is susceptible to a number of fungal diseases, such as leaf sport, black mold, canker, petal blight and root rot.[93,94]

Cultivation: Reproduction of tea plants is usually done by taking cuttings from selected plants, which will be raised in nursery beds for 12 to 18 months until replanting in the main plantation takes place. The leaves of such a plant can be plucked about 4 years after the replanting, while a constant pruning and shaping takes place to give the plant the required height of about 1.20 m. After the plant has reached is full size and begins to produce at the end of the fifth year, pruning still takes place at varying intervals (on average about every 2 years) to keep the height of plucking. Usually, a mature tea plant has a lifespan of 40 to 50 years, with some varieties reaching up to 100 years.[95] Leaf picking can take place the whole year, although most leaves are collected during the summer months, from October to March.[96,97]

Potential of tea for agrivoltaics:

Machinery: in terms of tea cultivation, there is still a lot of manual labor, or the use of small machinery, such as mini harvesters, making tea a potentially suitable crop for systems such as overhead agrivoltaics.

Shade tolerance: In terms of shade tolerance, tea originates from native habitats under the shade of forest trees. Plants can appreciate protection from the sun in the early morning and from the direct hot afternoon sun.[93] Several studies have been conducted on the effect of shade on tea, applying different shade levels, such as Mohotti (2004) and Wijeratne et al. (2008) in Sri Lanka.[98,99] Thereby, a medium level of shade (35% reduction in incident photosynthetically active radiation) has been found beneficial for leaf photosynthesis rate, increasing photosynthesis compared to full sun exposure or under a high shade of 65%. In a study conducted by Philip Owuor (1988) in Kenya, tea cultivated under artificial shade produced black tea of a higher quality compared to unshaded conditions. They reported tea with a higher theaflavin and reduced thearubigin concentrations and with a better flavor index and tasters' evaluation for shaded conditions, while caffeine content stayed the same for shaded and unshaded conditions.[100] In terms of shade level impact on yield quantity, there are few results. A study by Fang (2022), in which different colored shade nets were used to cover Camellia sinensis with 95% shade for 2 weeks in June 2021, found that this high level of shade greatly reduced bud density (-54.8%), bud fresh weight (-23.9%), and yield (-65.8%) for the black shade net, while the results for the blue and red shade nets showed only a slight reduction compared to non-shaded conditions.[101]

Climate: Tea is mainly cultivated in the fertile high-altitude areas of the Central Plateau in Mauritius.[102] Precipitation is higher compared to the coastal regions, and horizontal irradiation is lower, especially compared to the Northern coastal area, making it less suitable in terms of photovoltaic power generation, compared to other sides in the country. In contrast, average temperatures are lower on the Central Plateau, potentially positively impacting PV module efficiency.[103]

International experience: In terms of international examples on tea cultivation within agrivoltaic systems, tea is ranked among the most popular crops in Japan. As of 2021, 15 systems have been installed on Japanese farms. They found that the PV modules provide milder growing conditions, mitigate harsh direct sunlight during the hot seasons and prevent frost formation during the colder season. In general, they found that agrivoltaic has the potential to revitalize the tea farming in certain regions, such as Shizuoka prefecture.[104]

Example of agrivoltaic system with tea cultivation in Japan: https://www.businessinsider.com/agrivoltaic-farming-solar-sharing-growing-more-popular-in-japan-2022-12

Further synergies: It has been reported that labor conditions on the open field are harsh due to hot temperature and irradiation, starting from midday. Shading provided by the PV modules could therefore improve the working conditions.

Conclusion: Generally, tea seems to be a suitable crop for the cultivation within an agrivoltaic system, as tea seems to be able to tolerate the shade applied and even can benefit in terms of yield quality. Further, due to the high amount of manual labor, machinery should not be an exclusion criterion, but shading could even improve the working conditions. There are already some agrivoltaic systems in place in other countries, for example, in Japan, making it a popular system. As far as photovoltaic power generation is concerned, tea is grown in an area with above-average precipitation and mountainous terrain, which means that cloud cover reduces solar yields.

Ornamental plants

Ornamental plants can be considered as export commodity in Mauritius.[105] Commonly cultivated are anthurium, rose, gerbera, chrysanthemum, orchids, foliage, tropical exotics, with anthurium, rose and gerbera being the main crops. In total, around 67 hectares are currently being used for ornamental crop production in Mauritius.[70] In terms of a combined ornamental crop production and PV electricity generation within an agrivoltaic system, there is not yet any literature available. However, it has been shown, that anthurium plants require some shade for a satisfactory growth and flowering.[106,107]

5.2.2 Food Crops

While most of the arable land is dedicated to the cultivation of sugar cane, there is the need to increase and diversify local food production to reduce import dependencies and to increase self-sufficiency. In the following, the crops tomato and cucumber are analyzed in more detail, while suggestions for further crops are given. More information on the shading tolerance of different crops is given within the crop clusters in the following chapter.

Tomato (Lycopersicon esculentum Mill.)

The tomato production was 14,268 tons on 536.5 ha in 2022, thereof the covered tomato cultivation was, with 6,903 tons on 39 ha (177 tons/ha), highly more productive compared to the open field cultivation, where 7,365 tons were harvested on 497.5 ha (14.8 tons/ha). In 2022, the main months of harvest were from June to November, with a monthly harvest of at least 1,300 tons, while in

2021 the production was only higher than 1,300 tons in the months of September and October. In contrast, the highest monthly retail prices were observed in 2022 for the months from February to May (168.84 to 244.02 MUR per kg), while the prices were about half in the other months of the year. In terms of tomato production per district in 2022, most production took place in the northern and eastern coastal districts, namely Flacq, Pamplemousses, Riviere du Rempart and Grand Port.[67]

Physiology: Perennial plant, often grown as annual plant with a height of 1 to 2 meters.[93]
Cultivation: Cultivation on the open field is possible the whole year, where both the seedling production in nursery with following transplantation, as well as direct sowing are practiced. Sowing rates thereby are around 0.3 to 0.4 kg per hectare. Light, well-drained soil with a pH of 5.5 to 7.0 is usually preferred. The growing period depends on the tomato variety but is usually between 150 and 180 days. In terms of climate, the optimum for growth, yield and fruit quality is an average daily mean of 20-24 °C. High humidity leads to a higher incidence of pests, diseases, and fruit rotting. Therefore, dry climates are preferred.[108]

Potential for agrivoltaics: In Table 3, the effects of shading observed for the cultivation of tomato in different climatic zones are listed. As can be seen, in general, a shading rate between 25% to 35% seems to be beneficial for the (marketable) tomato yield, increasing the quality of the yield as well by the avoidance of sun scalding and fruit cracking. While shading levels between 40% to 50% might still be feasible without mature yield reductions, above 50% often a negative impact of shading on tomato yield is observed. Further, high shading ratios may increase the risk of certain pests and diseases.

Table 3: Effect of shading on yield and yield quality of tomatoes.

Location	Climate	GHI [kWh/m²]	Effect of shading
Experimental Garden of BPTP, (Malang, Indonesia)[109]	Tropical/ Equatorial (Am)	1,862.0	Highest production observed under 25% shading, compared to full sun and 50% shading (no significant difference in yield between full sun and 50% shading).
AgriLife Research Center at El Paso (Texas, USA)[110]	Arid (BWh)	2,177.4	At 50% no change in marketable tomato yield, at 70% yield reduction (although total yield, including unmarketable yield, was higher under full sun).
Agriculture Experimental Station at El Kanatir (Egypt)[111]	Arid (BWh)	2,117.4	Maximum tomato yield at 35% shading. Increasing shading ration up to 50% leads to an increase of fruits per plants, above (> 51%) leads to a decrease. Shading improved as well physical characteristics of tomato fruits. Highest weight, length diameter and volume of fruits was observed under 35%

			shading. Under shading, reduction as well of % of sunscald and puffy fruits.
New Anchialos, (Eastern/central Greece)[112]	Warm temperate (Csa)	1,629.1	Different shading levels between 34% and 49% applied, with an increase in fresh tomato yield observed. Shading did not reduce the total plant dry matter content, but increased the leaf area index, the number of fruits per plant, and the total fresh tomato yield. Shading reduced losses caused by tomato cracking by 50%, and thus increased the marketable tomato fruit yield by approx. 50% compared to growth under non-shaded conditions.
University Orchard, HC&RI, (Coimbatore, India)[113]	Equatorial (Aw)	1,987.3	At 35% higher yield compared to non-shaded conditions.

Cucumber (Cucumis sativus L.)

The cucumber production was 5,938 tons on 368.6 ha in 2022, thereof most cucumber cultivation took place on the open field, with 4,882 tons harvested on 361.5 ha and a productivity of 13.5 tons/ha. In contrast, covered cultivation was conducted only on about 7.1 ha with 1,056 tons harvested, therefore having an average yield of 148.2 tons/ha. In terms of monthly retail prices, prices were varying between 53.97 and 68.00 MUR per unit.[67]

Physiology: Recent forms range from thick, stubby little fruits, 7-10 cm long, to longer, more than 50 cm long fruits. Cucumbers are annual vines.[114]

Cultivation: Generally, cucumber prefer a light and well-drained soil and can be planted by direct sowing with a sowing density of about 1 kg per hectare. The length of the cropping cycle is about 90 to 120 days, they perform better in summer conditions.[108] While the "traditional" white cucumber, which makes about 70% of total production is cultivated on the open field, while the green cucumber, used e.g. for salads, is mainly produced in greenhouses and covers about 30% of production (personal communication, Mr. Goolaub).

Potential for agrivoltaics: As can be seen in Table 4, depending on the specific conditions, shading can have a beneficial impact on yield and quality of cucumber, while also could lead to a proportional increase in leave and stem biomass compared to root and fruits. For the trial at Aburaihan Campus in Iran, highest yield was found for a shading ratio of 35%.

Table 4: Effect of shading on cucumber.

Location	Climate	GHI [kWh/m²]	Effect of shading
Mahatma Phule Krishi Vidyapeeth (Rahuri, India)[115]	BSh Semi-arid	1,959.0	An increasing yield was recorded with an increase in shade level (35%, 50% and 75% shading). Yield under the shade nets was up to 10 times higher compared to open field cultivation.
Aburaihan Campus, University of Tehran (Iran)[116]	BSk/ Semi-arid/Mediterranean	2,107.1	The highest number of fruits per plant and the highest yield was reached for a shading level of 35%, while the number of fruits tended to decrease as shading density increased to 60%. Shading density also greatly influenced the physiological disorders like sunscald of cucumber fruits.
Pietermaritzburg, South Africa[117]	Cfa Humid subtropical	1,686.7	Applied shade by plastic tunnel (30% and 10%), as well as shade houses (15% and 40%). Under shading, cucumbers produced less total dry matter. Proportionally more dry matter was found in leaves and stems and less in roots and fruits.

Further crops

Potatoes were cultivated on about 686.3 hectares in 2022, with a total production of 16,519 tonnes, and a productivity of 24.1 tonnes per hectare. There have been several studies conducted on shade tolerance of potatoes, some of them specifically regarding agrivoltaic systems, such as in southern Germany. While they found a reduction in yield in wetter years, yield was increased when the weather was rather hot and dry during the growing season.[118] Another study on shade tolerance of potatoes in agroforestry systems in southern Germany found that potatoes appear to be shade tolerant and can cope with up to 26% shade.[119] In a study conducted in Sri Lanka, shading during the first four weeks after planting was found to improve tuber yield using an artificial shade with 50% light transmission. However, a reduction in tuber yield, weight and number of tubers was observed when shading was applied throughout the growing season, emphasizing the effect of the degree of shading.[120] **Onions** were cultivated on about 329.6 hectares in 2022, with a total production of 7,443 tonnes, and a productivity of 22.6 tonnes per hectare. A study conducted on the cultivation of different onion varieties during the rainy season in Indonesia found that plant height, number of bulbs, bulb weight and bulb diameter were significantly higher under non-shaded conditions compared to cultivation under plastic shade.[121] **Carrots** were cultivated on about 336.7 hectares in 2022, with a total production of 4,547 tonnes, and a productivity of 13,5 tonnes per hectare. Carrots generally have high light requirements and grow best in full sun.[122] A study conducted in Bangladesh on the effect of different shading treatments (no shade, coconut leaves and black or white polyethylene shade), found that highest marketable yield and therefore highest return were under no shade conditions.[123]

Leafy greens consider crops, such as *cabbage* and *lettuce*. Cabbage (Brassica oleracea L. var. capitata) is mainly produced on the open fields, with a total cultivation area of 312.7 hectares and a production of 5,901 tons, while the area used for covered production was under one hectare. Cabbage can be cultivated on all types of soil, preferring a pH between 6 to 6.5. A typical crop cycle lasts between 90 and 120 days, there are different varieties depending on summer/winter. Lettuce (Lactuca sativa L.) is mainly produced on the open field, with the area of production covering 149.5 hectares, while total production was 1,153 tons in 2022. In contrast, covered production only took place on about 15.9 hectares. Lettuce can be produced all year round but prefers winter conditions in Mauritius. Generally, a crop cycle has about 60 to 80 days, thereby seeds are sown in a nursery and then transplanted once three to four leaves are visible. The sowing rate is about 0.14 kg per hectare. Lettuce is suitable for all types of soil, although it should be well-drained with a pH between 6 to 6.8 and have a high organic matter content.[108] In terms of lettuce cultivation in an agrivoltaic system, a study conducted in France found that yield was hardly affected under moderate shade conditions, and for some varieties even increased.[124]

In terms of **culinary herbs**, such as thyme, coriander, mint, leek, bunching onion and parsley, the island of Mauritius has a high self-sufficiency.[125] A study conducted on mint in semi-arid Iran found, that the concentration of essential oils, as well as the number of leaves and leaf area, was highest in peppermint when shading it by 25% and applying about 120 mg/kg of nitrogen[126], similarly in a study in humid tropical India the highest herbage yield of peppermint was obtained under 25% shading.[127] According to a study conducted by Murillo-Amador et. al on thyme in a semi-arid zone in northwest Mexico, the physiological, morphometric and yield characteristics of thyme were better under shade-enclosure, compared to open-field conditions.[128] However, the highest content of essential oils was found when growing thyme under full sunlight, compared to shade levels from 55% to 85%.[129]

In terms of **ginger** cultivation, there have been 55.6 hectares under cultivation in 2022, with a total production of 1,165 tonnes and a production of 21 tonnes per hectare.[67] On the island, ginger is mainly cultivated in the northern region, such as Boulingrin, Camp-la-Boue, Crève-Coeur, Rivalland, Robinson, Thomassin, Congomah and Marianas.[130] Within the diversification strategy from 2008 to 2015, it was already considered to increase the ginger production in Mauritius, by means such as improving the access to quality and certified planting materials, devoting additional land area to ginger and applying good agricultural practices (GAP, see FAO principles).[125] Ginger does best in partial to complete shade but can be as well cultivated under open-field conditions. According to a study conducted in Egypt, ginger shows an increased growth with decreasing light transmission and increasing relative humidity and air temperature.[131]

Fruits

In terms of fruit cultivation, there is potential in using abandoned sugarcane land, targeting local and export market, thereby diversifying the income of sugarcane planters and increasing the food and nutrition security of Mauritius.[70]

Bananas are a further important crop in Mauritius, with an annual production of about 9,829 tonnes on a total of about 633.5 hectares, and a yield of 15.5 tonnes per hectare in 2022.[67] Cultivation is not mechanized. Thereby, common varieties cultivated in Mauritius are such as Dwarf Cavendish, Williams, Ollier, Gingeli types, Mamoul and Mamzellem, which are grown throughout the year, mainly in the south and east of the island and are replacing to some extent the cultivation of sugarcane.[132] Thereby, the Dwarf Cavendish is a common local dual purpose (dessert and culinary) variety, with an ultimate height of 2 to 3 meters. Due to its production on marginal land, it often suffers from low production and is constrained by the availability of quality planting material. A study from Indonesia found, that when interplanting Dwarf Cavendish under the estate forestry plant, shading did not have a significant effect on vegetative growth, but tended to increase plant height, as well as leaf length, leaf number and leaf width.[133,134]

The production of **pineapples** (Ananas Comosus L.) in Mauritius only takes place on the open fields, with a total production of 5,579 tons on an area of 272.1 hectares. Pineapples can be cultivated through the whole year, although BRIX values (sweetness/tastiness) are higher in summer.[67] In a study conducted in eastern Brazil under a tropical monsoon climate, the yield of pineapple under 30% and 50% shade was not significantly different from that under full sun. On the other hand, the percentage of sunburned fruit was significantly lower under shaded conditions.[135] In another study considering a fruit tree intercropping system in India, they found that growth rate and dry matter accumulation, as well as fruit yield, fruit weight, and fruit/crown ratio were increased under a moderate shade intensity of 48.6%, although soluble solids and sugar content slightly decreased with a reduction in light intensity.[136]

5.3 Suitable Agrivoltaic Systems

5.3.1 Open Field Systems: Overhead and Interspace

The design of an agrivoltaic system is influenced by various factors, including the local environmental and climatic conditions, the types of crops being grown, the farming systems in place, and the socio-economic context. These elements collectively shape the arrangement and setup of the system.

When using *interspace* ground-mounted (GM) PV, it is crucial to determine the appropriate pitch distance or spacing between rows. This distance must allow for effective agricultural activities to take place. In other words, there should be enough room for machinery to move unhindered between the rows, thereby preventing any potential damage to the PV installations. Additionally, a further buffer might be required between the crop line and the system to prevent shading on the PV modules.

In the case of *overhead* agrivoltaic systems, the layout of the PV modules needs to be optimized to ensure that the underlying crops receive sufficient sunlight. The specific arrangement depends on two key factors: the amount of solar radiation available in the location and the shade tolerance of the crops being cultivated. In regions with high solar radiation and photosynthetically active radiation (PAR), a denser arrangement of PV modules is feasible when cultivating shade-tolerant crops. Conversely, in agrivoltaic systems located at higher latitudes or with less shade-tolerant crops, a less dense PV module layout would be more appropriate. Table 5 provides an overview on selected crops and their response to shading considering the local climate. Thereby, the yield response relates to the impact of shading (increase/decrease in yield) compared to an unshaded reference.

Table 5: Examples of suitable open field crops and their shading response.

Crop	Shading ratio	Yield response	Location	Climate	GHI [kwh/m²]
			Vegetables		
Potato[137]	35%	-20.0% to 11.0%	Germany	Cfb - Warm temperate fully humid with warm summer	1,211
Cauliflower[138]	25%	31%	Sri Lanka	As - Equatorial savannah with dry summer	1,982
Carrot[123]	-	-11% to -25%	Bangladesh	Am- Tropical monsoon climate	1,622
Eggplant[139]	30%	-47% to -55%	Hawaii, USA	As - Equatorial savannah with dry summer	1,757
Sweet potato[139]	30%	-15% to 3%	Hawaii, USA	As - Equatorial savannah with dry summer	1,757
			Fruits		
Grape[140]	50%	2.2% to 12.9%	Israel	Csa - Warm temperate with dry, hot summer	2,030
Lemon[141]	50%	-35.0% to 15.0%	Spain	BSh - Arid Steppe hot	1,787
Orange[142]	25%	14.6% - 63.7%	Egypt	BWh - Arid desert hot	2,049

Pineapple[143]	45%	7,2%	Brazil	Aw - Equatorial savannah with dry winter	1,843
Pulses					
Peanut[139]	30%	1%	Hawaii, USA	As - Equatorial savannah with dry summer	1,757
Red bean[144]	32%	-37%	South Korea	Cfa - Warm temperate fully humid with hot summer	1,455
Soybean[144]	32%	-30%	South Korea	Cfa - Warm temperate fully humid with hot summer	1,455
Others					
Tea[145]	75%	4.9%	Japan	Dfa - Snow with fully humid hot summer	1,422
Basil[146]	50%	0%	Brazil	Aw - Equatorial savannah with dry winter	2,016
Thyme[147]	73%	16.7%	USA	Cfa - Warm temperate fully humid with hot summer	1,445

Leafy greens such as spinach, lettuce, cabbage, and kale are also excellent crops for cultivation under agrivoltaic systems.

The height of the PV modules plays a crucial role in facilitating farming activities beneath them. The optimal height is determined by considering the planned crops and cultivation methods. If the crops are taller in height or if mechanized farming techniques are employed, a taller PV module mounting structure is necessary to accommodate the growth and cultivation of these crops effectively. Conversely, shorter crops that are manually harvested require a lower PV module height. It is important to note that even if large agricultural machinery is not used, the PV modules should still be positioned at an adequate height to avoid any potential damage that may occur during farming operations.
Due to the complexity of the agro-ecological zones, as well as the different characteristics and requirements of the crops, the most suitable approach to assess and recommend potential agrivoltaic systems is therefore not according to the zone, but rather according to the crop clusters. Crop clusters group crops into types that have similar growing conditions and/or have been shown to perform well under shading and have high economic value. Based on one or several of these factors, they may therefore be suited to be grown within a particular agrivoltaic system.

5.3.1.1 Crop Cluster I

Crop Cluster I contains horticultural crops that are shade tolerant to some extent and benefit from protection. Crops such as leafy greens (lettuce, cabbage, and spinach), as well as root crops such as potatoes, radishes, beets, and carrots fall into this category. Also included in this cluster are other high-value crops/ small fruit trees such as grapes, plums, apples, that would be suited to overhead agrivoltaic system.

Potential Agrivoltaics Systems: Overhead and Orchard Agrivoltaics
The higher tolerance to shade of the horticulture crops in Crop Cluster I, mean that overhead agrivoltaic systems are generally suitable. Orchard agrivoltaics is simply a sub-category of overhead agrivoltaics, being essentially overhead systems that are modified for use over fruit trees and vines such as grapes. Some possible overhead agrivoltaic designs are shown in Chapter 4 – Technology Screening.

5.3.1.2 Crop Cluster II

Crop Cluster II includes grains such as rice, maize, wheat, barley, sorghum and potentially sugar cane. As many of these are subject to import and are not economically viable in Mauritius, they may not be too important for this feasibility study but will be discussed shortly. Many of the crops mentioned, such as maize and sugar cane, are C4 crops. They use the C4 carbon fixation pathway to increase their photosynthetic efficiency by reducing or suppressing photorespiration, which occurs mainly under low atmospheric CO_2 concentration, high light, high temperature, drought, and salinity. As a result, they are not suited to high shade conditions.

Potential Agrivoltaic System: Interspace Agrivoltaics
Depending on the system design, the area of land directly below the PV modules could be blocked and unable to be cultivated. Although the overall productivity of the land will increase through the installation of agrivoltaics (i.e., increase in the LER), crops such as wheat, maize and rice are typically expected to have reduced yields under the partial shading of agrivoltaic systems. Therefore, and this applies for most cereals (rice, wheat, maize, barley, millet, sorghum), roots and tubers (potatoes, cassava), low capital expenditure (CAPEX) agrivoltaic systems should be considered. This would make vertical and interspace GM PV (see Chapter 4) viable options.
Although rice, wheat and maize are produced in many countries in large quantities, they are not considered high value cash crops (having a low selling price per square kilometer). The higher CAPEX of overhead agrivoltaic systems therefore must be taken into consideration in project planning and may be a prohibitive factor. However, there may be isolated cases where the installation of higher cost photovoltaic systems on lower value crops could be beneficial.

5.3.2 Closed Systems: PV Greenhouses

In contrast to open field systems, greenhouses allow for an optimization of the (interior) environmental conditions, potentially promoting crop growth and development. Examples of crops cultivated in greenhouses and their response to shading are shown in Table 6.

Table 6: Examples of suitable PV greenhouse crops and their shading response.

Greenhouse Crops	Shading ratio	Yield response	Location	Climate	GHI [kwh/m²]
		Vegetables			
Bell Pepper[148]	50%	14.0%	Egypt	BWh - Arid desert hot	2,108
Cauliflower[138]	50%	79.5%	Sri Lanka	As – Equatorial savannah with dry summer	1,982
Lettuce[149]	40%	1.0%	Egypt	BWh - Arid desert hot	2,108
Tomato[150]	20%	-5.6% – 5.9%	Spain	BSh - Arid Steppe hot	1,878
		Fruits			
Strawberry[151]	73%	-3.1% - 48.4%	Egypt	BWh - Arid desert hot	2,031
		Others			
Basil[152]	50%	28% – 169%	USA	BSh - Arid Steppe hot	2,150
Ginger[153]	50%	2.3% - 60.1%	India	Aw - Equatorial savannah with dry winter	1,860

As outlined in Chapter 4, greenhouses can either be retrofitted with PV modules, or can be directly considered in the planning process. Figure 39 shows an example of a greenhouse that was remodelled to incorporate PV modules in its roof. Additionally following points need to be considered when retrofitting a greenhouse:

- **Light availability**: a 20%-25% Ground Cover Ratio
- **Temperature and humidity control**: Enough ventilation as to avoid any pests and diseases by increased temperature and humidity due to reduced ventilation.
- **Greenhouse structure**: It is recommended to have either a Venlo or chapel shaped structure.
- **Material being used**: The material of the greenhouse should ideally be glass. An alternative such as polycarbonate is also favourable followed by polyethylene plastic, which is most used. In that case special attention needs

to be given on the placement of the PV modules as the plastic needs to be changed every 2-5 years. Additionally, to sustain the additional weight of the PV modules it is recommended that the greenhouse mounting structure is made of galvanized steel to maintain the structural integrity.

Figure 39: Exterior and interior of remodeled greenhouse.[154]

For Mauritius, a typical greenhouse is dome-shaped to better withstand the cyclone winds (see Figure 40). It is still possible to retrofit this design with PV modules, but careful planning, design and engineering are required.

Figure 40: Tunnel greenhouse
Source: Business Mauritius

6
Water Management Assessment

6.1 Executive Summary of Water Management Assessment

This section explores the integration of rainwater harvesting into agrivoltaic systems as a sustainable solution to address water scarcity challenges faced by smallholder farmers in Mauritius. The island's dependence on intermittent and unpredictable rainfall necessitates innovative approaches to enhance agricultural productivity. Agrivoltaic systems, which leverage solar power for irrigation, coupled with rainwater harvesting, offer a promising strategy to improve crop yields, reduce reliance on natural water sources, and prevent soil erosion.

The analysis of precipitation patterns across different regions of Mauritius highlights the varying potential for rainwater harvesting. Coastal areas generally receive less precipitation compared to inland regions, with the highlands, particularly Inland Regions 2 and 3 (see Figure 44: Spatial distribution of precipitation in Mauritius), identified as attractive locations for implementing integrated agrivoltaic and rainwater harvesting systems.

Key considerations in the successful implementation of these systems include system design, choice of gutter materials, water storage options, and proper sizing based on water demand and availability. Water quality concerns are addressed through the implementation of filtration and purification systems, catering to both non-potable uses like irrigation and potable uses such as drinking and cooking. Regular testing ensures the safety and effectiveness of the harvested rainwater.

The potential costs associated with rainwater harvesting integration are highlighted. These costs are generic and not specific to the planned agrivoltaic project, therefore emphasizing the need for local expertise and consultations for precise cost assessments and system design.

The Annex includes a table with the typical component needed to implement a rainwater harvesting system within an agrivoltaic system (Table 16).

In conclusion, the integration of rainwater harvesting into agrivoltaic systems holds substantial potential to enhance agricultural sustainability, mitigate water scarcity risks, and contribute to the overarching goals of water-energy-food security in Mauritius. This executive summary provides a concise overview of the report's key findings, emphasizing the need for strategic planning, local expertise, and technology integration to achieve successful and sustainable outcomes.

6.2 Introduction

Most Mauritian smallholder farmers rely heavily on rainfall which is both intermittent and unpredictable. Utilization of the abundant solar potential in agriculture can have a major impact on the quality and quantity of the agricultural products. Irrigation improves crop yields and is critical to agricultural productivity. Solar powered irrigation solutions offer a unique solution for Mauritian farmers by leveraging clean, sustainable solar power to run irrigation systems and increase overall productivity. To unlock solar irrigation's potential, many smallholder farmers require both training and financial support.

Capturing rainwater in above ground or below ground cisterns is an ancient practice many homeowners, businesses and municipalities are adopting to use for irrigation, topping ponds and pools, greenhouse water, livestock, wildlife, firefighting, and potable water. [155] Untreated harvested rainwater can be used for non-potable uses, such as toilet flushing, clothes washing, other household uses, garden irrigation, etc., while potable uses are also common in several countries (e.g., Australia and the United States of America), but they may require appropriate treatment of harvested rainwater, depending on its quality. A rainwater harvesting system consists of a method to collect, divert, store, filter and distribute water into the landscape. [155]

While the concept of rainwater harvesting from rooftops is not new, the integration of the approach in agrivoltaic systems is only recently being explored. Photovoltaic module surfaces have the potential to be utilized as water catchment canopies to harvest rainwater which can then be stored and used for irrigation, PV module cleaning and other site-specific needs. Aside from the direct benefits of providing water, the efficient use of resources provided by the potential integration of rainwater harvesting in agrivoltaics are also realized in electricity and water savings. Harvested water is used at point of collection, saving energy usually required to pump irrigation water over long distances from remote water sources. The closed storage and transport over shorter distances also reduces water losses (especially compared to some traditional methods of open irrigation ditches) and water usage can be better monitored and adapted in real time.
Additionally, the following benefits of rainwater harvesting are being realized in existing agrivoltaic installations:

- Water collection and storage for irrigation during periods of low rainfall,
- Supplement and reduce burden on natural rainfall and existing water sources (rivers/ groundwater),
- Prevent soil erosion, particularly of areas directly below the PV module edges,
- Prevent water pooling (puddles).

6.2.1 Rainwater Harvesting Designs

Currently two approaches are taken for integrating water collection in agrivoltaics.

Standard Gutter System

The system resembles the standard rainwater conduction system placed on residential rooftops. The rain gutter is attached to the existing mounting structure or directly to the bottom of the PV module as shown in Figure 41: Ground mounted agrivoltaic system with integrated rain gutter for collecting rain-water.[156]. The 105 kWp agrivoltaic system is installed at the Central Arid Zone Research Institute installed in Jodhpur, Western Rajasthan. With a total surface area of 651m², the installation is found to have an efficiency of 70%-80% and the potential to provide 37.5 mm irrigation over an area of 1 acre (equivalent to 375m³ total water supplied). The design mimics a typical rooftop and gutter setup, with a gutter placed along the lower edge of the PV modules. [156]

Figure 41: Ground mounted agrivoltaic system with integrated rain gutter for collecting rain-water.[156]

V-Shape design with central rain gutter

Fraunhofer ISE has recently developed and applied for a patent (*Deutsche Patentanmeldung: 10 2020 122 843.0- Titel: Vorrichtung und Verfahren zur simultanen Kultivierung von Nutzpflanzen und energetischen Nutzung von Sonnenlicht*) for an integrated agrivoltaic rainwater harvesting system. The concept for the rainwater harvesting design developed by Fraunhofer ISE, deviates from the previously described approaches in which a rain gutter is attached to the mounting structure at the lower edge of the PV modules. In the Fraunhofer ISE design, the mounting structure is fixed in a "V-shape" that can be constructed to the required PV module tilt angle and allows for the mounting of any type of PV module. The design was proposed to create material-use efficiency and limit the shading effect of an additional structure on each module row (by having two rows share a single rain gutter) and close the loop in the Water-Energy-Food security nexus.

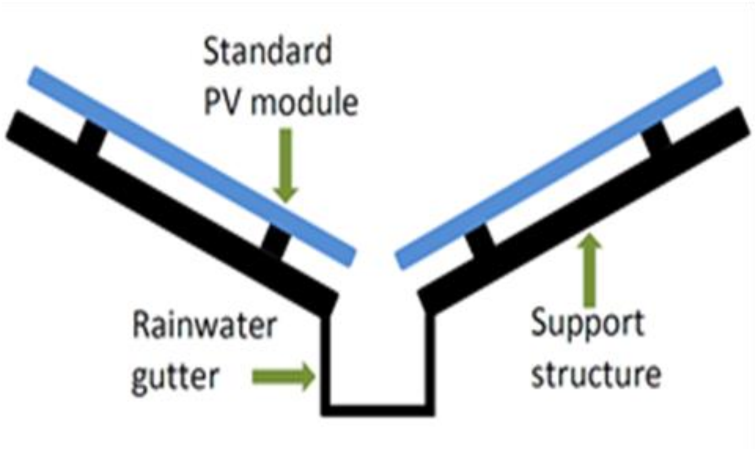


Figure 42: V-shape rainwater harvesting PV[6]

6.3 Mauritius Precipitation Distribution

According to the World Meteorological Organization a long-term period of at least 30 years is considered appropriate for estimating climate factors such as precipitation. The calculations in the following chapter are derived from the long term mean precipitation for the island of Mauritius (Figure 44) as well as spatial variability within the island. As shown in the figure below the highest precipitation falls between the months of January and March with precipitation above 250mm decreasing as the year progresses. Between June and November precipitation remains below 135mm, after which it starts to increase again in December, which shows similar precipitation amounts as April and May. The total long term yearly precipitation lies at 2020 mm/year. [157]

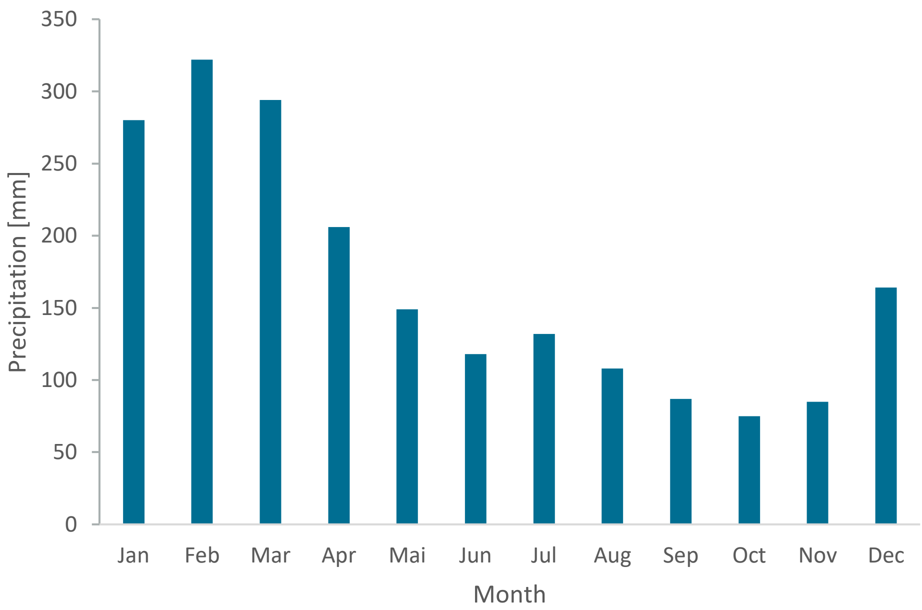


Figure 43: Long-term mean monthly precipitation 1991-2020. [157]

However, looking at the spatial distribution of the precipitation in the island, another picture can be drawn; as shown in Figure 44. According to the recent study done by Raja and Aydin [158] analysing precipitation data from 52 meteorological stations for the period 1981-2010 in Mauritius, the island can be divided into six regions dependent on the amount of rainfall received.

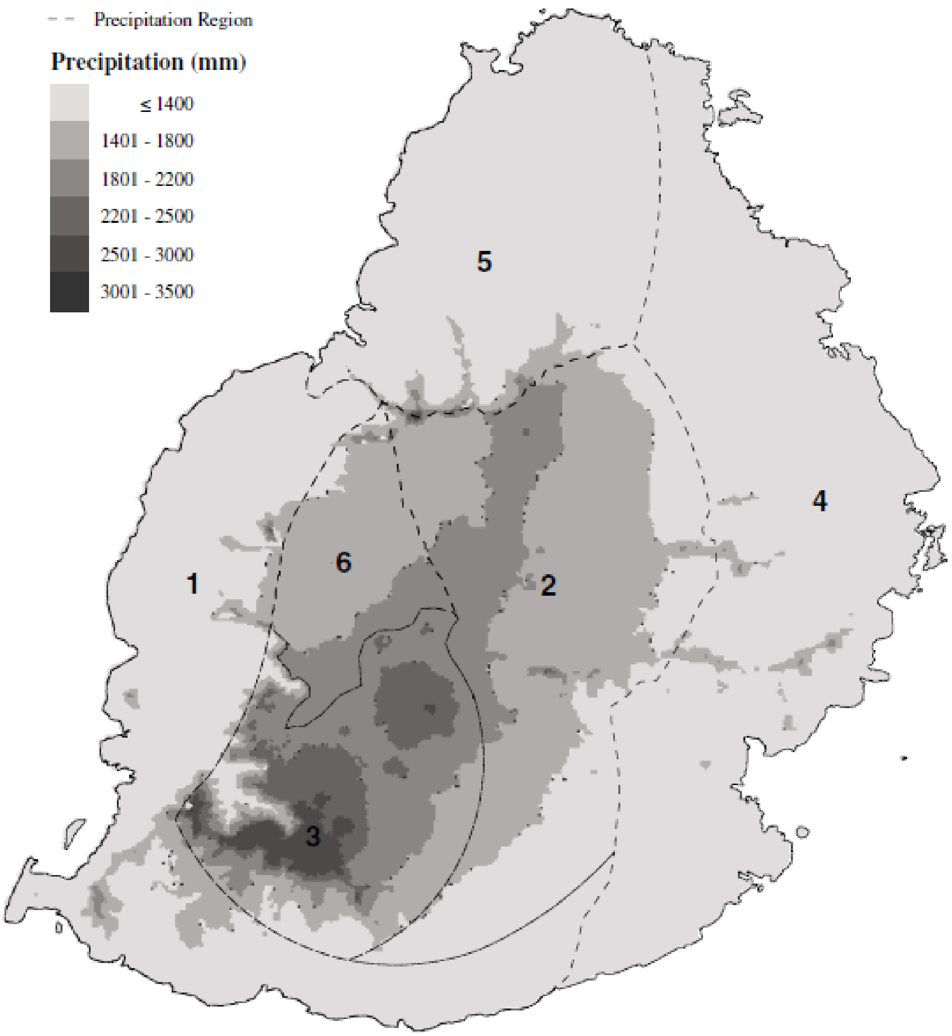


Figure 44: Spatial distribution of precipitation in Mauritius. [158]

Geographical categorization reveals that Regions 1, 4, and 5 are situated along the coastline, whereas Regions 2, 3, and 6 are inland, occupying the central plateau. Region 1 encompasses stations located on the western and southern peripheries of the island. Characterized by a mean elevation of approximately 60 m and an average precipitation of around 850 mm, it stands out as the driest and lowest-lying region. Region 4 is positioned on the eastern coast, featuring a mean elevation of approximately 65 m and an average precipitation of about 1,700 mm. Encompassing a significant portion of the island's northern expanse, Region 5 boasts an average elevation of 100 m and experiences precipitation of approximately 1,200 mm. Region 2, situated on the eastern central plateau, exhibits a mean elevation of approximately 350 m and an average precipitation of around 2,800 mm. Region 3, which includes the Black River National Park, represents the highest elevated area with an average altitude of approximately 600 m, experiencing the highest precipitation at 3,200 mm. Notably, the Luchon station, located within Region 3, deviates statistically from other stations in the region due to its lower elevation within the National Park compared to its counterparts in the same cluster. Concluding the geographical delineation, Region 6 occupies the northwestern sector of the central plateau, featuring an average elevation of approximately 390 m and an average precipitation of approximately 2,800 mm. A summary is shown in Table 7.

Table 7: Characteristics of precipitation groups according to principal components. [158]

Groups	Type	Mean Precipitation [mm]	Distance to coast [m]	Elevation[m]
1	Coastal	870	3,619	62
2	Inland	2,828	7,273	349
3	Inland	3,250	11,693	602
4	Coastal	1,703	5,277	67
5	Coastal	1,237	6,999	100
6	Inland	1,536	7,651	389

The prevailing winds, called the south-east trade winds, supported by the sea breeze, bring in moist air which rises along the slope between the coast and Mauritius' central plateau, resulting in orographic rainfall.

Rainwater harvesting in context of rainfall volume

The primary goal of harvesting rainwater would be to supplement the irrigation water requirements during the dryer months from May to November, which also correspond to the most critical period for crops. However, it is not only during these months in which there could be a water deficit. It is also possible that during the months of higher rainfall, the rate of evapotranspiration and general water usage at the site, exceeds the water availability, not only from rainwater, but from all water sources. Therefore, the water supply from all other sources needs to be taken into consideration to provide a complete overview of the water availability versus demand, and the quantity of rainwater to be harvested and stored to supplement any deficit.

6.4 Calculation of Theoretical Rainwater Harvesting Potential

The simplified, but widely accepted formula for calculating rainwater that can be harvested from a surface is used [159]. The Total Water Harvested (TWH) is then calculated by applying the standard equation for calculating rainwater collection off surfaces:

$$\text{TWH} = Rm * \eta * \text{total surface area}$$

Where Rm = Share of rainfall incident on PV module surface

η = PV modules I harvesting efficiency (0.8), accounting for losses due to rainwater and surface dynamics (e.g., not all rain hitting a surface will be captured due to the kinetic force of raindrops hitting the surface).

The total surface area is defined as the area covered by the PV modules. Here it is assumed that the agrivoltaic system will be built on a 1000m² area. Dependent on the final system design this total area will have a ground cover ratio (GCR) between 30%-45%. This translates to a total area between 300m²-450m² covered by the PV-modules. Taking into consideration the spatial distribution or rainfall on the island the results are shown on the following chapters.

6.4.1 Coastal Regions

The coastal regions in general receive less precipitation than the inland. The highest total harvestable water is in coastal region 4 in the north-eastern part of the island followed by coastal region 5 in the east and coastal region 1 in the western part.

Coastal region 1

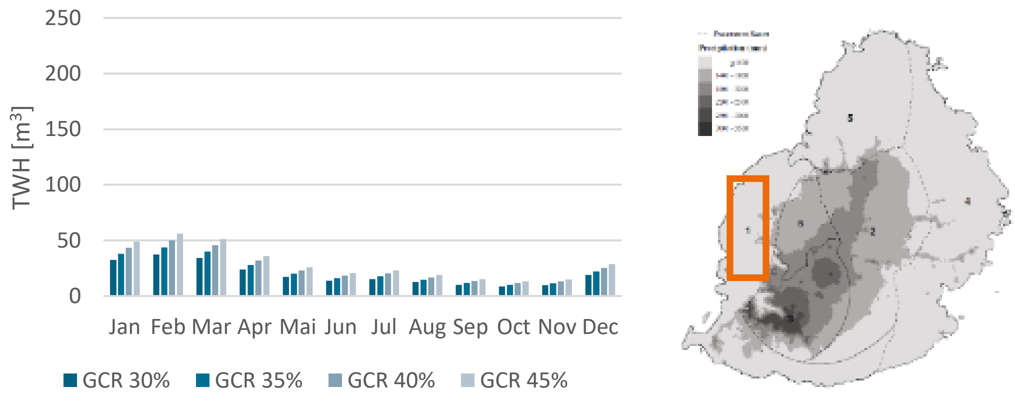


Figure 45: Monthly total water harvested in m3 for four different ground cover ratio (GCR) scenarios.

Coastal region 1 has the least amount of total harvestable water from all regions on the island of Mauritius with the maximum amounts being collected in the months of January, February and March. The maximum amount collected is around 50m³ on a GCR of 45% followed by less coverage ratios. The minimum amount of water collected is in the months of September, October and November.

Coastal region 4

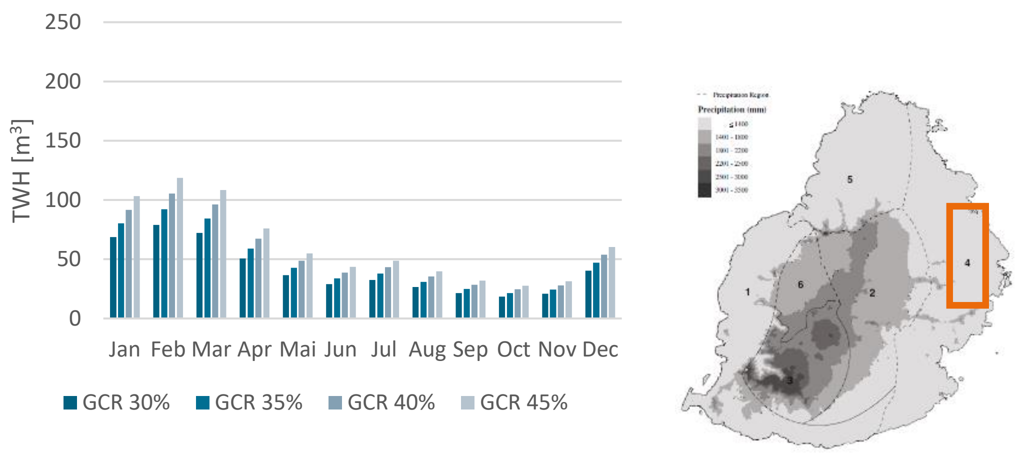


Figure 46: Monthly total water harvested in m3 for four different ground cover ratios (GCR) scenarios.

The north-eastern part of the island, coastal region 4 has the highest precipitation amounts of all regions on the coast and therefore also the highest harvestable water. Especially in the months of January, February and March. The minimum amount is in the month of October.

Coastal region 5

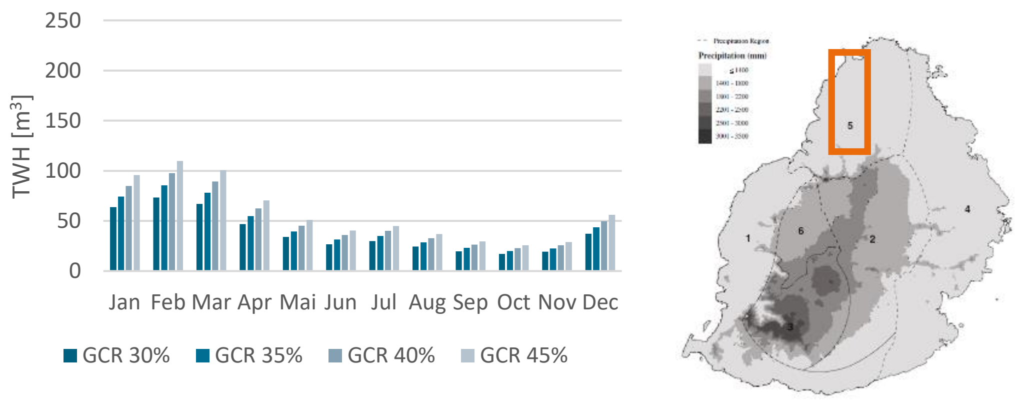


Figure 47: Monthly total water harvested in m3 for four different ground cover ratio (GCR) scenarios.

The eastern part of the island identified here as coastal region 5 has the second most rainwater harvesting potential and follows the same precipitation pattern shown in the graph above. This is directly correlated with the total water collected across all GCR scenarios. The eastern part of the island receives almost twice as much rainfall compared to the western part and therefore the rainwater harvesting potential increases proportionally to the amount of precipitation.

6.4.2 Inland

The inland regions receive higher amounts of precipitation compared to the coastal regions and therefore have a higher potential for rainwater harvesting, especially in the highlands where tea cultivation also occurs. Taking only rainwater harvesting potential into account, the highlands seem very attractive for the implementation of agrivoltaics with an integrated rainwater harvesting system. Nevertheless, incident irradiation also plays a vital role for energy production and crop growth and therefore would take precedence over rainwater harvesting.

Inland region 3

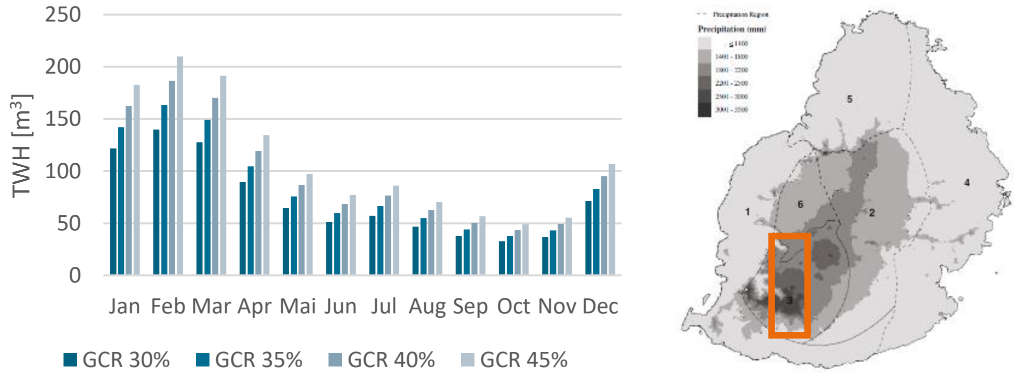


Figure 48: Monthly total water harvested in m3 for four different ground cover ratio (GCR) scenarios.

The south-western part of the island, inland region 3 has the highest precipitation amounts on the whole island and therefore also the highest harvestable water, especially in the months of January, February and March. The lowest amount is harvested in October.

Inland region 2

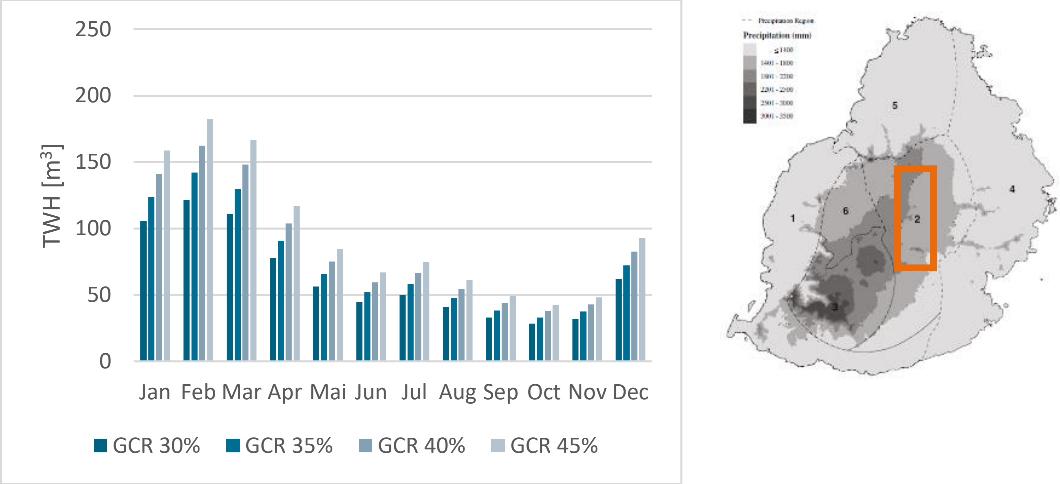


Figure 49: Monthly total water harvested in m3 for four different ground cover ratio (GCR) scenarios.

The central part of the island identified here as inland region 2 has the second highest rainwater harvesting potential and follows the same precipitation pattern shown in the graph above. This is directly correlated with the total water collected across all GCR scenarios. The eastern part of the island receives almost twice as much rainfall compared to the western part and therefore the rainwater harvesting potential increases proportionally to the amount of precipitation.

Inland region 6

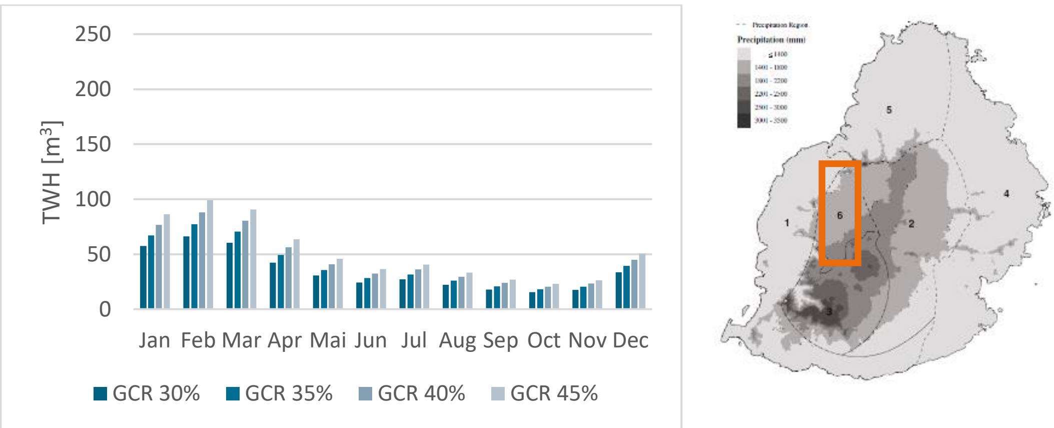


Figure 50: Monthly total water harvested in m³ for four different ground cover ratio (GCR) scenarios.

Inland region 6 has the least amount of total harvestable water from all regions inland on the island of Mauritius with the maximum amounts being collected in the months of January, February and March. The maximum amount collected is around 100 m^3 on a GCR of 45% followed by less coverage ratios. The least amount of water collected is in the months of September, October and November.

6.4.3 Conclusion

In conclusion, the assessment of rainwater harvesting potential across different regions of the island of Mauritius highlights distinct variations between coastal and inland areas. Coastal regions, in general, receive lower precipitation compared to their inland counterparts, influencing the total harvestable water available. The findings from specific coastal regions and inland areas are shown in Table 8 and are discussed below:

Table 8: Total harvestable water for the different study areas for an agrivoltaic system built on a 1000m^2 area

Group	Region	Total Harvestable Water [m^3] GCR 30%	GCR 35%	GCR 40%	GCR 45%
1	Coastal	234,9	274,1	313,2	352,4
2	Inland	763,6	890,8	1018,1	1145,3
3	Inland	877,5	1023,8	1170,0	1316,3
4	Coastal	496,0	578,7	661,4	744,0
5	Coastal	459,8	536,4	613,1	689,7
6	Inland	414,7	483,8	553,0	622,1

Coastal Regions:

Coastal Region 1: Positioned in the western part of the island, Coastal Region 1 exhibits the least amount of total harvestable water. Maximum amounts are collected in the months of January, February, and March, reaching around 50 m^3 on a GCR of 45%. The minimum collection occurs in September, October, and November.

Coastal Region 5: Identified as the northeastern part of the island, Coastal Region 5 holds the second-highest rainwater harvesting potential among coastal areas. Precipitation patterns follow a similar trend to the eastern part, almost twice that of the western part. The maximum water collection is directly correlated with higher precipitation, emphasizing the region's potential for rainwater harvesting.

Coastal Region 4: The eastern part of the island, Coastal Region 4, boasts the highest precipitation amounts and, consequently, the highest harvestable water. Particularly in the months of January, February, and March, the region presents an attractive option for rainwater harvesting initiatives, despite a minimum collection in October.

Inland Regions:

Inland Region 2: The central part of the island, identified as Inland Region 2, holds the second-highest rainwater harvesting potential among inland areas. Similar to Coastal Region 4, precipitation patterns correlate with total water collected across different GCR scenarios. The eastern part receives nearly twice as much rainfall as the western part.

Inland Region 3: Located in the south-western part of the island, Inland Region 3 stands out with the highest precipitation amounts on the entire island. The months of January, February, and March witness the peak harvestable water, with a minimum collection in October.

Inland Region 6: This region, positioned inland, records the least amount of total harvestable water among all inland regions. Maximum collection occurs in January, February, and March, reaching around 100 m^3 on a GCR of 45%, with the minimum amounts in September, October, and November.

In evaluating the rainwater harvesting potential, it is evident that the highlands, especially in Inland Regions 2 and 3, present attractive opportunities for the implementation of agrivoltaics with integrated rainwater harvesting systems. However, it is essential to consider incident irradiation as a crucial factor, taking precedence over rainwater harvesting, to ensure the overall suitability of these regions for agrivoltaic systems on the island of Mauritius. This makes coastal region 4 on the eastern part of the island another viable option. However, in general rainwater harvesting would benefit the agricultural production in most regions.

6.5 System Components

Regardless of the agrivoltaic rainwater harvesting design, there are general considerations that should be made in the overall system design. For gutters, the standard slope of 1.25 cm per 3 m toward the downspout (approximately 0.25° slope angle) must be factored in to ensure efficient flow of runoff. Also, it is advisable to install a downspout every 10 m to ensure that no single downspout is taking in too much water and that no part of the gutter is keeping too much water at any moment. [160]

6.5.1 Gutters and Piping

The single gutter setup (similar to the gutter systems installed in rooftops) is deemed to be the most viable for the areas identified, from an economic and technical point. The gutters can be installed at almost any stage of the agrivoltaic installation (either immediately when the support structures are erected or at a later stage once a full assessment is completed). This flexibility also allows for rainwater harvesting functionality to be installed in phases and scaled up as necessary.

Gutters are a central component in the overall rainwater harvesting infrastructure as they are the conduits responsible for the transfer of water from the collection surfaces to the storage containers. Proper sizing is essential to system efficiency and in the case of rainwater harvesting, material choice plays an important role in both the long and short-term quality of water collected.

The table below highlights advantages and disadvantages of common gutter types, as well as approximate price ranges per meter.

Table 9: Advantages and disadvantages of common gutter types and price ranges.

Material	Pros	Cons	Price Range (€/meter)
uPVC	Affordable	Short life expectancy: extreme weather conditions can flex & break uPVC; excessive sunlight can bleach colour and reduce strength	4 – 10
Aluminium	Light & resistant to rust	Higher cost; more susceptible to bending & cracking	12 – 15
Galvanized	Stronger than aluminium	Heavier & requires soldering; tends to develop rust over time	~ 10
Copper	Aesthetic, upscale Extremely long lasting	Expensive	20 – 30
Steel	Affordable	Heavy – can lead to sagging	12 - 17

6.5.2 Water Storage

Water storage options fall into two categories, namely natural, which includes the use of existing water bodies such as streams, ponds and dams and underground locations such as aquifers; and man-made, which includes aboveground storage options (e.g., open reservoirs, storage tanks) and underground storage (e.g., prefabricated tanks installed underground).

- Natural
  - Existing water bodies
  - Underground storage – aquifers

The existing water bodies need to be further delineated and studied, including the regulatory conditions dictating their use, maintenance and replenishment using harvested rainwater. The use of existing, natural water bodies can potentially be presented as an advantage, given the goals of the project in revitalizing the area. However, groundwater pollution, such as that caused by washed-off bird droppings, must be avoided to prevent contamination of drinking water sources.

- Man-Made
  - Aboveground storage

Aboveground water storage can come in the form of rigid or flexible polyethylene, galvanized steel or concrete tanks that are at ground level or elevated, or open reservoirs/ponds with or without a geomembrane (reduce infiltration into the ground). A potential advantage of man-made a reservoir/ pond is the potential to be used for multiple activities in addition to supplying irrigation water (increasing biodiversity through fish breeding, attracting animals, etc).

Figure 51: Above-ground water storage options.

- Underground storage

Underground water tanks are commonly made of high-density polyethylene (HDPE), steel or concrete and have the distinct advantage over above-ground tanks in that they have zero visual impact. Concrete rainwater tanks are usually the most affordable underground tank option available, can be built much larger than plastic options, have little to no risk of splits or leaks and can be buried deep underground [161] .When covered with load-bearing lids, they can be fitted under driveways or other structures. Additionally, installing a tank underground results in much cooler water temperatures, and combined with the lack of light, means that algae growth is limited [161]..

Underground tanks are not temporary structures and the job of installing them isn't insignificant and should only be undertaken by properly qualified individuals who have carried out a thorough assessment, including legal compliance (e.g., complying with building codes).

Figure 52: Underground water storage options.

The choice of water storage system, either above or below ground, should correlate with the overall project goals related to the aesthetics and reduced visual impact. Underground storage should primarily be considered, unless measures can be taken to mitigate the visual impact of above-ground structures.

Water storage sizing

Optimal sizing of the water storage requires analysis of the site's overall water demand (detailed crop water requirements and irrigation demand and other potable and non-potable uses) and the existing water availability from all sources. Once the relationship between supply and demand is established and the water deficit or surplus is known, the need for and the sizing of water storage can be more accurately determined.

Generally, water storage should be sized according to planned budget and in a way that ensures that water demand is met without either oversizing or undersizing the system. Methods for sizing the rainwater harvesting tank vary from country to country. For example, in the UK, the BS 8515 2009 Code of Practice is used, which states that the capacity of the rainwater harvesting storage tank must be the least of either 5% of the annual rainwater yield (ARY) or 5% of the annual rainwater demand (ARD). Larger tanks are not allowed, because of the risk of bacteria breeding which may cause health hazards [8].

6.5.3 Water quality and treatment

Rainwater is slightly acidic and very low in dissolved minerals; as such, it is relatively aggressive [9]. It is relatively free from impurities, except those dissolved from the atmosphere, but can be impacted during harvesting and storage. Wind-blown dirt, leaves, faecal droppings from birds and animals, insects and contaminated litter on the catchment areas can be sources of contamination of rainwater, leading to health risks from the consumption of contaminated water from storage tanks [162].

- **Non-potable uses:** For irrigation and other non-potable uses, clean water is essential for efficiency during distribution. Rainwater requires filtration before storage and distribution to remove any particles and debris. Debris off the harvesting surface will accumulate in the storage, damage pumps and clog nozzles. Gutters should be kept free of leaves and other debris by installing wire mesh or cleaning at least twice a year.[163]

- **Potable uses:** For uses such as drinking, cooking, cleaning, it is recommended to use water purification systems. Several options exist, ranging from single stage systems to multistage membrane filtration (pre-filtering, medium filter, ultrafiltration) and activated carbon and UV treatment.

Overall, it is recommended that harvested rainwater should be tested prior to installation of storage and purification systems and at regular intervals during operation of the agrivoltaic power plant.

6.5.4 Integrated Irrigation Systems

Overhead agrivoltaic systems offer the possibility of integrating water delivery systems (overhead irrigation sprinklers) that have a minimal impact on agricultural activity.

Figure 53: Overhead sprinkler systems as installed in greenhouses [164]

Other irrigation options: The choice of irrigation system is not limited to those that can be integrated into the support structure. As water is stored in an external structure, any suitable type of irrigation, in accordance with the soil maintenance, machinery usage, crop cultivation layout and cultivation practices, can be considered. This includes drip irrigation and sprinklers placed on the ground.

6.6 System Costs

Research data for costs associated with rainwater harvesting integration into agrivoltaics is virtually non-existent, therefore only the separate component costs can be presented here to provide an estimate of the general costs.
Full economic analysis is dependent on the final water harvesting required and the system design and input/quotations from local rooftop gutter installers should be sought. The costs presented in the following section should therefore not be used directly in economic estimations but can be taken as a guideline.

6.6.1 Storage Tank Costs

Water storage tank data and costs are gathered from information supplied by commercial installers in Australia and the United States, where low rainfall and high variability have made water storage in large structure over 100,000 liters economically viable and widely applied.

The table below shows system costs for assorted sizes.

Table 10: Storage tank costs. [165]

Product	Source	Tank Size (L)	Price Range (€)
Galvanized Steel	Bushman Tanks Australia	22,500 – 130,000	3,200 – 6,850
Galvanized Steel	Bushman Tanks Australia	152,000 – 363, 000	7,500 – 17,500

6.6.2 Gutter Material and Installation Costs

The estimated costs of installing different types of gutter materials are taken from a collection of gutter suppliers and installation cost averages in the United States of America. The costs presented in the table below are based on 200 linear feet (60 meters) of guttering.

Table 11: Approximate gutter material and installation costs for 60 meters of guttering. [166]

Material	Vinyl	Aluminum	Steel	Copper
Gutters (200 linear feet/ 60meters)	€520 –1,050	€860 – 2,600	€1,050 - 4150	€3,100 – 5,200
Hangers (40) and brackets (40)	€140	€175	€275	€1,350
Downspouts (6 x 10 linear feet/ 3 meters)	€100–200	€100-260	€260- 520	€520 – 1,300
End caps (6)	€8	€13	€18	€20
Elbows (6)	€24	€35	€65	€80
Flashing (260 linear feet/ 80 meters)	€110	€110	€110	€110
Splash blocks (6)	€42	€42	€42	€42
Labor costs	€700	€1,050	€1400	€1,750
Total gutter installation costs	€850 -2,250	€3,350 – 5,600	€3,200-6,500	€7,000 – 9,800

The costs presented in the table above should only be used as a reference. Local gutter experts should be consulted for a more precise cost estimate.

6.7 Rainwater Harvesting System Maintenance

The following procedures and documentation can be applied to an agrivoltaic RWH system to ensure to ensure optimal function:

- Develop a maintenance checklist.
- Develop and use a schedule for maintaining system.
- Keep a Diary of maintenance –and Usage.
- Trim tree branches away from roof.

- Keep debris out of gutters and downspouts.
- Clean filters/screens going into and out of cistern.
- Inspect tanks, lines, and connections for leaks. Repair any leaks.
- Empty First Flush after each rainfall or install an automatic or semiautomatic drain.
- In colder climates, empty first flush before a freeze and protect pipes from freezing temperatures.
- Flush debris from cisterns if necessary.
- Clean and maintain filters, especially those on drip irrigation systems.
- Lower level in system before each rainfall. Lower level in cistern to allow for freeze expansion in cold climates.

6.8 Conclusion of water management assessment

In conclusion, the integration of rainwater harvesting into agrivoltaic systems presents a promising and innovative approach to address water scarcity challenges faced by smallholder farmers in Mauritius. The island's reliance on intermittent and unpredictable rainfall makes the utilization of abundant solar potential for agriculture a crucial strategy to enhance both the quality and quantity of agricultural products. The proposed agrivoltaic rainwater harvesting systems offer a sustainable solution by leveraging clean solar power to meet irrigation needs, reduce reliance on natural water sources, and prevent soil erosion.

The analysis of Mauritius' precipitation patterns across different regions underscores the varied potential for rainwater harvesting. Coastal areas generally receive less precipitation compared to inland regions, with specific regions identified as having higher harvestable water potential. Notably, the highlands, particularly Inland Regions 2 and 3, emerge as attractive locations for implementing agrivoltaic systems with integrated rainwater harvesting.

While the potential benefits are substantial, the successful implementation of such systems requires careful consideration of factors such as system design, gutter materials, and water storage options. The choice between aboveground and underground storage should align with project goals and aesthetic preferences, with underground storage offering advantages in visual impact reduction. Proper sizing of water storage systems is essential, considering both water demand and existing water availability from all sources.

Furthermore, the assessment of costs associated with rainwater harvesting integration provides valuable insights, although it is emphasized that these costs are estimations and may vary based on local factors. Local expertise and consultations are recommended for precise cost estimates and system design.

In addressing water quality concerns, appropriate filtration and purification systems must be implemented, considering both non-potable uses such as irrigation and potable uses like drinking and cooking. Regular testing of harvested rainwater ensures the safety and effectiveness of the system.

In summary, the integration of rainwater harvesting into agrivoltaic systems in Mauritius holds significant potential to enhance agricultural productivity, mitigate water scarcity risks, and contribute to sustainable farming practices. As climate-resilient technologies, these integrated systems align with the broader goals of promoting water-energy-food security in the region and offer a pathway towards more sustainable and efficient agricultural practices.

7
System Design Evaluation

The designs presented here are conceptual and meant to provide the main parameters to be considered in the agrivoltaic system to provide the conditions that enable optimal energy and crop production, namely module tilt angle and configuration, table height, row distance and overall system orientation. Design parameters such as foundation, mounting and racking infrastructure and other BOS components are not considered as these require detailed analysis and design by engineers with the certification requirements of the country.

7.1 Executive Summary

The following section presents conceptual designs for agrivoltaic systems, focusing on parameters crucial for optimal energy and crop production adopted to the Mauritian context. These parameters include module tilt angle, configuration, table height, row distance, and system orientation. Detailed engineering aspects such as foundation, mounting, and racking infrastructure are not covered, as they require specialized analysis and design based on local conditions.

Two agrivoltaic systems are proposed for implementation in Mauritius: one fixed and one tracked system, with locations identified on the West Coast and in the highlands. The selection of design parameters aims to maximize crop performance and energy yield while minimizing interference with agricultural activities.

Uncertainties exist regarding crop response in Mauritius' specific climate, necessitating further research during implementation. A conservative shading rate of 30% is chosen for design, with module row spacing designed to balance light distribution and machinery access.

The selected module for simulations, Jinko Solar's Tiger Pro 144 Cell: JK03M, represents market availability and quality but does not exclude other options. System height is set at 2.5m to accommodate agricultural activities and machinery, with an east-west orientation chosen for optimal light distribution.

Light simulations are conducted using the APyV tool, providing detailed insights into irradiation and shading rates. Results indicate homogeneous light distribution and confirm the effectiveness of the chosen system orientations.

Comparing fixed and tracked systems, the latter offers higher specific yield but lower power production per hectare due to larger row-to-row distances. Considering all metrics and capital expenditure, the fixed system appears more suitable for Mauritius' context.

7.2 Design Selection

The overall selection of the design and its parameters aims to ensure that the selected crops have the highest possible performance (quality and yield) while the energy yield of the PV system is equally optimal. Additionally, some parameters such as system height and module row spacing, are set to ensure that the agricultural activity below the PV modules can be undertaken with as little interference/modification as possible while avoiding damage to the PV system. After several meetings and discussions with local experts and taking into account the intended use and the crops grown in the region, a total of two systems are proposed (Figure 55). A fixed rooftop shaped configuration agrivoltaic system and an agrivoltaic system with horizontal single axis tracking.

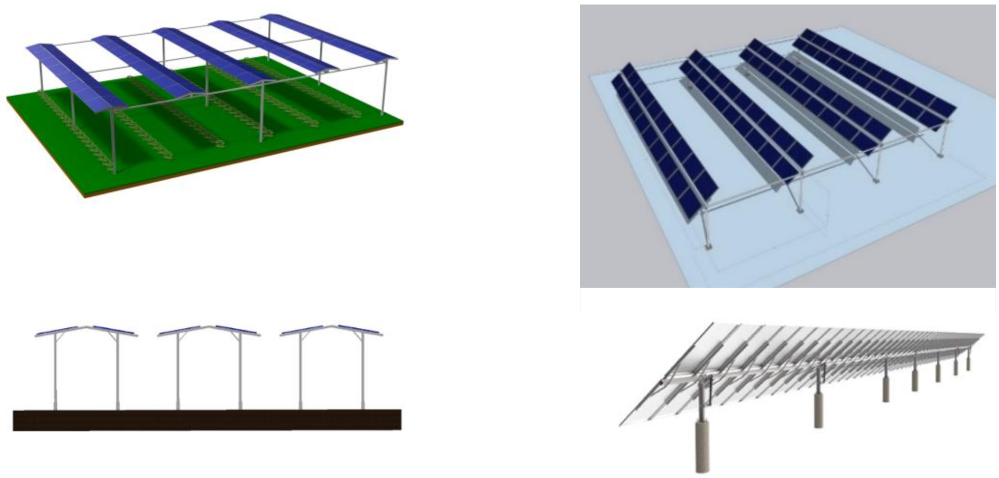


Figure 54: Selected designs to be compared. Fixed rooftop shaped configuration (left). Tracked system (right).[9]

7.3 Additional Design Considerations for Tracking Systems

7.3.1 Corrosion

In coastal areas, salt deposits can cause rust and wear and tear on metallic surfaces. To address this, the following factors should be considered when selecting one-axis PV trackers:

- Corrosion-Resistant Materials: Trackers should be chosen made from materials that resist corrosion, such as stainless steel or aluminum alloys with protective coatings.
- Sealed Components: Ensure that critical components (such as bearings, gears, and motors) are well-sealed to prevent saltwater ingress.
- Regular Maintenance: Implement a robust maintenance schedule to clean off salt deposits and inspect for any signs of corrosion.

- Coating and Surface Treatments: Some manufacturers offer specialized coatings or surface treatments to enhance durability in coastal environments. Hot-dip galvanizing, rust protection paint or plastic coating may protect steel posts and beams.

The electrochemical series of metals should be taken into account, as fewer noble metals dissolve more quickly when they are in direct contact with more noble metals. This is important, for example, when joining different metals using screws.

7.3.2 Cyclonic Winds

One-axis photovoltaic (PV) trackers play a crucial role in maximizing energy harvesting by following the sun's daily trajectory. When it comes to adapting them for **cyclonic conditions**, the following practices should be considered:

1. **Robust Design and Materials**:
   - **Sturdy Construction**: Robust materials such as **galvanized steel** or **aluminum alloys** with protective coatings are recommended. These materials resist corrosion and withstand strong winds.
   - **Reinforced Bearings and Joints**: Use heavy-duty bearings and reinforced joints to handle wind-induced stresses.
   - **Corrosion Resistance**: Ensure all components are resistant to saltwater corrosion, especially in coastal areas.
   - **Firm anchoring of the support piles** in the ground is essential. In the basalt rock in Mauritius, driven foundations are probably not possible, and holes must be drilled, and the piles are then set in concrete. Although this is labor-intensive and costly, it also ensures that the substructure can withstand the high pull-out forces that can occur during a storm.

2. **Wind-Resistant Geometry**:
   - **Low Profile**: Design the tracker with a low profile to minimize wind exposure. A lower center of gravity reduces the risk of tipping during cyclonic winds.
   - **Wind-Deflecting Features**: Consider aerodynamic features like **wind fences** or **wind deflectors** to reduce wind pressure on the tracker.

3. **Wind-Tracking Algorithms**:
   - Implement advanced algorithms that adjust the tracker's position based on real-time wind data. These algorithms can optimize tracking angles during strong winds.
   - **Wind Sensors**: Install wind sensors to detect sudden gusts and trigger protective actions (e.g., stowing the tracker).

4. **Emergency Stow Position**:

    - Define a specific **emergency stow position** for extreme wind events. When cyclonic winds are detected, the tracker should automatically move to this safe position.
    - The stow position minimizes the tracker's profile and reduces wind resistance.
    - The time to stow position with the wind alert strategy should be as short as possible.

5. **Regular Maintenance**:

    - Inspect the tracker regularly for signs of wear, loose bolts, or damage.
    - Lubricate moving parts to ensure smooth operation during wind events.
    - There should also be no parts in the vicinity that could break loose during a storm and fall onto the PV system due to the strong winds.

7.4 Location

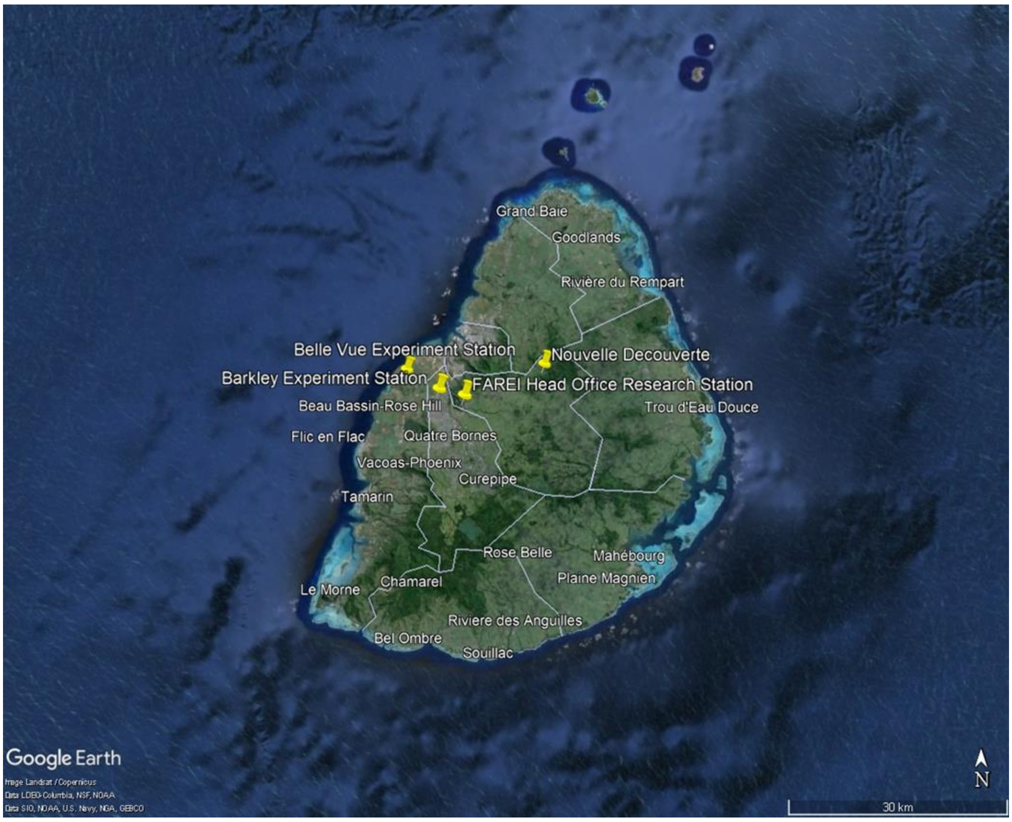


Figure 55: Investigated locations for the agrivoltaics systems.

Two sites were selected for detailed analysis after discussion with FAREI, Business Mauritius and the Ministry of Agriculture. These two define the extremes and it is the Belle Vue Experiment Station due to the proximity to the capital, the available space at the coastal area and the high incident solar irradiation. The second extreme location in Nouvelle Decouverte at the Central Plateau was selected as to explore the possibility of implementation of agrivoltaics in combination with tea cultivation. Further assessment has been made for Barkley Experiment Station and FAREI Head Office Research Station. The full list of possible locations can be found in the Annex.

7.5 Shade tolerance and shading ratio

Although average shade tolerances of the crops of interest are known through research in other environmental and climatic contexts, several uncertainties exist regarding the expected performance and the suitable shading rate that should be applied in agrivoltaic systems in the specific local climates of Mauritius. Uncertainties should be taken into consideration and the design and installation of an agrivoltaic system with the dimensions outlined below, should not be taken as a guarantee of optimal crop performance. As this is a flagship project in Mauritius, the implementation of the agrivoltaic system at the two possible locations, the West Coast area and in the highlands should be seen as an opportunity to conduct applied research on crop response in the local environment.
The shading tolerance rates of the crops proposed in Section 4 range from between 30 to 45%. Therefore, a conservative shading rate of 30% is selected for the agrivoltaic system design. One fixed system with a rooftop shape system and one tracked system are selected to be analyzed.

7.6 Module row spacing

The module row spacing has two functions. First is to control the overall amount of light incident on the field and crops below the PV modules. As describe in the section above, the shading rate for both fixed-tilt and single-axis tracking systems is set to 30%. This is achieved by setting the module row space (pitch distance) to 7.28m for the fixed-tilt system and 10.06-10.25 m for the single axis-tracking system (Table 1). The second is to create enough space for any machinery to pass through without hitting the vertical support posts. Both spacings should be sufficient to allow the safe passage of smaller agricultural machinery. However, the size and dimensions of any planned machinery needs to be thoroughly researched and documented and any changes to the final engineering design made to accommodate the equipment.

Table 12: Summary of the calculated pitch distances for both locations and systems

Location	System type	Pitch distance [m]
Coastal	Fixed	7.28
Coastal	Tracked	10.25
Highlands	Fixed	7.27
Highlands	Tracked	10.06

7.7 Module selection

The module selected to conduct the simulations are based on a market availability. The current state of the art for agrivoltaics uses standard mono-facial or bi-facial modules or in special cases like apples or grapes, high light transmission glass-glass modules. Standard mono-or-bi-facial PV modules result in the best economic performance, since they are widely available and cost-efficient. However, the modules selected for the energy yield simulations are not a recommendation and are only selected based on the market availability and quality associated with products from the manufacturer. The module type selected for the simulations does not exclude other brands, capacities or technologies and it is recommended that the contracted solar EPC company further assesses the modules to be installed based on their local experience and expertise.

Table 13: Module Characteristics of the module selected for simulations.

Module characteristics	
Module Name	Tiger Pro 144 Cell: JK03M
Module Manufacturer	Jinko Solar
Maximum Power at STC	535 to 555 Wp
Efficiency	20.71 to 21.48%
Number of Cells	144 (6x24)
Type of Cells	P type Mono-crystalline
Dimensions	2278×1134×30mm
Weight	31kg

Source: Jinko Module Data sheet https://jinkosolar.eu/wp-content/uploads/JKM535-555M-72HL4-BDVP-F6-EN.pdf

7.8 System Height

Regarding system height, the DIN SPEC provides recommendations on the height of agrivoltaic systems, stating, "A clearance height of at least 2,10 m above the area used for agriculture shall be ensured so that the previous use of the area remains unaffected. The clearance height is defined as the free vertical area between the base of the agricultural land and the lower edge of the lowest structural element under self-weight deformation. In the case of movable structural elements, the lowest bottom edge shall be measured where the clear height is at a maximum". The height of 2.5 m is selected as it is assumed that a mix of manual labor and smaller machinery will be used during soil preparation, cultivation and harvesting. The clearance height of 2.5 m should ensure that the PV modules and electrical infrastructure will not be damaged. The hub height, which is defined as the length of the substructure form the ground is therefore different between the fixed tilt system (2.7m) and the tracked system (3.5), whereas the clearance height remains the same. Given that grains such as wheat and maize are not planned for cultivation under the system, the height is kept at a minimum as large machinery (combine harvesters) will probably not be used. If the agricultural plan changes to include different crops with larger machinery requirements, this should be taken into consideration before implementation. Increasing the system height would also be beneficial for the light distribution in the crops. However, this would also increase costs due to the greater use of materials for the higher supporting structure and the risk of damage from hurricanes would also increase.

7.9 System orientation and module configuration

The entire system is oriented at an azimuth of 90° (east-west orientation), and while the energy yield is reduced as compared to the best case scenario at -180° (north orientation; the exact energy yield reduction will depend on the site), at this orientation, the light distribution is at its most homogeneous at this orientation,, meaning that over the course of a day/season, crops receive an almost equal exposure to sunlight and shade.

7.10 Simulation tool

The light simulations are based on the 'APyV' tool, developed by Fraunhofer ISE specifically for the agrivoltaic systems. The tool is based on the backwards ray-tracing engine of Radiance, which is highly validated for decades in a number of applications. The tool allows the exact calculation of the light reaching the front and back (rear) side of bifacial modules (when used) as well as on the crop level. As a result, an accurate simulation of the bifacial gains is possible. More importantly the light available for photosynthesis can be calculated with a high spatial resolution. The light availability is reported through heatmaps, which show in kWh/m^2, the daily light reaching the ground. Moreover, for each case average daily shading rates are calculated. The shading rate is the relative reduction of the light reaching to the crops (Icrop), compared to the unobstructed incoming sky irradiation (Isky) (see Equation 3.1). The shading rate is a very common metric for the evaluation of light availability in agrivoltaic systems.

$$Shading\ Rate\ (\%) = \frac{I_{sky} - I_{crop}}{I_{sky}} * 100\ \%$$

In summary, for each system:

- The final selected design parameters are presented.
- The light reaching the front side of the modules is modelled and the expected electricity production is calculated.
- The light reaching to the plants is also modelled, and the mean shading rates are calculated for each month.

The results of the evaluation will first be presented separately for each system type, describing the values obtained. For further clarity and ease of reading, the results will then be summarized and compared in the conclusion.

7.11 Results of system design

7.11.1 Fixed-tilt system coastal

In Figure 57, the main selected parameters for the fixed agrivoltaic system in landscape orientation are illustrated.

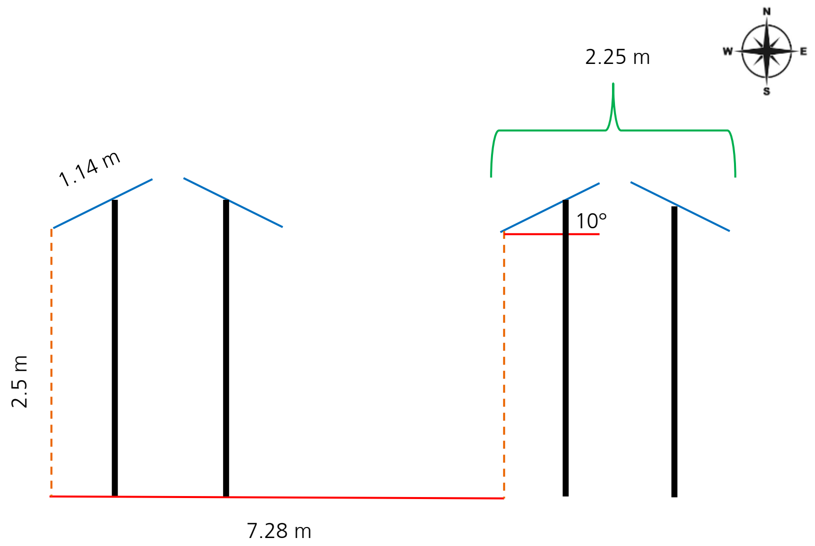


Figure 56: Fixed agrivoltaic system with modules in landscape orientation and a reduction in solar radiation of 30%

7.11.1.1 Electrical Yield Analysis

The in-plane irradiation provides the amount of irradiation in kilowatt-hours (kWh) incident on the PV modules per square meter, while the energy production states the number of kWh of energy produced for each kWp installed. The monthly energy production and in-plane irradiation for the landscape 30%

shading rate system is detailed in Figure 57: Monthly energy production (top) and in-plane irradiation (bottom). below. The usage of bifacial modules results in an annual specific energy yield of 1764.5 kWh/kWp.

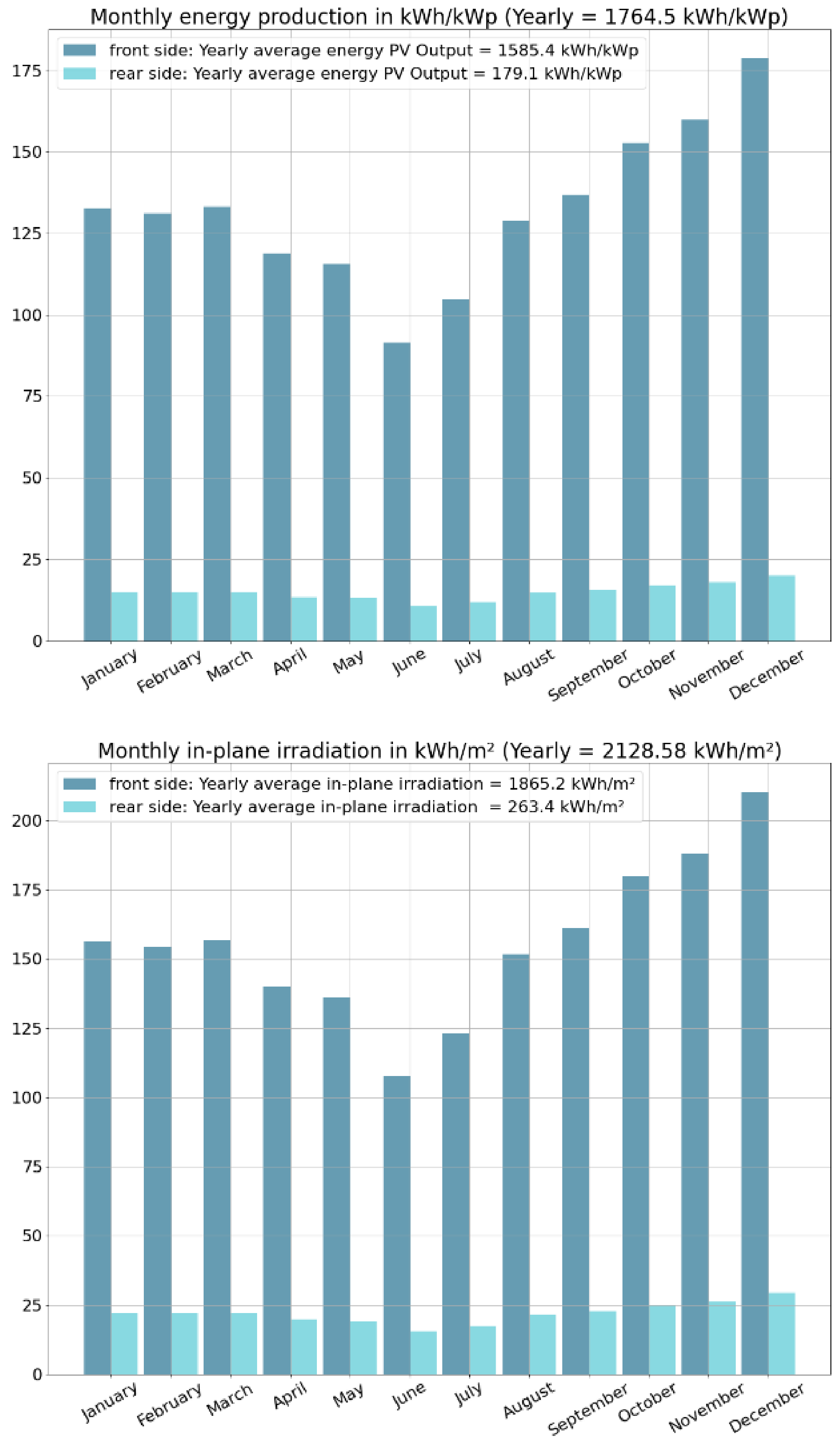
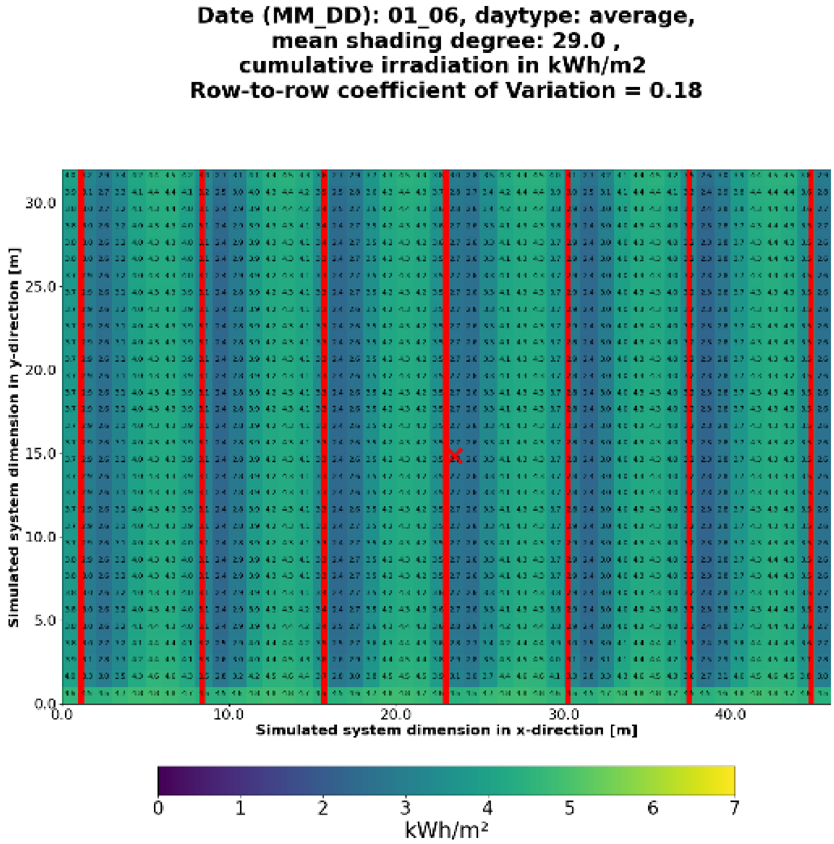


Figure 57: Monthly energy production (top) and in-plane irradiation (bottom).

7.11.1.2 Light Availability Analysis

The irradiation simulation at ground level provides the cumulative irradiation in kWh/m² incident below the PV modules. Simulations are done in hourly time-steps which are then averaged into daily results for selected typical days (three days in each month of the year), resulting in a total of 48 simulation heatmaps. For clarity, one map is presented for each quarter of the year (see Figure 58: Heatmaps of the fixed system for randomly selected days in January and March. and Figure 59: Heatmaps of the fixed system for randomly selected days in July and October.). The remaining heatmaps will be provided upon request and can be sent in a separate folder. The main purposes of the heatmaps presented below is to present the light distribution below the PV modules and confirm that the selected E-W orientation of the system results in a homogenous distribution of light. With regards to the spatial distribution of the irradiation incident on the ground under the PV modules, the system shows a significantly homogeneous distribution of sunlight as indicated by the nominal shading bands and marginal difference in color between bands.



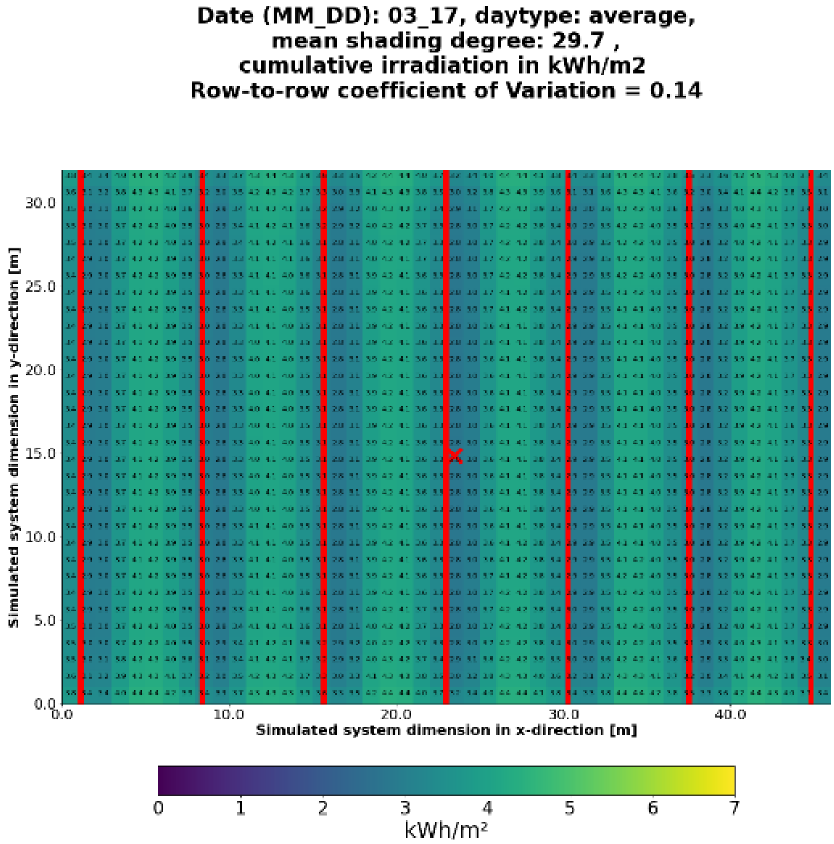


Figure 58: Heatmaps of the fixed system for randomly selected days in January and March.

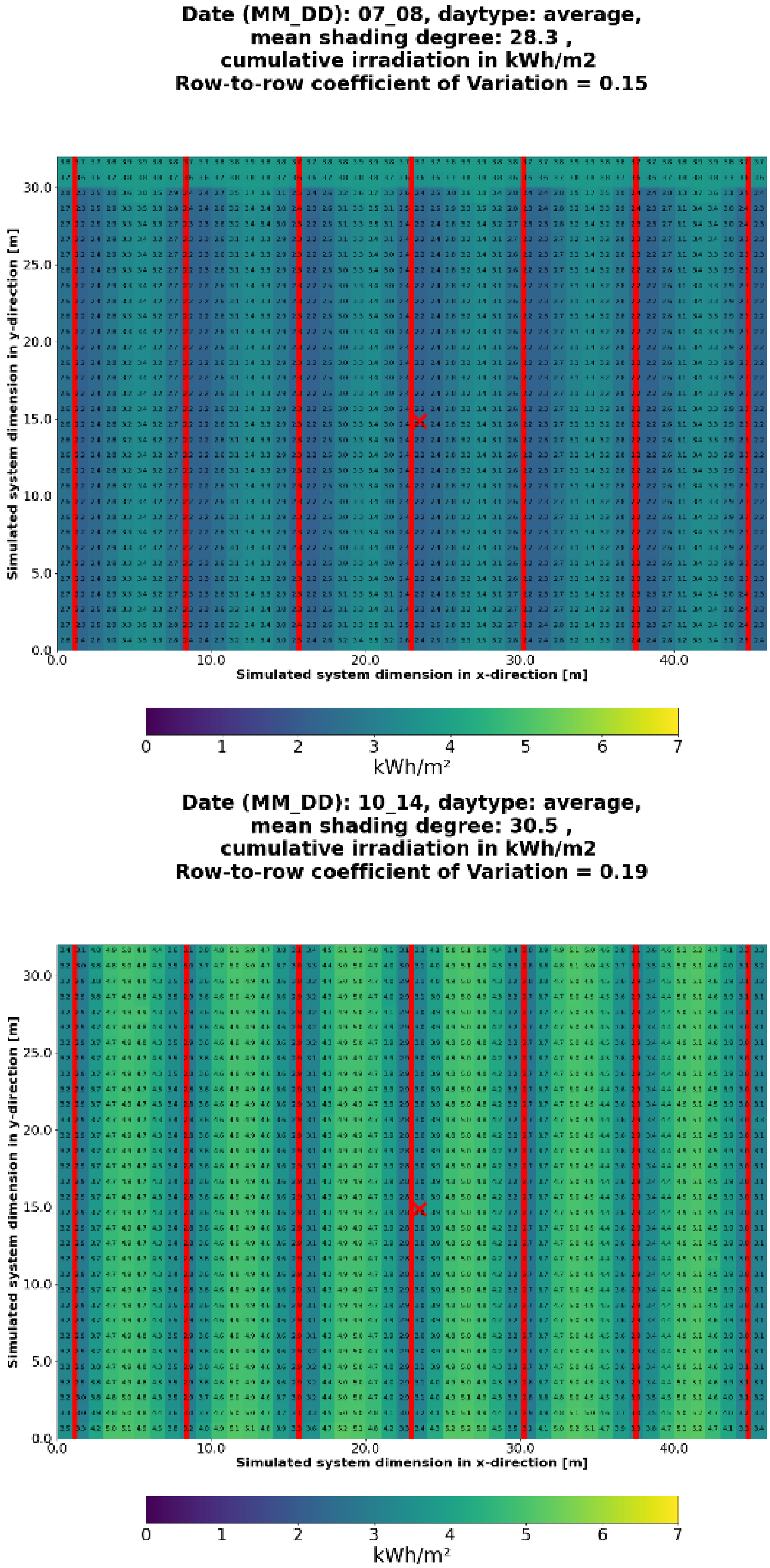


Figure 59: Heatmaps of the fixed system for randomly selected days in July and October.

7.11.2 Fixed-tilt system highlands

In Figure 60: Fixed agrivoltaic system with modules in landscape orientation and a reduction in solar radiation of 30%., the main selected parameters for the fixed agrivoltaic system in landscape orientation are illustrated in the highlands.

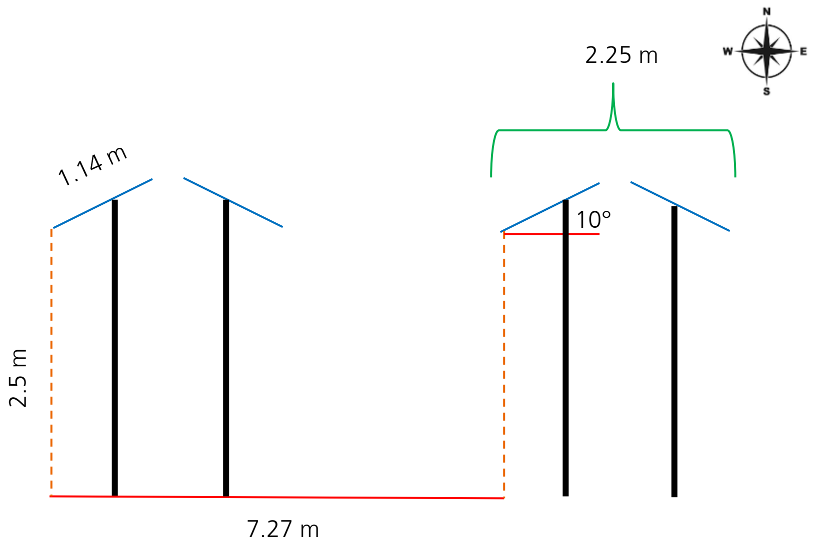


Figure 60: Fixed agrivoltaic system with modules in landscape orientation and a reduction in solar radiation of 30%.

7.11.2.1 Electrical Yield Analysis

The monthly energy production and in-plane irradiation for the landscape 30% shading rate system is detailed in Figure 61: Monthly energy production (top), monthly in-plane irradiation (bottom). below. The usage of bifacial modules results in an annual specific energy yield of 1620.5 kWh/kWp. Which is a slight reduction compared to the location on the coast.

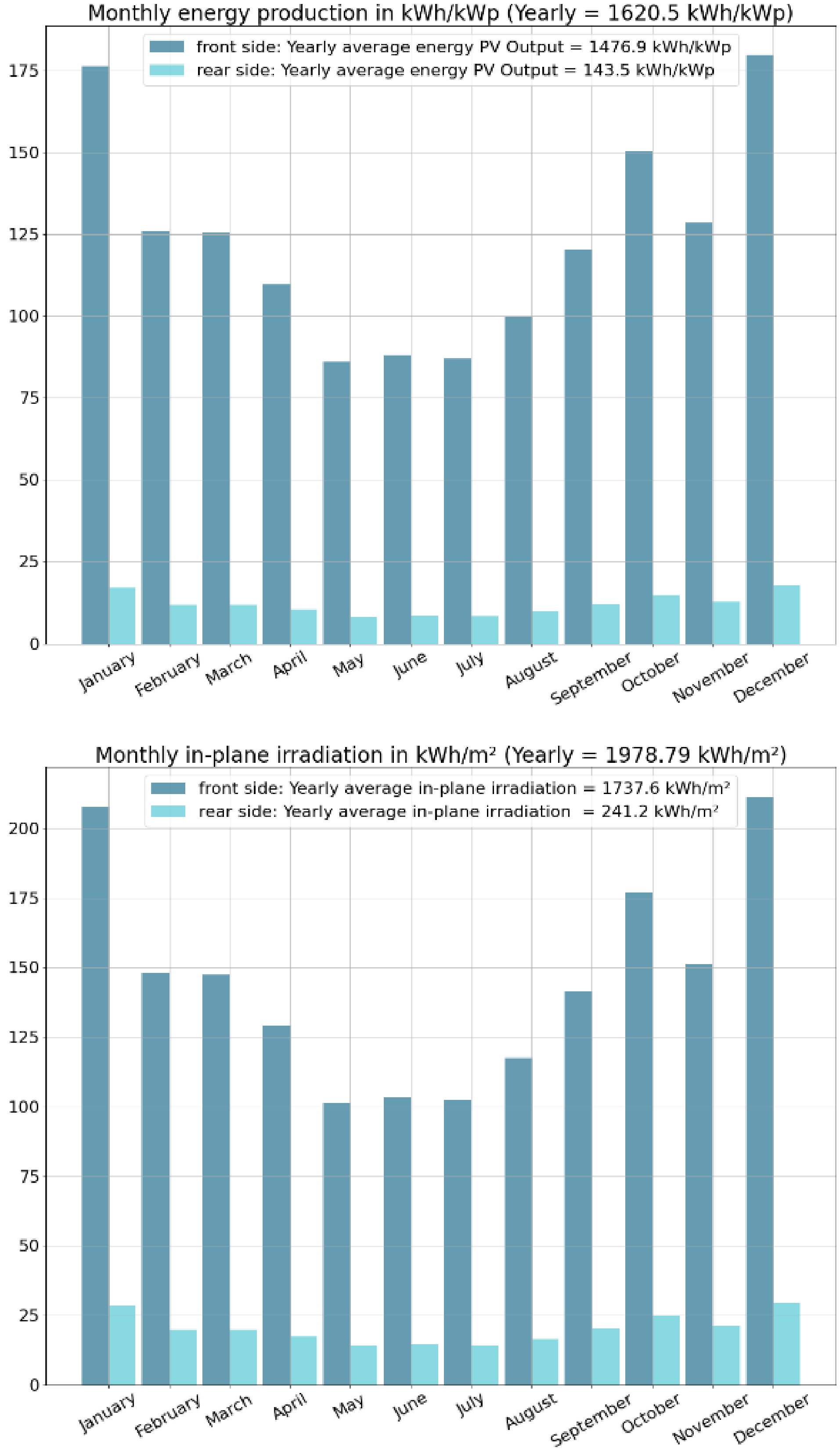


Figure 61: Monthly energy production (top), monthly in-plane irradiation (bottom).

7.11.2.2 Light Availability Analysis

For clarity, one map is presented for each quarter of the year. The remaining heatmaps will be provided upon request. The heatmaps for the highlands location are similar to the coastal area as there are very little differences in the system design with a slight reduction in the row-to-row distance – see Figure 62: Heatmaps of the fixed system for randomly selected days in January and March. and Figure 63: Heatmaps of the fixed system for randomly selected days in July and October..

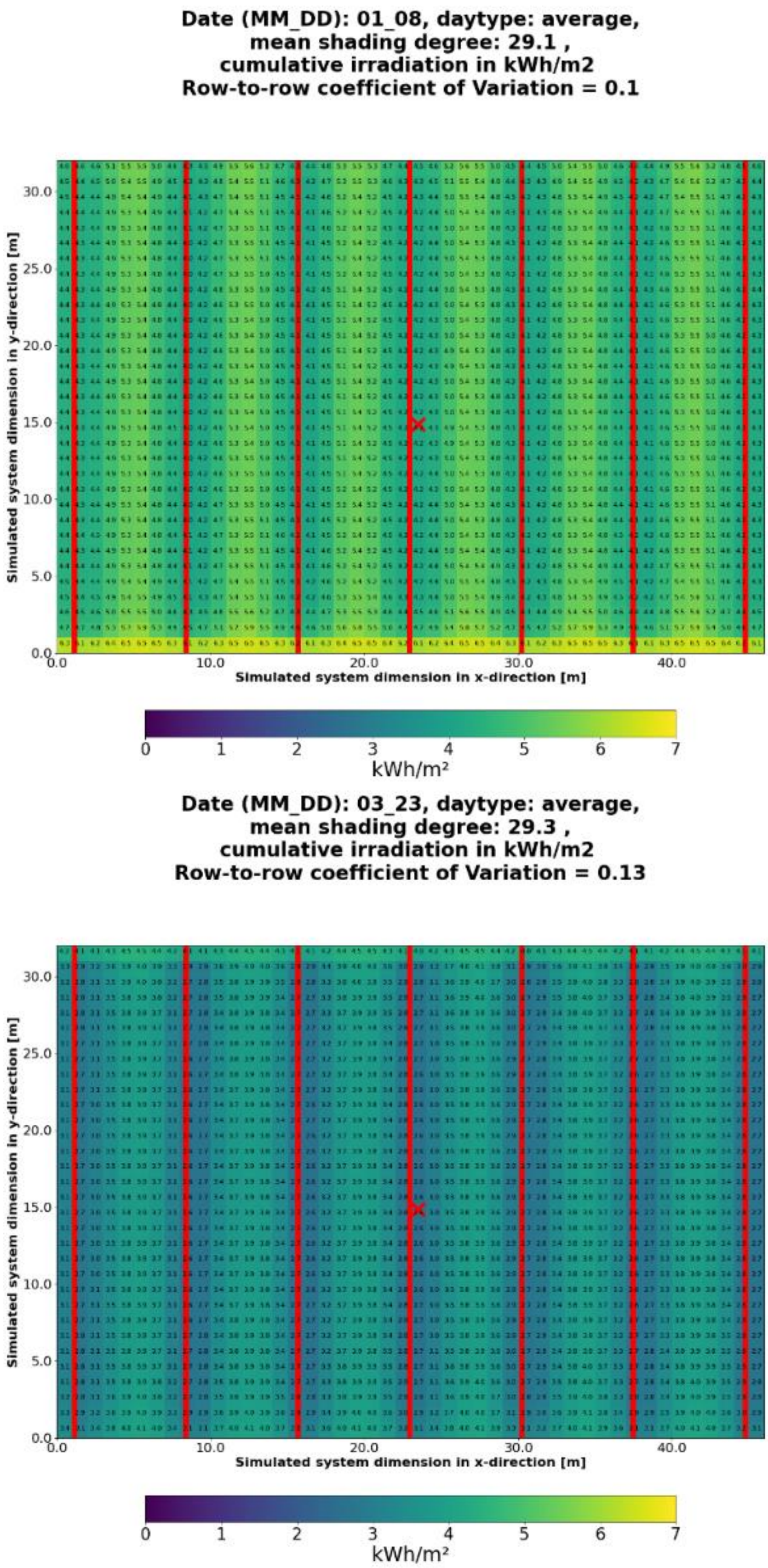
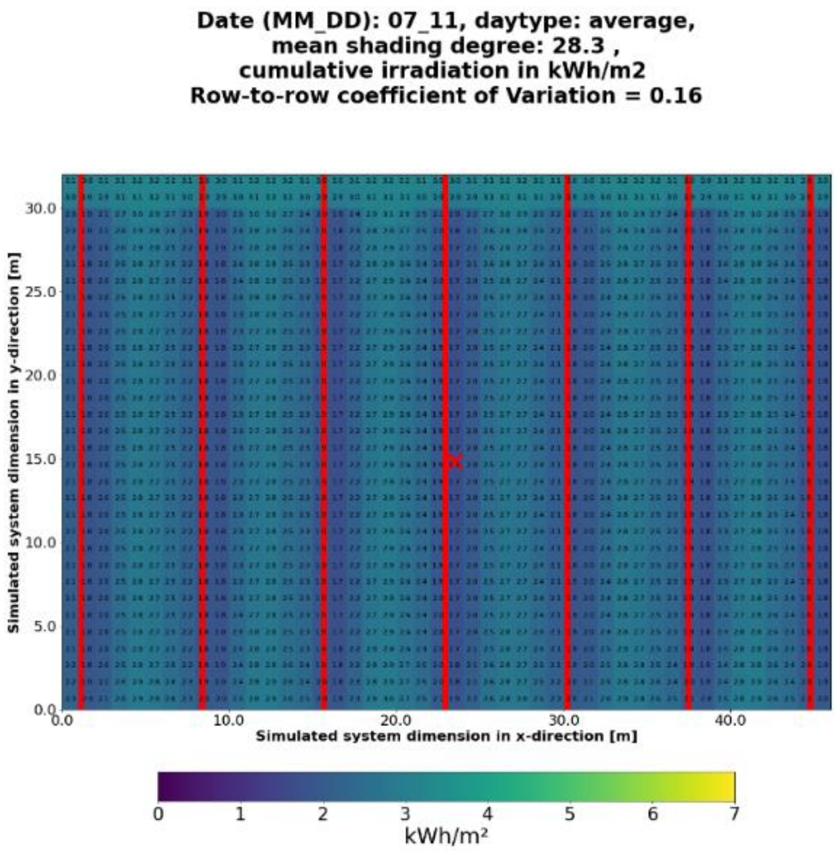


Figure 62: Heatmaps of the fixed system for randomly selected days in January and March.



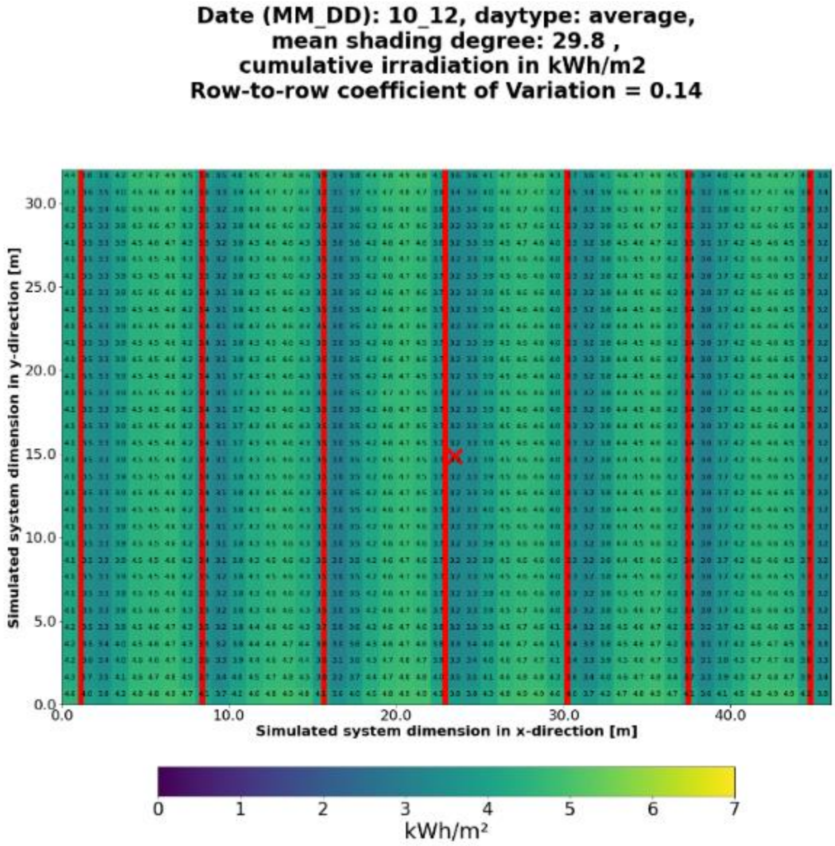


Figure 63: Heatmaps of the fixed system for randomly selected days in July and October.

7.11.3 Tracked System Coastal

One of the most prevailing agrivoltaic systems are the overhead dynamic systems. Already in France, most of the newly installed agrivoltaic systems have a tracking mechanism, which have the great advantage of dynamic control of light availability. The modules, when tracking the sun, can produce more energy than the static systems, while according to the crop needs, customized tracking mechanism can be developed. In this way, more light can be available for the crops during critical periods, for example, the growing phase. In Mauritius in particular, the high level of solar irradiation speaks in favor of tracking systems. The most common applied tracking system are the single-axis tracking systems, which track the East-West movement of the sun, with an increase of applied systems globally.

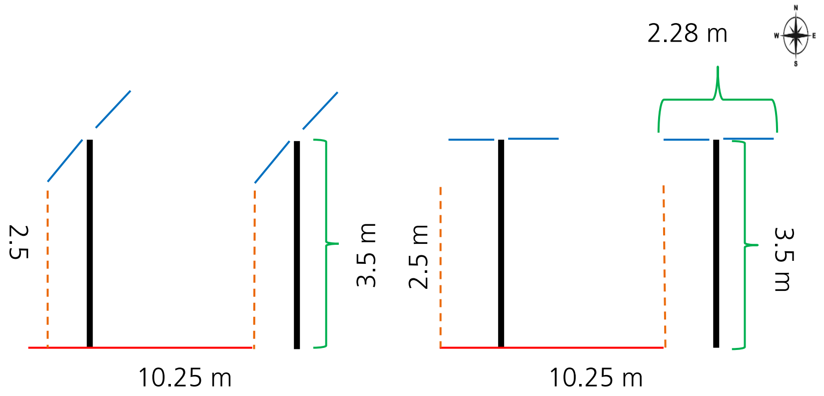


Figure 64: Fixed agrivoltaic system with modules in landscape orientation and a reduction in solar radiation of 30%.

Figure 65 illustrates the main selected technical parameters for the single-axis tracking system:

- The PV modules in landscape orientation allow for a moderate clearance height (height from ground level to the maximum tilt angle of the module) of 2.5 m. This allows a maximum tilt of the PV module while still providing a hub height of over 3.5 m.
- A pitch of 10.25 m (coastal), 10.04 m (highlands) is applied, to give a shading rate of 30%.

7.11.3.1 Electrical Yield Analysis

As seen in Figure 66, the tracking function results in an annual in-plane irradiation of 2709.51 kWh/m² and an energy production of 2225.5 kWh/kWp. This represents an increase of approximately 460 kWh/kWp installed over the fixed systems (20% increase).

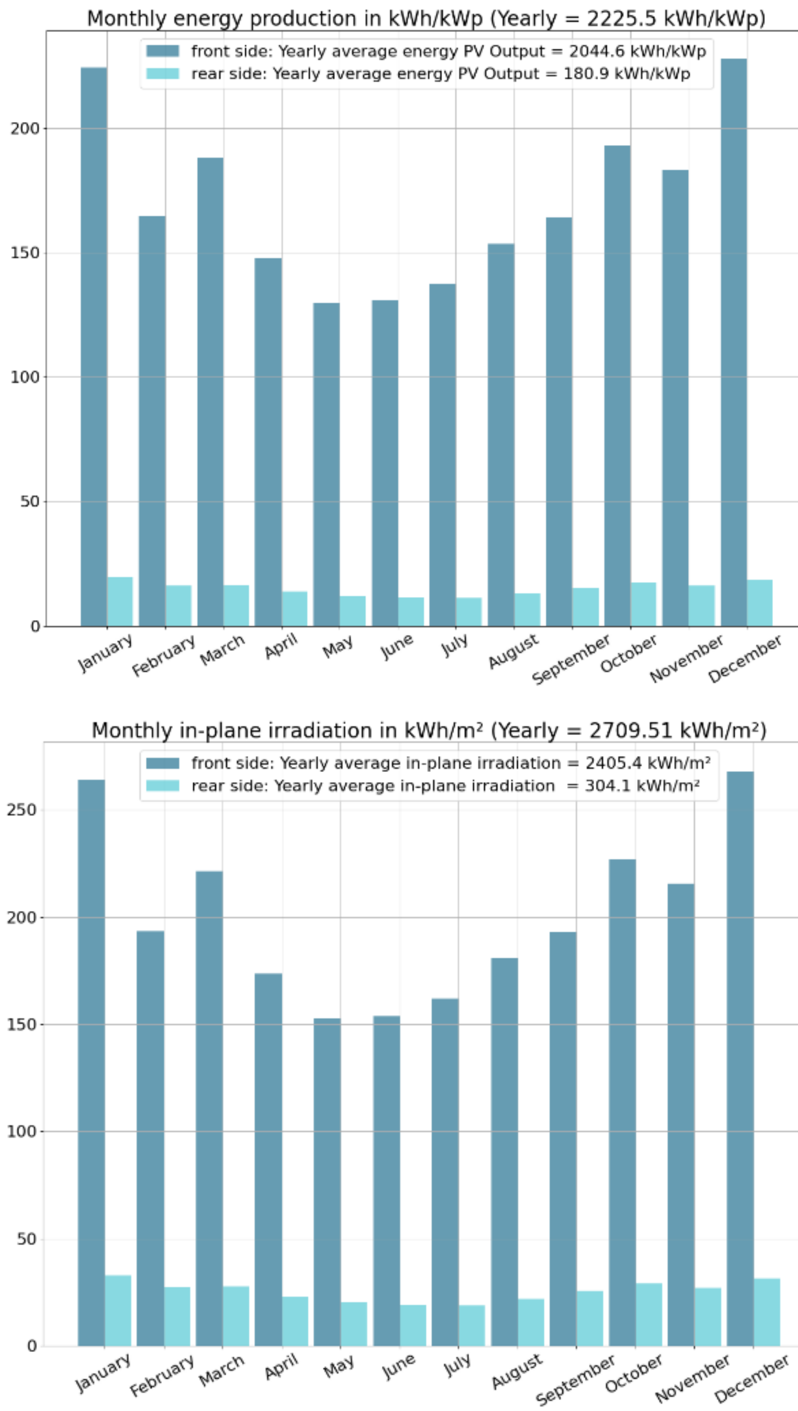


Figure 65: Monthly energy production (top), monthly in-plane irradiation (bottom).

7.11.3.2 Light Availability Analysis

Comparing both system designs, the single-axis tracking system shows the greatest light homogeneity. Very nominal shading bands are observed almost directly below the PV modules and when compared to the areas between module rows that receive higher solar irradiation, it is observed that the color difference between the bands is marginal – see Figure 67: Heatmaps of the tracked system for randomly selected days in July and October. and Figure 68.

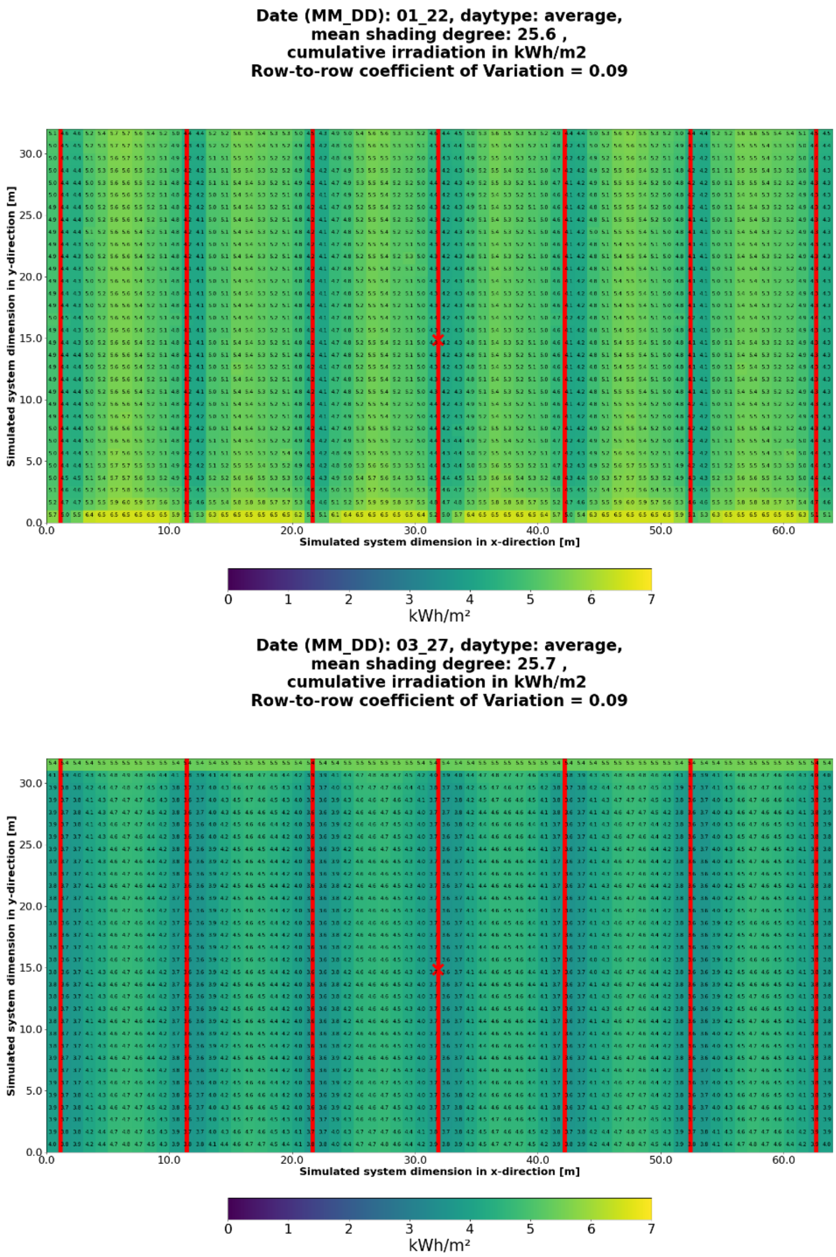


Figure 66: Heatmaps of the tracked system for randomly selected days in January and March.

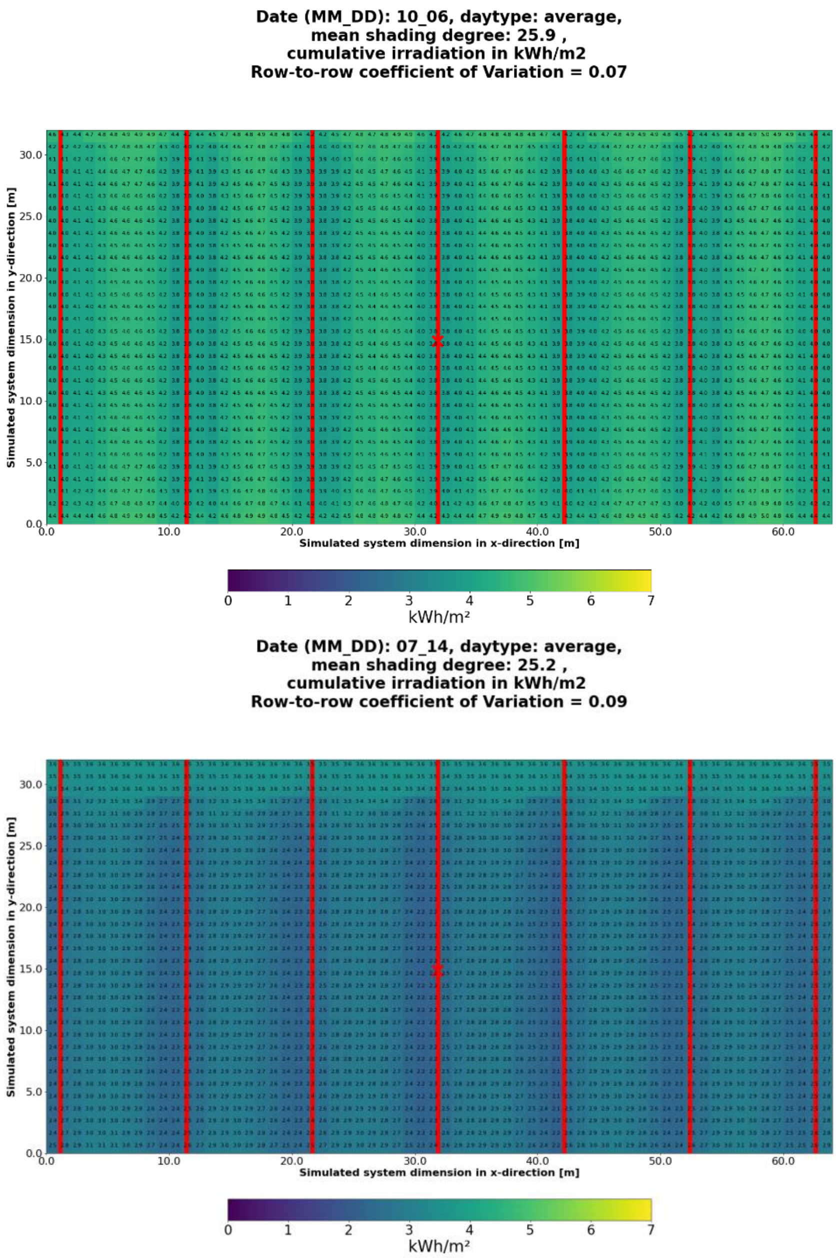


Figure 67: Heatmaps of the tracked system for randomly selected days in July and October.

7.11.4 Tracked System Highlands

In Figure 69, the main selected parameters for the tracked agrivoltaic system in landscape orientation in the highlands are illustrated. The main difference compared to the coastal region lies within the row-to-row distance which decreased to 10.06m.

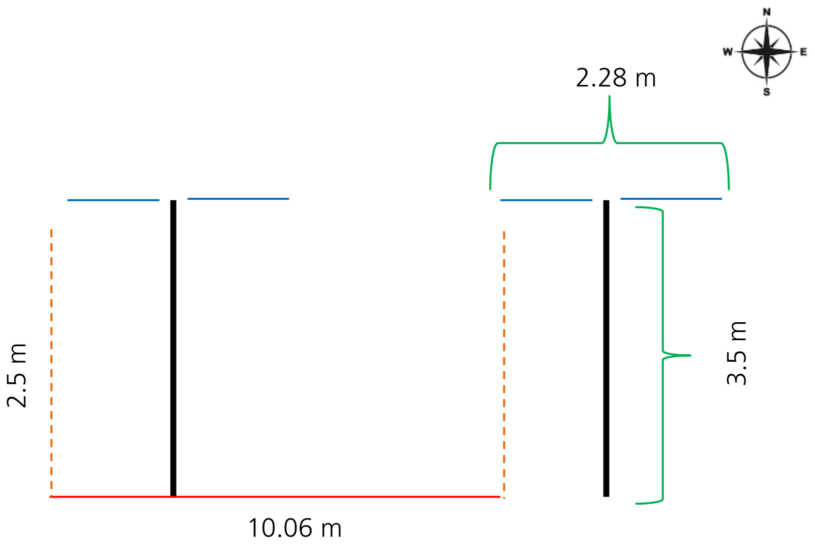
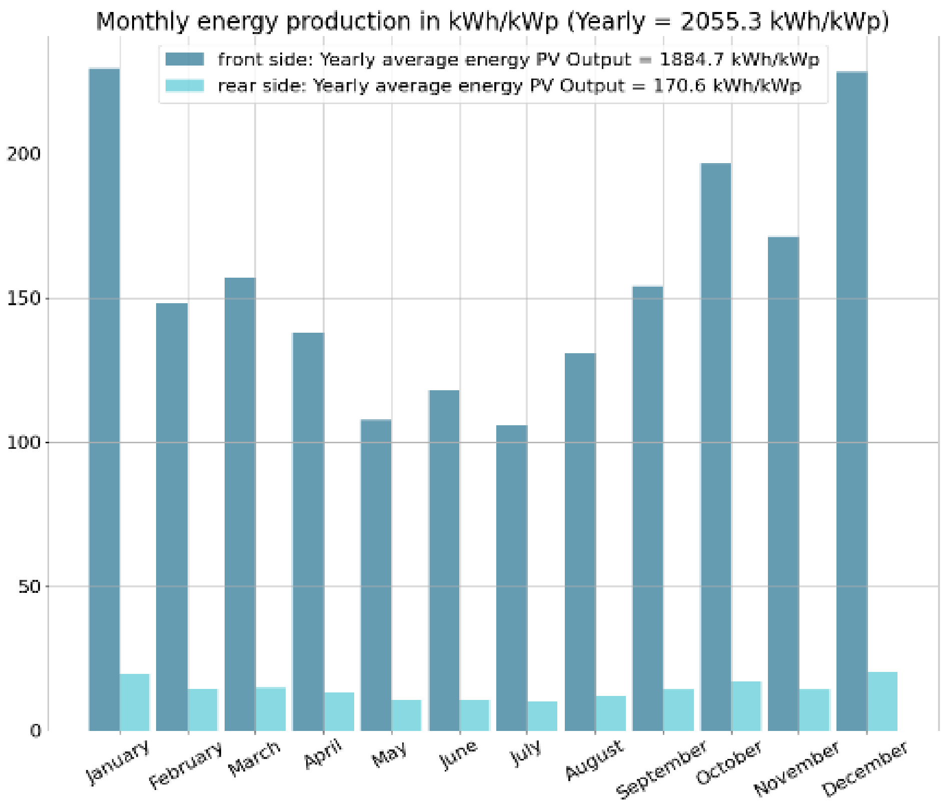


Figure 68: Fixed agrivoltaic system with modules in landscape orientation and a reduction in solar radiation of 30%.

7.11.4.1 Electrical Yield Analysis

As seen in Figure 70 the tracking function results in an annual in-plane irradiation of 2503.97 kWh/m² and an energy production of 2055.3 kWh/kWp. Similar to the coastal region the tracked system has a higher specific yield, which represents an increase of approximately 435 kWh/kWp installed over the fixed systems (20% increase). The production for the landscape 30% shading rate system is detailed in Figure 70 below. The usage of bifacial modules results in an annual specific energy yield of 2055.3 kWh/kWp.



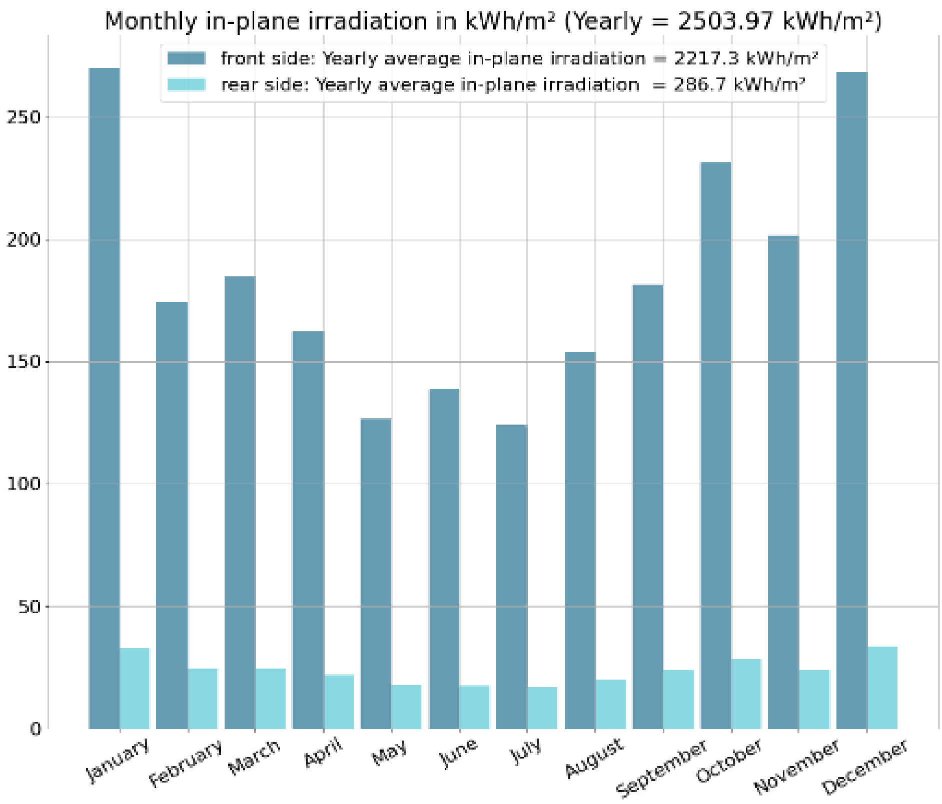


Figure 69: Monthly energy production (top), monthly in-plane irradiation (bottom).

7.11.4.2 Light Availability Analysis

Comparing both system designs, the single-axis tracking system shows also here the greatest light homogeneity. Very nominal shading bands are observed almost directly below the PV modules and when compared to the areas between module rows that receive higher solar irradiation, it is observed that the color difference between the bands is marginal – see Figure 71 and 72

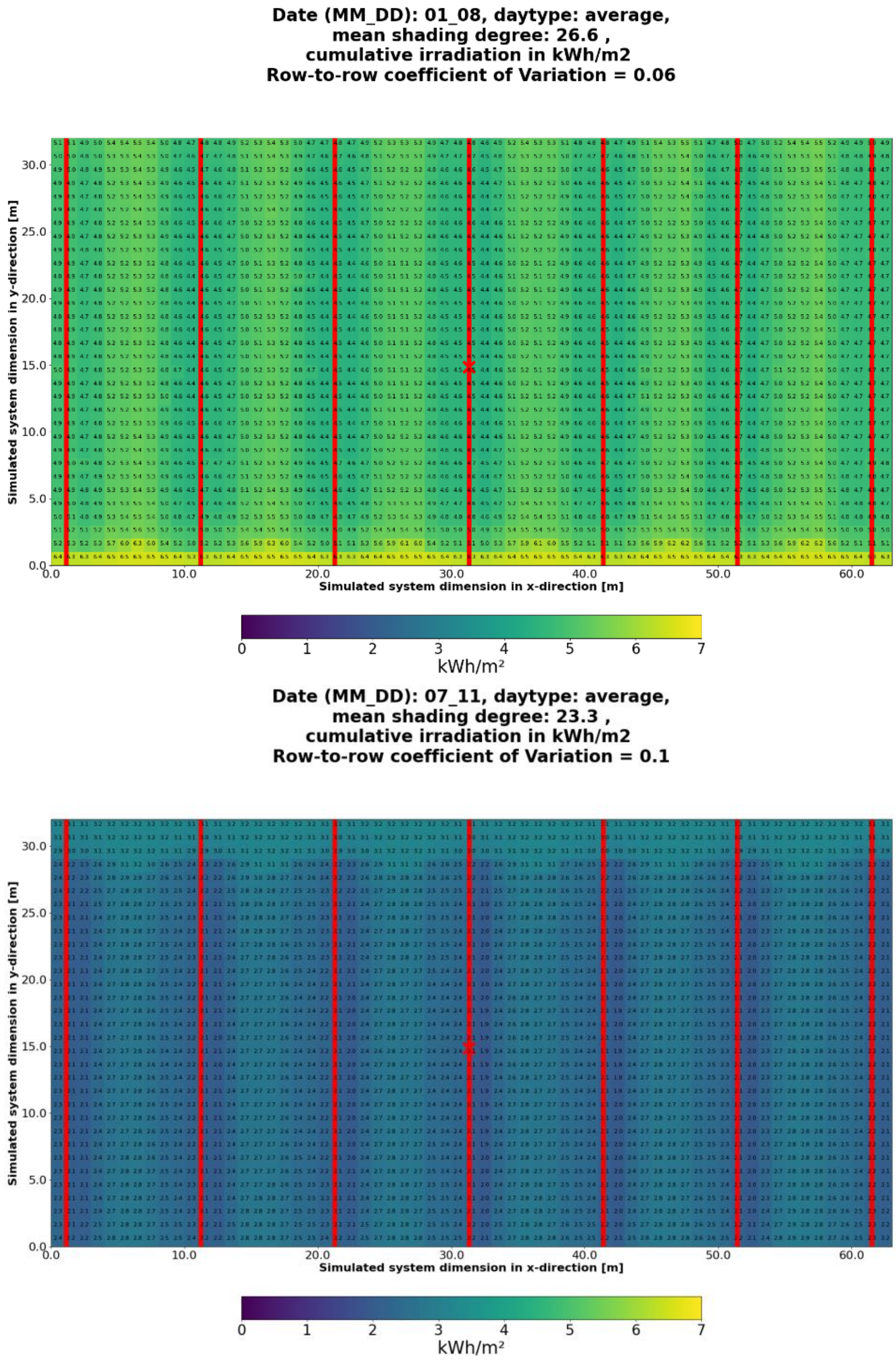
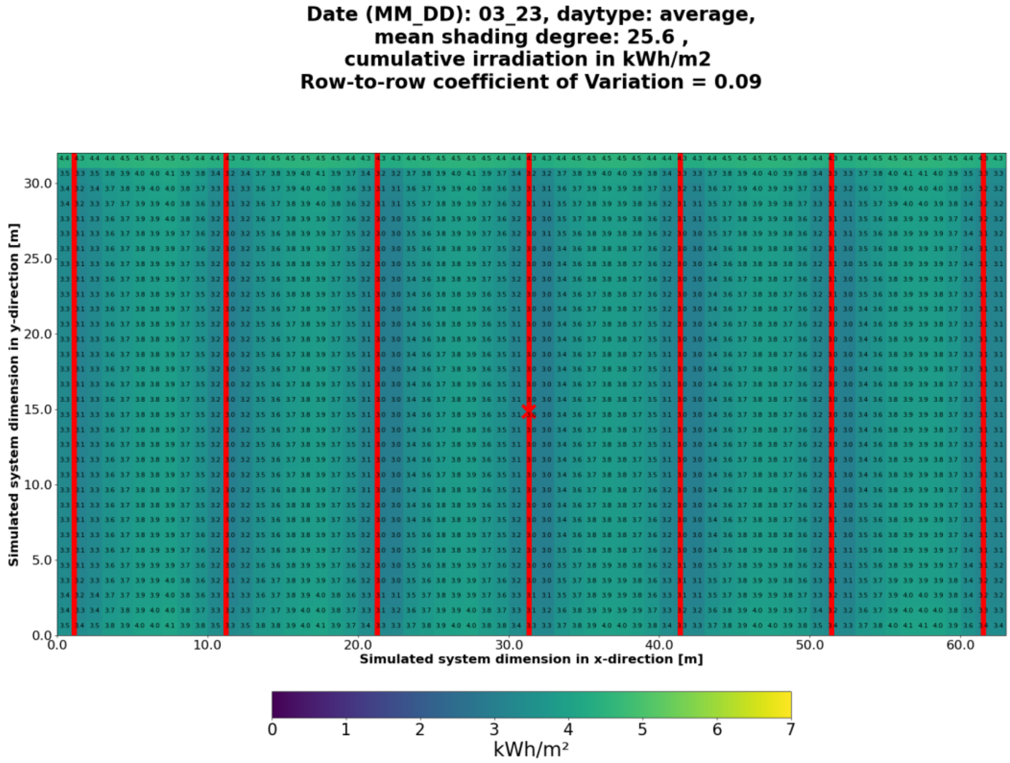


Figure 70: Heatmaps of the tracked system for randomly selected days in January and March.



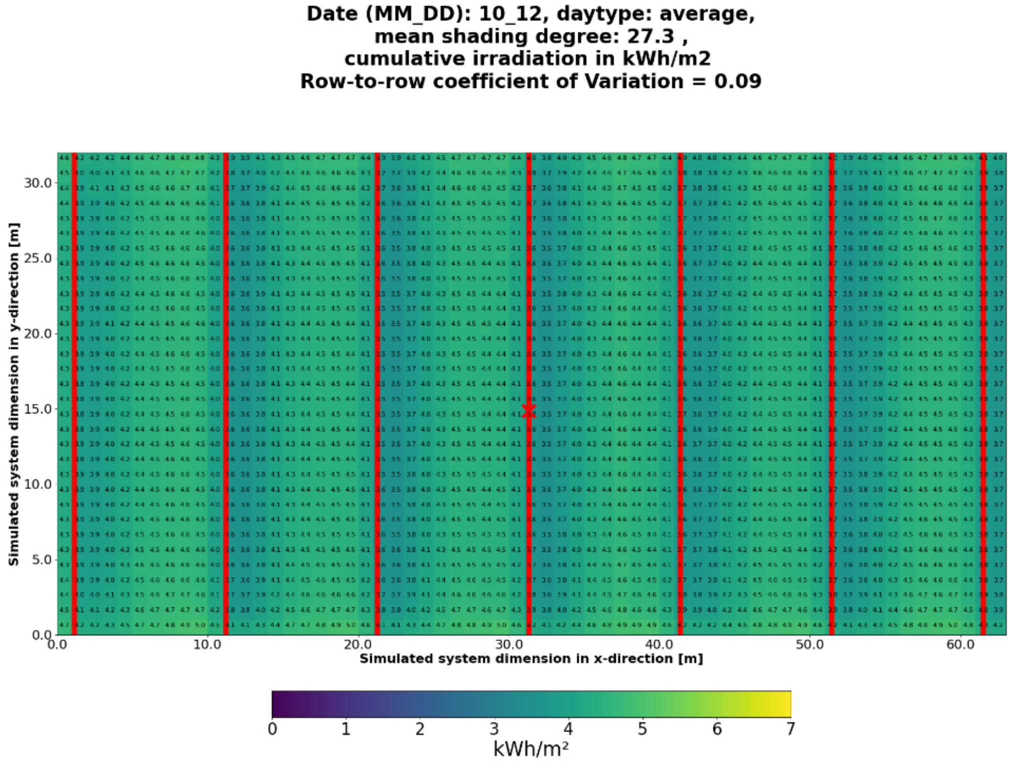


Figure 71: Heatmaps of the tracked system for randomly selected days in January and March

7.12 Summary of Energy and Irradiation Analysis

The Table 14 below summarizes the results of the energy yield simulations conducted for the agrivoltaic system designs described in the previous section. The main outputs can be summarized as follows and can be seen in Figure 72: Comparison of power production for all system types and locations below:

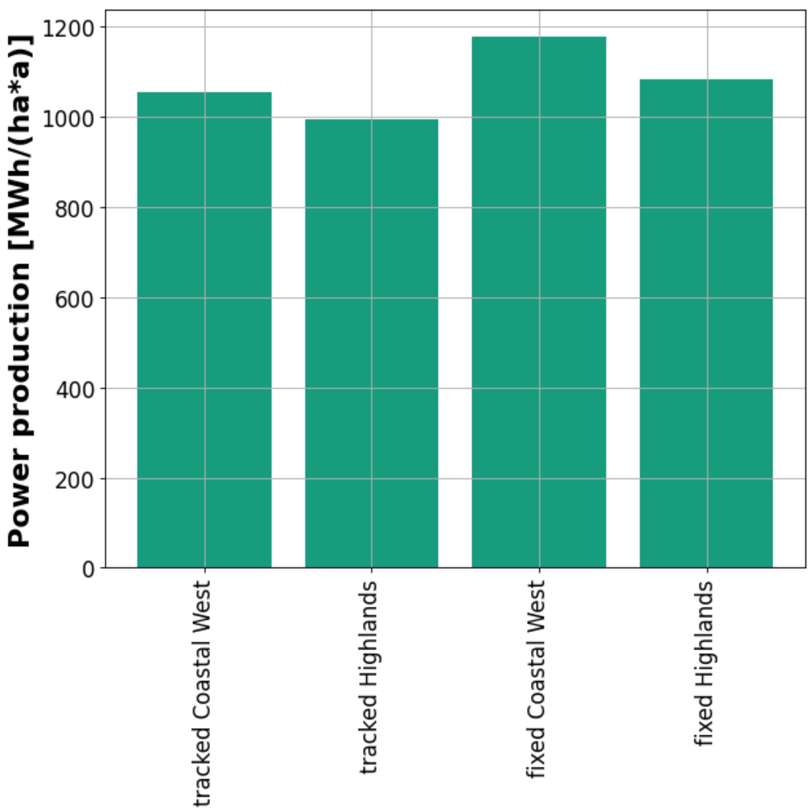


Figure 72: Comparison of power production for all system types and locations

Figure 73 shows a comparison of the power production per year and ha for all locations and systems simulated. The highest power production can be seen in the fixed system in the coastal region, whereas the lowest values can be seen in the tracked system in the highlands.

Table 14: Summary of the simulation results of all locations and system types

Location	System Type	Bifacial gain [%]*	Installed capacity [kWp/ha]	Specific yield [kWh/kWp]	Power production [MWh/ha*year]
Coastal	Fixed	11.29	667.7	1764.5	1178.2
Coastal	Tracked	8.85	474.2	2225.5	1055.4
Highlands	Fixed	9.71	668.8	1620.5	1083.5
Highlands	Tracked	9.05	483.2	2055.3	993.1

*Albedo: 0.2

In Table 14 all-important parameters are summarized. Comparing all systems, the fixed system seems to be outperforming the tracked system in all metrics except the specific yield. One would expect the tracked system to have a higher power production. However due to the very large row-to-row distance the fixed system seems to be superior. Taking also into account the additional capital expenditure associated with a tracking system, the rooftop configuration seems to be the most suitable configuration in a Mauritian context.

8
Economic Analysis

8.1 Executive Summary of economic analysis

This chapter provides background information for the economic assessment of agrivoltaic systems in Mauritius and explains the Excel tool elaborated to calculate Levelized Costs of Electricity (LCOE).

In this economic analysis, describing the functionality, the relevant input parameters are listed and the influencing factors for profitability will be analyzed by applying sensitivity analysis. It must be considered that an agrivoltaic system is not only optimized for high yield from solar PV power generation, but also takes agricultural yields into account. For example, , increased height in overhead systems to accommodate and optimize farming activity (i.e. to allow the unobstructed passage of machinery under the PV modules) leads to higher costs for the substructure, wider spacing between rows results in lower energy yield/electrical output per unit area (i.e. more land required to produce the same energy as a standard ground-mounted-PV system), and semi-transparent PV modules are more expensive compared to opaque standard modules without spacing between solar cells, as more module area is required for the same electrical output.

In Mauritius, advancing the agrivoltaic system market requires greater incentives than those for standard utility-scale photovoltaic systems. This necessity arises from the unique structural demands of agrivoltaic systems, where the photovoltaic modules are elevated to facilitate agricultural activities underneath. The design must also account for the region's cyclonic winds, necessitating robust mounting structures that can withstand these forces and are securely anchored to prevent displacement.

Additionally, the transportation of hardware contributes to increased costs. For instance, the capital expenditure (CAPEX) for the only significant agrivoltaic system installed in Mauritius (200 kWp) stands at approximately €1,600 per kWp, which is about 60% higher than that of typical utility-scale PV systems. The reasons include not just the reinforced substructure but also the smaller scale of the Agrivoltaic system compared to utility-scale PV plants, which often exceed 1 MW in capacity. Due to economies of scale, a 1 MWp PV system incurs substantially lower specific investment costs than a 200 kWp system as larger systems require less specific CAPEX in terms of € per kWp than smaller ones.

To prevent excessive hikes in the feed-in tariff, it's advisable for agrivoltaic systems in Mauritius to avoid being too small. A size ranging between 200 kWp and 1 MWp is considered optimal for these systems, balancing cost-effectiveness with the structural requirements unique to the region.

The price trends for utility-scale PV systems and the resulting price estimates in Mauritius for Agrivoltaic systems are presented in chapters 8.4 and 8.5 respectively.

The sensitivity analysis in chapter 8.6 provides insights to the influence of parameters and allows defining the level of support. A suitable feed-in tariff can be calculated with the LCOE plus a small profit margin. A subsidy can be calculated from CAPEX sensitivity analysis and an interest reduction by the Interest rate sensitivity analysis.

Disclaimer
Although the Microsoft Excel calculation tool has been extensively tested, no liability can be accepted for the accuracy of the calculations. For economic decisions, a comparison tool (such as PV GIS or a commercial design and simulation tool) should always be used to rule out errors. The creators of this calculation tool exclude any liability for possible damages that may result from its use. This also applies to the results presented in this report, as they are based on the Excel tool.

8.2 Introduction

To assess the need for incentive schemes like grants and Feed-In Tariffs (FITs), the costs to produce the electricity with a Solar PV system need to be known.

The LCOE is a fundamental calculation used in the preliminary assessment of an energy-producing project.

Why is the Levelized Cost of Energy important?
The LCOE can be used to determine whether to proceed with a project or as a means to compare different energy-producing projects.

- LCOE is a key factor in deciding whether to proceed with building a power-generating asset. Projects with unfavorable LCOE are often not pursued.
- LCOE is essential for comparing diverse energy sources like wind, solar, and nuclear.
- It facilitates comparison despite differences in project life span, capital cost, size, and associated risks.
- The specific discount rate used for each project indicates the associated risk level.

How to calculate the LCOE
The LCOE can be calculated by first taking the Net Present Value of the total cost of building and operating the power generating asset. This number is then divided by the total electricity generation over its lifetime. See formula (1) below.

$$\text{LCOE} = \frac{\text{NPV of Total Costs Over Lifetime}}{\text{NPV of Electrical Energy Produced Over Lifetime}} \tag{1}$$

In more details, the formula can be displayed as follows (2):

$$LCOE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1 + r)^t}}{\sum \frac{E_t}{(1 + r)^t}} \qquad (2)$$

Input parameters:
The initial cost of investment expenditures (I)
Maintenance and operations expenditures (M)
Fuel expenditures (if applicable) (F)
The sum of all electricity generated (E)
The discount rate of the project (r)
The life of the system (n) with the respective year (t)

It is not easy to understand why in the denominator the produced energy is also depreciated. However, this reflects the circumstance that there is a kind of insecurity that this amount of electricity will be produced in the future and the more it will be in the future, the more it will be depreciated.

It is important to note that the **energy sales price** does not affect the LCOE calculation, but it does affect the Internal Rate of Return [IRR], the payback period, and the Net Present Value [NPV].

8.3 Experience from Germany

8.3.1.1 The German Renewable Energy Act

The German Renewable Energy Act (Erneuerbares Energien Gesetz, EEG) is in force since the year 2000. It significantly bolstered the installed capacity of PV and Wind power in a highly effective and robust manner. The EEG guarantees a fixed feed-in tariff for the year of installation plus next 20 years. While in older schemes all generated power was fed to the grid, nowadays self-consumption is also feasible and with the given high electricity tariffs in Germany, this is the most attractive model today. Additionally, self-consumed electrical energy does not affect or overload the grid.

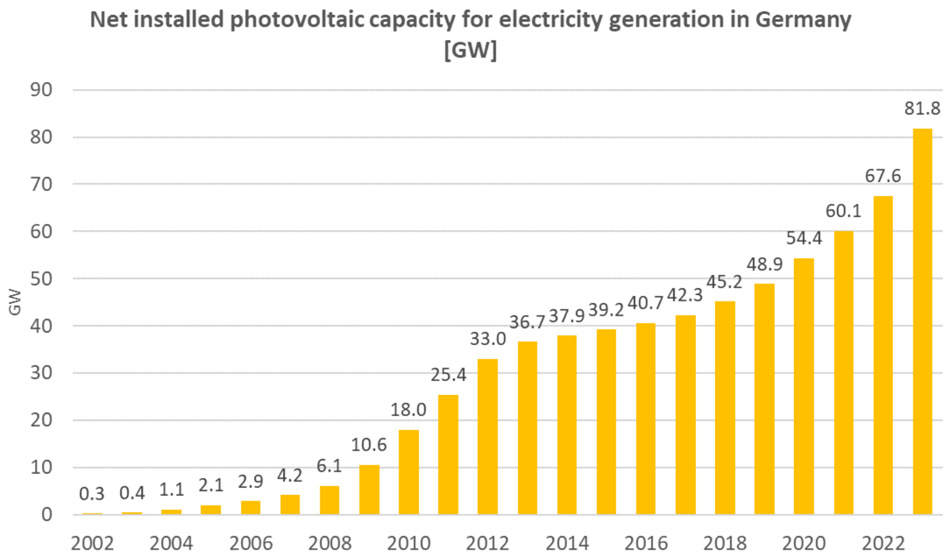


Figure 73: Solar PV installed net capacity in Germany.

Data: energy-charts.info (last update: 24.01.2024); Graph: PSE Projects GmbH 2024

To promote investments in Solar PV, projects must be profitable. The profitability of Solar PV projects can be calculated by the LCOE plus a profit margin. In Germany a profit margin of 6% or more turned out to stimulate the market.

Typically, profitable PV projects in Germany have a payback period of half of their total lifetime or less. Therefore, in Germany the payback period is typically not longer than 10 years.

The EEG is not financed by taxes, but by an additional fee on the power tariff. To avoid high costs for power consumers, the FIT was adapted periodically to the market situation. In the case of PV-systems, this means adoption to the CAPEX for PV modules, inverters, and Balance of Systems (BoS) including mounting work.

8.3.1.2 PV-Tender Scheme in Germany

The lowest PV-Tender round in Germany was in February 2018 with 4.33 ct€ / kWh as average quantity weighted award price as shown in Figure 74.
The German PV-Tender scheme started in April 2015 and total capacity of this scheme accumulated to 9 GW by Nov-2022, with 5.8 ct€ / kWh as latest average quantity weighted award price.
These utility-scale tender award values are quoted here to give an understanding of the lower limit for an adequate Feed-in tariff (FIT).

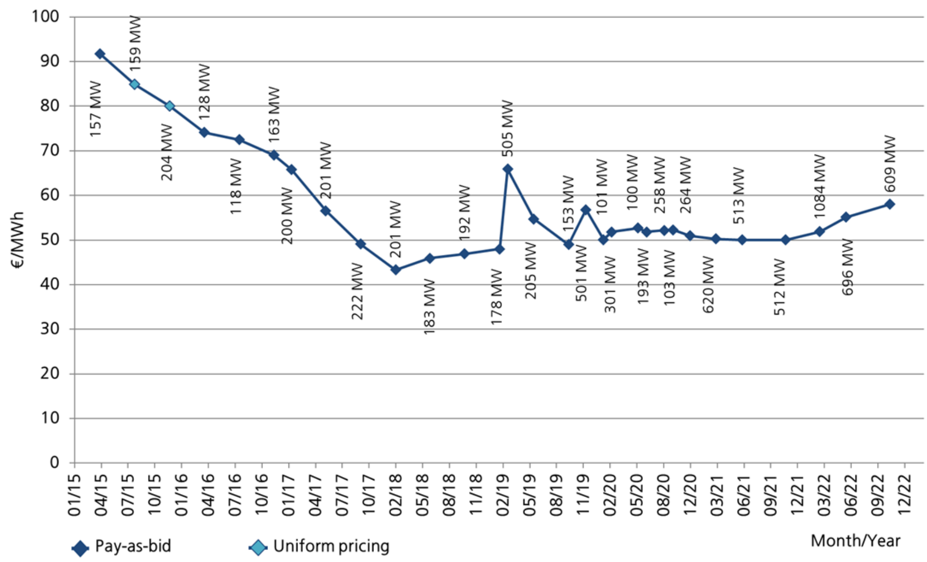


Figure 74: PV-Tender in Germany with average, quantity weighted award value

Note: Special tenders are not displayed in the graph.

8.3.2 Feed-In tariff in Germany

The feed-in tariff for photovoltaic systems (PV systems) in Germany is adjusted annually and is based on the EEG. The feed-in tariffs for 2024 are as follows, depending on the system size and commissioning date:

- Up to 10 kWp: The feed-in tariff is 8.2 cents per kilowatt hour (kWh) for partial feed-in.
- 10 to 40 kWp: The feed-in tariff is 7.1 cents per kWh.
- Up to 100 kWp: The tariff is 5.8 cents per kWh.

From February 1, 2024, the remuneration rates will be reduced by 1 percent every six months. For systems up to 10 kWp, the following remuneration rates will then apply:

- Partial feed-in 8.1 cents per kWh
- Full feed-in 12.9 cents per kWh

From August 1, 2024, these values will be reduced to 8.0 cents and 12.8 cents per kWh respectively. Please note that this information only applies to new systems commissioned after January 31, 2024 [1].

An additional premium of 0.3 ct/kWh can be achieved for agrivoltaic systems. However, several conditions must be met at the same time [2]:

- The loss of agricultural land is less than 15 %.
- Vertically aligned Agri-PV systems must be at least 0.8 meters high and elevated systems at least 2.1 meters high.
- Nitrogen fertilization on the area is generally reduced by 20 % and herbicides are not used.
- A flowering strip or, in the case of grassland, an old grass strip must be created on 5% of the area.

The feed-in tariff is a statutory payment for solar power fed into the grid and is guaranteed by the state for the year of installation and the following 20 years and is independent of the electricity exchange price.

8.3.3 Feed-In tariff in France

The feed-in tariff for Agri-PV systems in France is subject to adjustment based on the system size and the period. For the period from August 2023 to January 2024, the new tariffs range from €0.2077/kWh for installations below 3 kW in size to €0.1208/kWh for arrays ranging in size from 100 kW to 500 kWhttps://www.pv-magazine.com/2024/01/04/france-announces-new-fit-rates-for-pv-systems-up-to-500-kw/. The French government raised the size limit for PV projects that can qualify for fixed tariffs from 100 kW to 500 kW in October 2022 [3]. For the second quarter of 2023, the tariffs ranged from €0.2395/kWh for installations below 3 kW in size to €0.1268/kWh for arrays ranging in capacity from 100 kW to 500 kW [4].

Installations dont la demande complète de raccordement a été effectuée :		01/08/2023 – 31/10/2023	01/11/2023 – 31/01/2024
Tarifs d'achat (Vente en totalité des installations de moins de 100 kWc) en c€/kWh selon le coefficient E*			
T_a	0 < P + Q ≤ 3 kWc	20,77	17,35
	3 kWc < P + Q ≤ 9 kWc	17,65	14,74
T_b	9 kWc < P + Q ≤ 36 kWc	14,41	13,82
	36 kWc < P + Q ≤ 100 kWc	12,53	12,02
Primes à l'investissement (Vente en surplus des installations de moins de 100 kWc) en €/Wc selon le coefficient F*			
P_a	0 < P + Q ≤ 3 kWc	0,44	0,37
	3 kWc < P + Q ≤ 9 kWc	0,33	0,28
P_b	9 kWc < P + Q ≤ 36 kWc	0,21	0,20
	36 kWc < P + Q ≤ 100 kWc	0,11	0,10
Tarif de rachat du surplus (Vente en surplus des installations de moins de 100 kWc) en c€/kWh			
Tarif	0 kWc < P + Q ≤ 9 kWc	13,39	13,00
Tarif	9 kWc < P + Q ≤ 100 kWc	8,03	7,80
Tarif d'achat des installations de puissance supérieure à 100kWc respectant les critères généraux d'implantation en c€/kWh			
Tc	100 kWc < P + Q ≤ 500 kWc	12,77	12,08
$Tc * K_{N+1} / K_N$	100 kWc < P + Q ≤ 500 kWc	12,40	/
$Tc * K_{N+2} / K_N$	100 kWc < P + Q ≤ 500 kWc	/	/

Figure 75: Feed-in tariffs of installations for which a complete connection request has been made.

Source: [3]

8.4 Utility System Price development

Prices for PV modules, inverters, and Balance of System (BoS) differ quite significantly between different countries as can be seen in Figure 76. Balance of System costs refer to all other costs except for the given costs for PV modules and inverter.
Since some years, India has the least costs for ground-mounted utility scale PV systems. However, this does not provide insight into the performance of these systems. For example, low quality plugs and connectors can result in high resistance or even interruptions in strings which can lead to a reduced power yield.

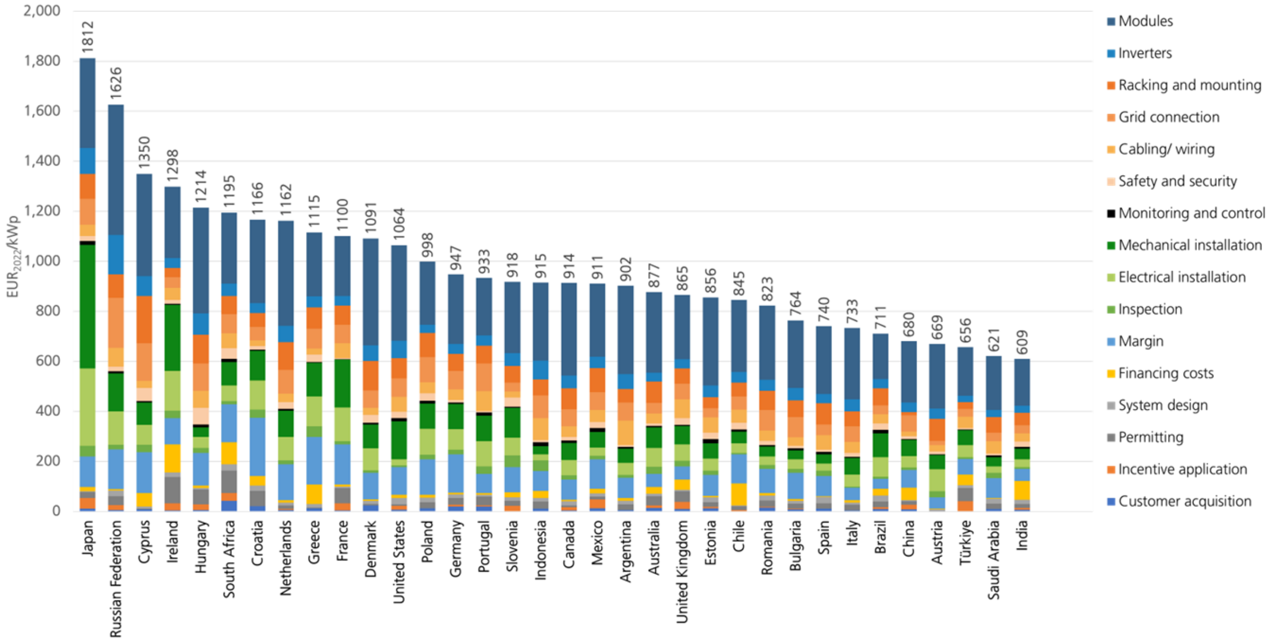


Figure 76: Detailed breakdown of utility-scale solar PV total installed costs by country, 2022
Data source: IRENA Renewable Power Generation Costs in 2022
Graph: PSE Projects GmbH, 2024

The breakdown of cost components as an average of available country data for 2022 are shown as a pie chart in Figure 77. All hardware costs add to about 60% of the total costs. Installation and soft costs each account for one fifth of the total costs.

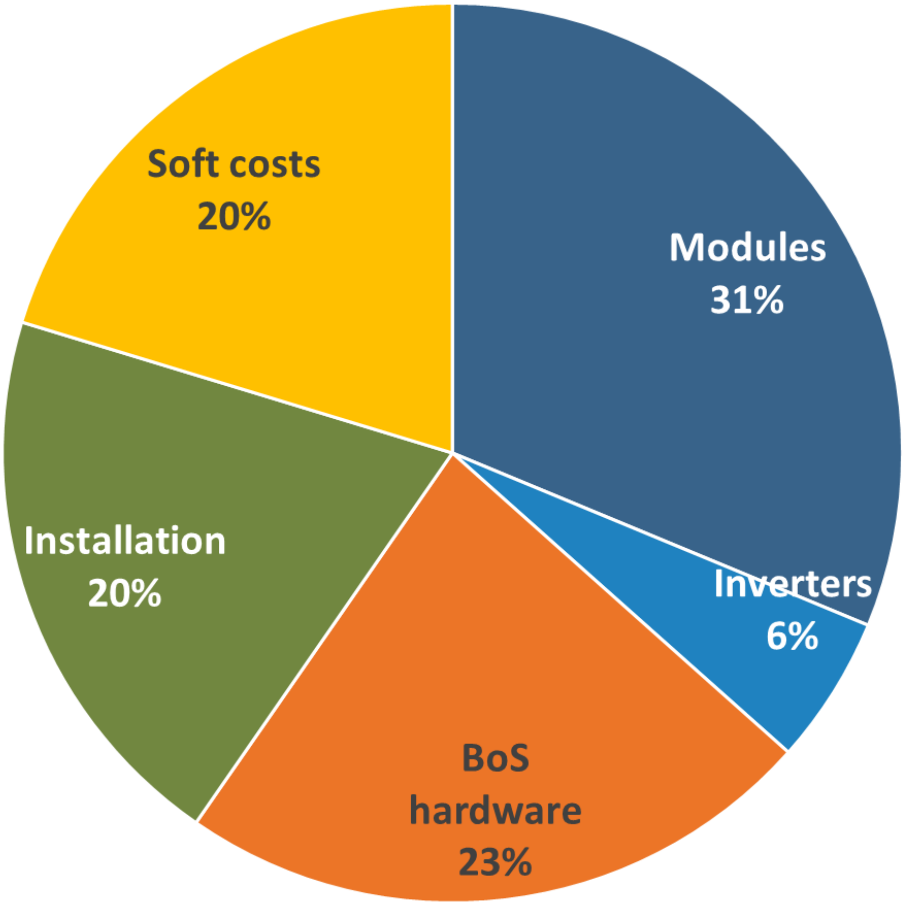


Figure 77: Breakdown of cost components (average of available country data) 2022
Data source: IRENA Renewable Power Generation Costs in 2022
Graph: PSE Projects GmbH, 2024

Category	Cost Component
Module and inverter hardware	Modules
	Inverters
BoS hardware	Racking and mounting
	Grid connection
	Cabling/ wiring
	Safety and security
	Monitoring and control
Installation	Mechanical installation
	Electrical installation
	Inspection
Soft costs	Margin
	Financing costs
	System design
	Permitting
	Incentive application
	Customer acquisition

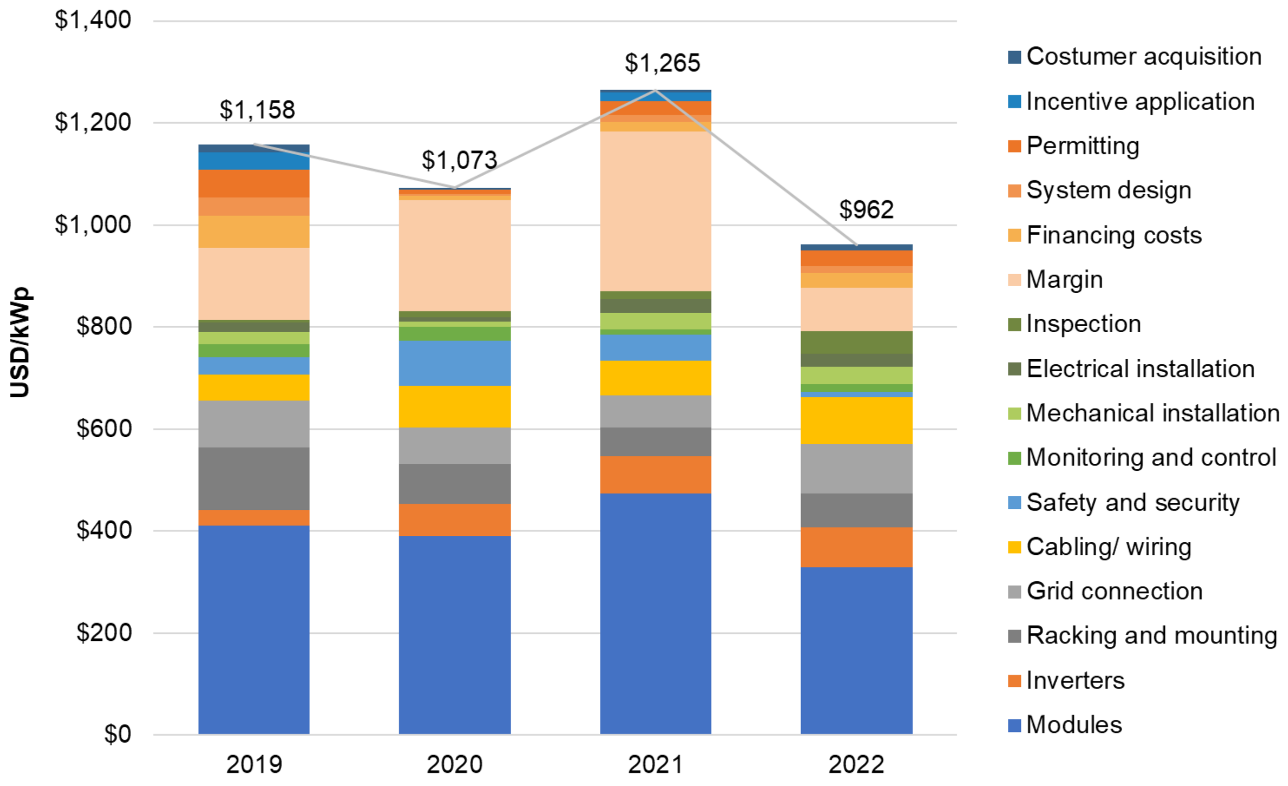


Figure 78: Detailed breakdown of utility-scale solar PV total installed costs in Indonesia
Data source: IRENA Renewable Power Generation Costs in 2022 (and older versions)
Graph: PSE Projects GmbH, 2024

The cost development in US-dollar (annual currency) is provided in Figure 78 for Indonesia. Unfortunately, IRENA does not provide such data for Mauritius and since Indonesia is an island dominated country, we choose this country as a reference case. The peak in 2021 is caused by supply disruptions due to the corona pandemic. While PV module prices were about US$ 410 in 2019, they decreased to US$ 390 in 2020 and went up to US$ 474 in 2021. In 2022 the module price retreated again and was at a level of US$ 329 for PV modules on the Indonesian market.

In January 2024, the PV module prices were at: EUR 230 per kWp for **high-efficiency crystalline modules** with mono- or bifacial Heterojunction (HJT), N-type/TOPCon of IBC (Back Contacts) cells and combinations thereof, with efficiencies above 22 percent.

Mainstream modules traded for EUR 140 per kWp on the wholesale market. These are standard modules, typically with monocrystalline cells (also TOPCon), which are mainly used in commercial PV systems, and which have an efficiency of up to 22 percent.

The price of **low-cost modules** was reported at EUR 90 per kWp which are defined as factory seconds, insolvency goods, used or low output crystalline modules. These products have little or no warranty and are usually not bankable.

These prices sourced from PVXCHANGE are tax-free and reflect the average offer prices in retail and on the European spot market (customs cleared).

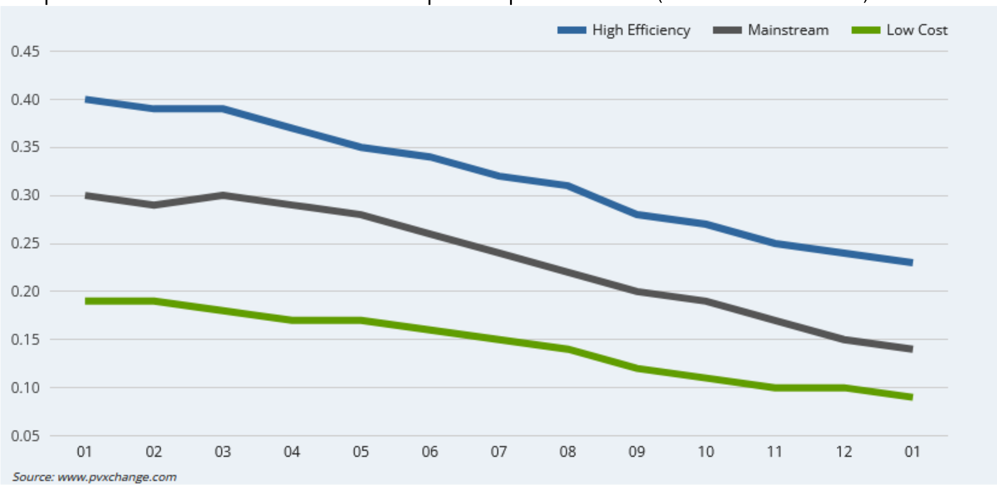


Figure 79: Price trend for solar modules by month from January 2023 to January 2024 per category in EUR
Source: https://www.pvxchange.com/Price-Index [Data was retrieved on 30.01.2024]
The prices shown reflect the average offer prices for duty paid goods on the European spot market.

CAPEX for utility-scale freestanding PV system is roughly 1 Mio. USD for a 1 MW PV system according to Business Mauritius.

SUNFARMING explained that investment costs are typically 5 to 10% higher than prices in Europe due to transport. A comparison to utility PV systems is difficult because of the higher elevated mounting structure.

According to SUNFARMING, insurance is available and affordable: several companies offer their services to insure the PV system and building, but the agricultural side cannot be insured.

The above figures are provided for utility-scale solar PV systems. It must be considered that an agrivoltaic system is not only optimized for high yield from solar PV power generation, but also takes agricultural yields into account.
Depending on the design of the agrivoltaic system, additional costs will be incurred: wider spacing between rows to optimize farming in an interspace design leads more land being required for the same electrical output; a higher elevation of the PV panels adds cost to the mounting structure; wind loads due to cyclonic winds that can occur in Mauritius require solid anchoring of the substructure piles to the ground, and semi-transparent PV modules are more expensive than to standard opaque modules without spacing between solar cells, as more module area is required for the same electrical output.

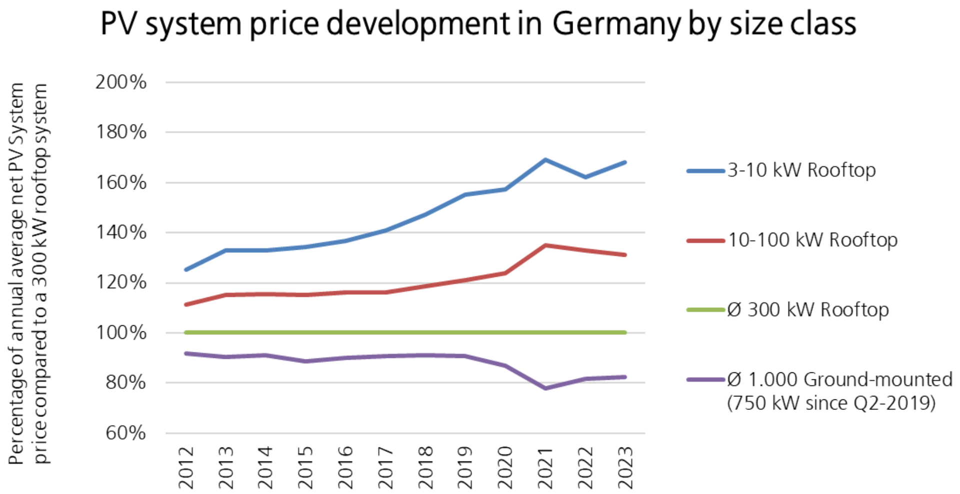


Figure 80: PV system price development by size class for Germany

Source: PSE
Note: historical actual EUR (not inflation adjusted)

Due to economies of scale, a 1 MWp PV system incurs substantially lower specific investment costs than a 200 kWp system. No cost figures for different size classes are available for agrivoltaic systems. However, Figure 80 shows a comparison of different annual average net PV system costs for rooftop systems. The average cost of a 300 kW rooftop PV system defines the 100% line. In 2012 a typical 300 kWp rooftop system costs 1,450 € per kilowatt peak. The price declined about -3.0% per year (Compound Average Annual Growth Rate, CAGR) until 2023. In the case of German rooftop systems, the 10 to 100 kWp PV system will be 31% more expensive than the 300 kWp system in 2023, and the small 3 to 10 kW system will even be 68% more expensive than the 300 kWp system.

To summarize: Size matters! To reduce the CAPEX of the project, the individual project should not be too small. For this reason, we recommend that the project size should not be less than 200 kWp, from a purely economic point of view, the bigger the better.

8.5 Price estimate for Agrivoltaics Systems on Mauritius

In the interviews with key stakeholders in Mauritius the following indications were made:

- Imported goods are mainly sourced from Asia (China, India), Africa, Middle East and Europe as shown in Figure 81 and Figure 82. Quality and price often differ depending on the export country, and a compromise must be found.
- The quantities imported are generally small, which prevents cost savings

by purchasing large quantities, and the transportation costs are also considerable. As a result, the price level for imported goods is relatively high.

- As Mauritius is not a large country, there are no metal products of its own that could be used for the substructures of the agrivoltaic systems. Iron components and aluminum profiles are all imported.

Figure 81: List of supplying markets for products imported by Mauritius in 2022

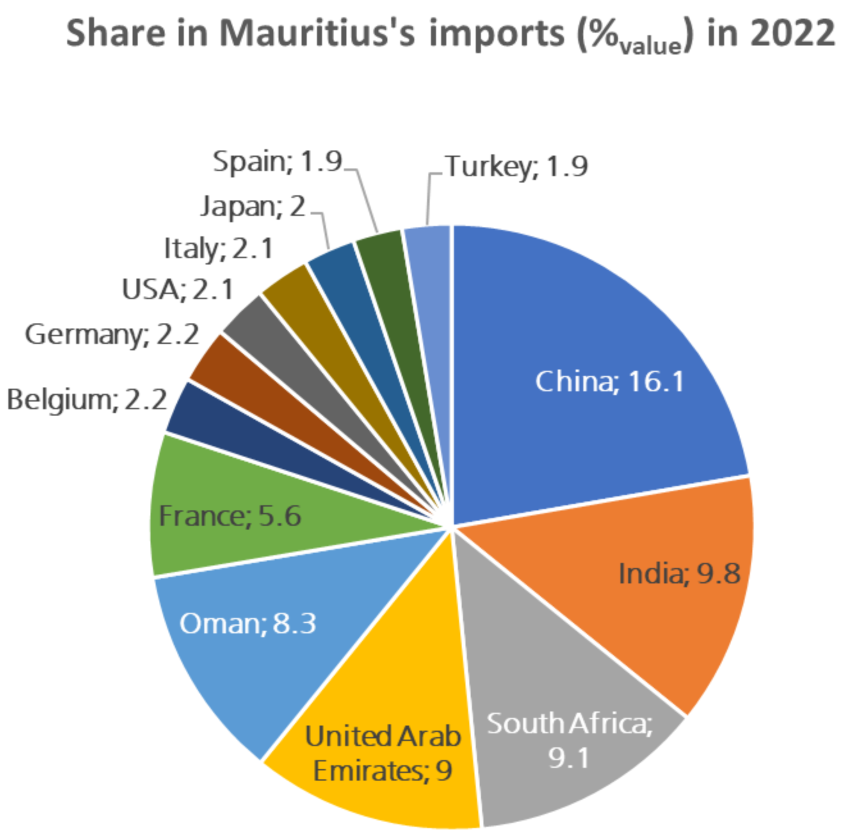


Figure 82: Share of Mauritius's imports (percentage of value in 2022)
Sources: ITC calculations based on [Central Statistics Office of Mauritius statistics](#).
Graph: PSE Projects GmbH, 2024

8.5.1 SUNFARMING's Agrivoltaic Training System

According to SUNFARMING the price for a 200 kWp agrivoltaic system had specific cost of about 1,600 € per kWp in Mauritius. The related system parameters are Orientation purely north, bifacial modules with 20° slope angle; minimum height 1.9 m and maximum height is 2.5 m on the topside of the module row; an increased row-to-row distance of 4 m is applied.

8.5.2 Labor costs

Labor costs were on average 6.3 times higher in Europe (€ 28.60 per hour according to destatis) compared to Mauritius (37451 MUR = € 4.51 per hour according to https://tradingeconomics.com/mauritius/labour-costs) in 2022.
As shown in Figure 77,installation work contributes approximately 20% to the total CAPEX. Instead of about 200 € per kWp installation cost in Europe, about 32 € per kWp installation cost for labor can be estimated for Mauritius. This does

not take into account the fact that due to the rocky soil on the island of Mauritius (volcanic basalt rock), pile ramming, as in Madagascar, is not possible, but that it is necessary to anchor the piles in the ground by drilling 1.5 m deep holes and filling them with concrete, which is very expensive (according to SUNFARMING, about twice as expensive as the pile ramming technique).

8.5.3 Land requirements

In Germany, less than 2 hectares of land are required to install a 1 MWp ground-mounted fixed-tilt utility-scale PV system. Of course, the module efficiency has a strong impact on the area needed. The largest utility-scale PV system in Germany, the Solar Park Weesow-Willermersdorf uses 400 Wp modules and has a nominal power of 187 MWp on 164 ha of land resulting in a specific land requirement of 1.14 MWp per hectare. The use of bifacial modules (PV panels that can generate electricity on both the front and back) also has an impact on the space requirements of PV systems. Furthermore, the latitude of the location has an influence on the Ground Coverage Ratio (GCR), which is defined as [5]:

GCR = Area of solar panels / Area of the land used for the AV system

To compare with the Heggelbach agrivoltaic system (an agrivoltaic system installed under the research project "APV-RESOLA" – https://www.ise.fraunhofer.de/en/research-projects/apv-resola.html): The area of the photovoltaic system was 2,500 m² for 194.4 kWp electrical DC output. This results in a specific land requirement of 0.78 MWp per hectare.

Power density for utility scale PV systems in the United States [6] are provided for 2019:
0.87 MW_{DC}/hectare (0.35 MW_{DC}/acre) for fixed-tilt and
0.59 MW_{DC}/hectare (0.24 MW_{DC}/acre) for tracking plants.

8.5.4 Conclusion

Utility scale PV systems cost about US$ 1,000 per kWp installed. Due to the elevated and enforced substructure which must be able to withstand strong cyclonic wind speed (up to 250 km/h), costs for agrivoltaic systems in Mauritius will be significant higher. The only existing agrivoltaic systems in Mauritius installed by SUNFARMING and commissioned in August 2023 is a 200 kWp Agrivoltaic Training system. It indicates that specific cost of about 1,600 € per kWp in Mauritius are realistic. The capital expenditure (CAPEX) is valid for a fixed-tilt system and however also depends on the system design.
Due to economies of scale, a 1 MWp PV system incurs substantially lower specific investment costs than a 200 kWp system.

8.6 Sensitivity Analysis

In the Excel-LCOE calculation tool, no costs for land leasing are considered. There is the option to add "Annual profit or loss from agriculture" in sheet "Inputs&Results" at cell C37 which can be used to add such costs if applicable.

8.6.1 Sensitivity Analysis on LCOE

The Levelized Cost of Electricity (LCOE) have been calculated for the following parameters and baseline values:
[A] System Price 1,200 €/kWp
[B] Energy Sales price 0.10 €/kWh
[C] Interest rate 7 %
[D] Specific yield 1,500 kWh/kWp
[E] System lifetime 18 years

For *[A] System Price* and *[D] Specific yield* these baseline values are lower than the actual level that is applicable to Mauritius, as the relative change of the parameters (±50% deviation from the baseline) should still be made for reasonable figures. *[B] Energy Sales price* is with 0.10 €/kWh slightly higher than the actual net metering tariff of 0.0849 EUR/kWh (= 4.2 MUR/kWh). The other parameters *[C] Interest rate* and *[E] System lifetime* are based on default values communicated by Business Mauritius.

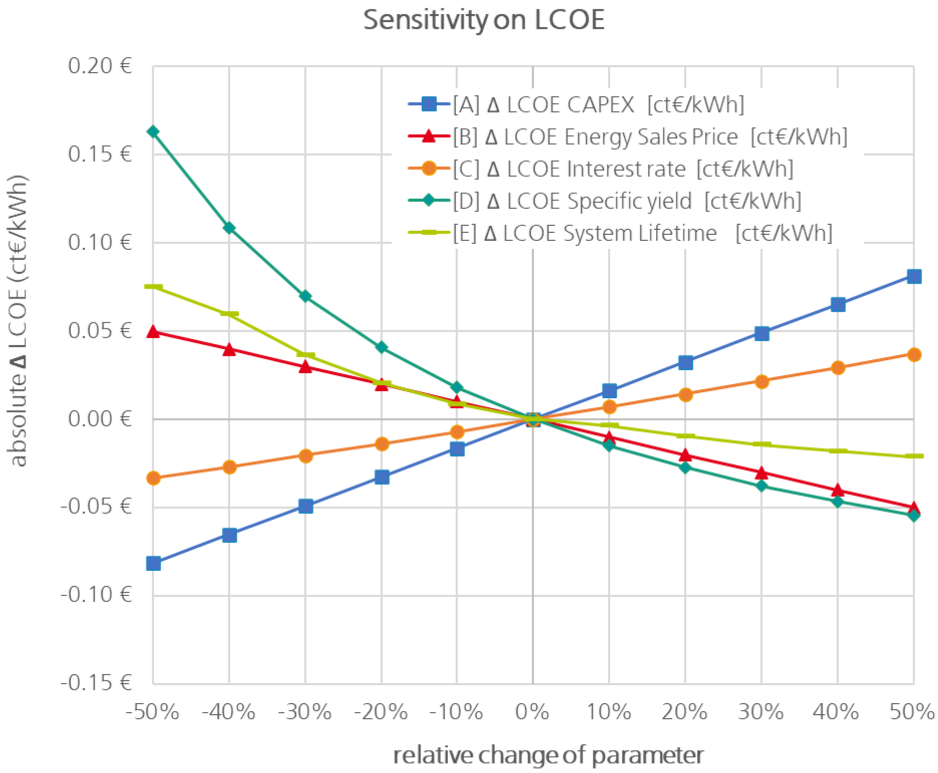


Figure 83: Sensitivity on changes of LCOE in dependency of CAPEX, Energy sales price, Interest rate, Specific yield and System lifetime

Further input parameters (default values): 18 years system operation; Energy sale price 0.0849 EUR/kWh (= 4.2 MUR/kWh); OPEX 2% of initial investment and 2% annual increase; annual PV performance depredating by 0.3%; 80% debt financing and a repayment period of 7 years.

These baseline values define the zero point for the result lines in Figure 83. The x-axis shows the relative change of the parameters, while the y-axis displays the absolute deviation from the LCOE (also known as delta) compared to the LCOE calculated for the baseline value.

Most influencing aspects of Solar PV electricity generation cost:

- [D] Specific yield of the agrivoltaic system (a higher specific yield leads to a lower LCOE, and it must be emphasized that a lower Specific yield greatly increases the LCOE)
- [A] CAPEX of Agrivoltaic system (higher CAPEX leads to higher LCOE)
- [E] System lifetime (higher PV system operation lifetime reduces the LCOE, and it must be emphasized that a lower System lifetime significantly increases the LCOE)

Less influencing aspects of Solar PV electricity generation cost:

- [B] Energy Sales Price (higher Energy Sales Price reduces the LCOE)
- [C] Interest rate for debt financing (higher interest rate increases the LCOE)
- OPEX (not shown in the graph; higher OPEX increases the LCOE)

As can be seen from Figure 83,

- the [D] Specific yield has a strong influence on the LCOE: with 50% of the Specific yield (in the model 750 kWh/kWp instead of 1,500 kWh/kWp), the absolute LCOE would increase by 16 ct€/kWh. This is not symmetric: A 50% higher Specific yield (here 2250 kWh/kWp) will reduce the LCOE by 5 ct€/kWh.
- the [A] CAPEX has a strong influence on the LCOE, and it is symmetric: with 50% of the CAPEX (in the model 600 € instead of 1,200 € per kWp), the absolute LCOE would decrease by 8 ct€/kWh.
- the [E] System lifetime is also not symmetric: with 50% of the System lifetime (in the model 9 years instead of 18), the absolute LCOE would increase by 8 ct€/kWh. However, a 50% higher System lifetime (here 27 years) will reduce the LCOE only by 2 ct€/kWh.
- a higher [B] Energy sales price makes the project more profitable and 50% increase result in 5 ct€/kWh lower LCOE. This parameter is symmetric.
- Finally, the [C] Interest rate for borrowing 80% of the debt funded investment has also some influence: with 3.5% interest instead of 7%, the absolute LCOE would decrease by 3 ct€/kWh. A 50% higher interest rate (10.5% instead of 7%) will increase the LCOE by 4 ct€/kWh.

The absolute LCOE calculation in ct€ per kilowatt hour generated PV electrical power is shown in Figure 84 below.

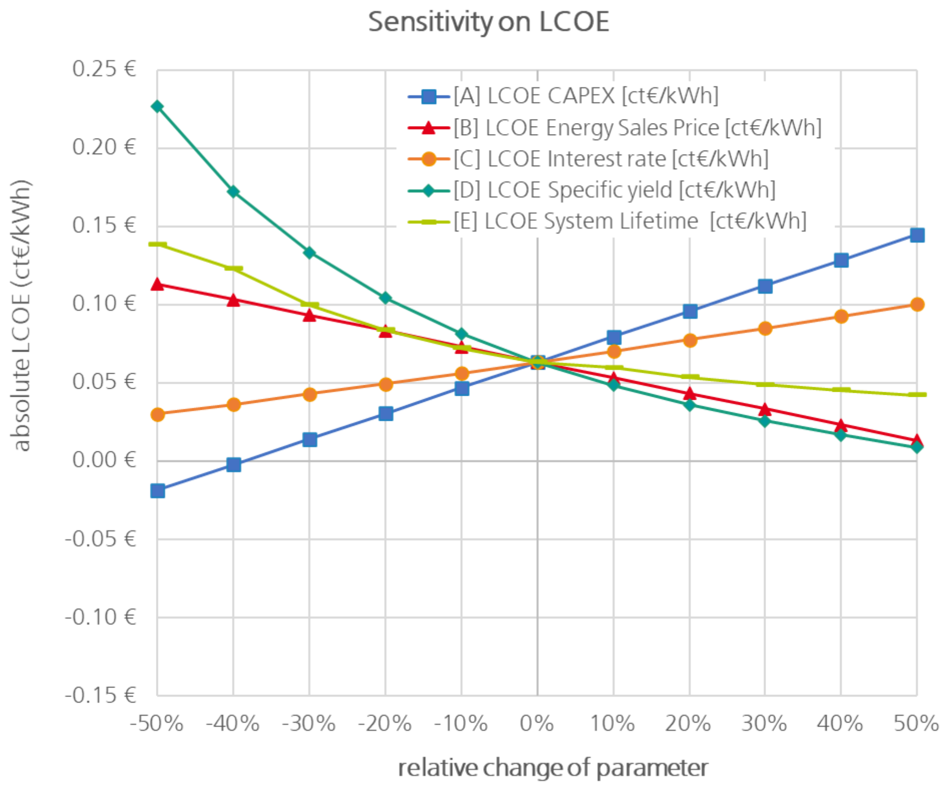


Figure 84: Sensitivity on absolute LCOE in dependency of CAPEX, Energy sales price, Interest rate, Specific yield and System lifetime

8.6.2 System Cost Sensitivity

This 'System Cost' sensitivity analysis shows the dependency of Amortization in years, Internal Rate of Return (IRR) and the Levelized Costs of electrical Energy (LCOE), from the CAPital EXpenditure (CAPEX).

As shown in chapter 8.4, the investment costs consist of:

- Module and inverter hardware
- BoS hardware
- Installation work
- Soft costs

For the hardware, costs for the transportation to Mauritius also need to be considered.

A higher CAPEX result in higher LCOE and increased number of years when the break-even is reached (Amortization). The IRR decreases with a higher CAPEX – the investment gets less profitable.

Figure 85 shows the dependence of CAPEX, Interest rate and Specific yield on the relative change of parameters. The X-axis shows the values of the system price (CAPEX). No unit is indicated on the Y-axis, as three different units are shown in the graph (amortization in years; IRR in percent and LCOE in €/MWh), which result from the respective X-axis values.

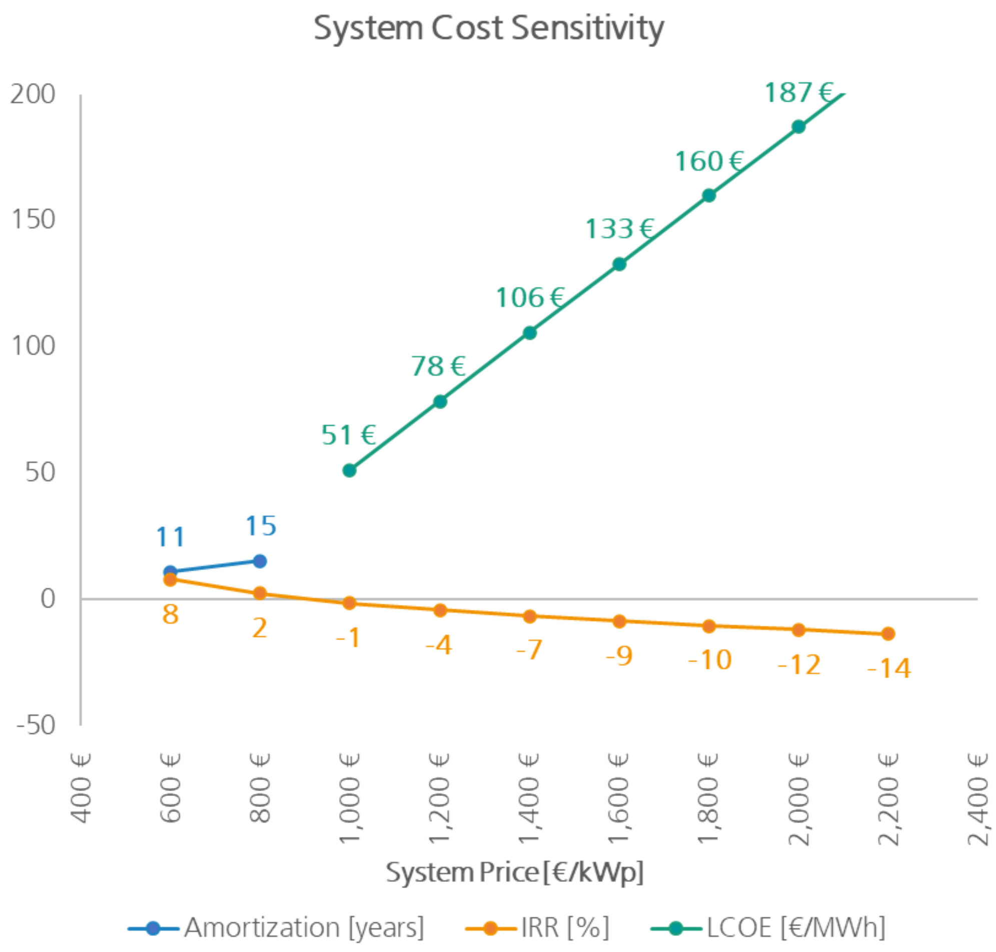


Figure 85: System Cost Sensitivity for an Agrivoltaic System in Mauritius with the given input parameters

Input parameters (default values): 18 years system operation; Energy sale price 0.0849 EUR/kWh (= 4.2 MUR/kWh); Specific yield 1,500 kWh/kWp; interest rate 7% with 80% debt financing and a repayment period of 7 years; OPEX 2% of initial investment and 2% annual increase; annual PV performance dep-redating by 0.3%.

Because the project lifetime is limited to 18 years in Mauritius, this value is the maximum shown here. At higher CAPEX (higher than ~ 1,000 €), the break-even cannot be reached during project lifetime.
The IRR is indirect proportional to the CAPEX: increased CAPEX reduces the IRR and at 915 € the profitability is zero. With higher CAPEX (beyond 915 €) the project will be in deficit.
With the given parameters, system price of less than 900 € per kWp is needed to make an Agrivoltaic project economic viable. There could be subsidies to compensate the difference in actual price and the price level required to make the investment attractive.

8.6.3 Electricity Sales Price Sensitivity

This 'Energy Sales Price' sensitivity analysis shows the dependency of Amortization in years, Internal Rate of Return (IRR) and the Levelized Costs of electrical Energy (LCOE), from the Sales Price for electrical power generated by the PV system and fed into to the grid.

Business Mauritius and CEB reported an amount of 4.2 MUR per kilowatt hour as the electricity sales price for PV systems today in Mauritius. Converted in EUR this is about 0.0849 EUR/kWh (see https://www.xe.com/de/currencyconverter/convert/?Amount=4.2&From=MUR&To=EUR).

Figure 85 shows the dependence of CAPEX, Interest rate and Specific yield on the relative change of parameters. The X-axis shows the values of the system price (CAPEX). No unit is indicated on the Y-axis, as three different units are shown in the graph (amortization in years; IRR in percent and LCOE in €/MWh), which result from the respective X-axis values.

Input parameters (default values): 18 years system operation; Energy sale price 0.0849 EUR/kWh (= 4.2 MUR/kWh); Specific yield 1,500 kWh/kWp; interest rate 7% with 80% debt financing and a repayment period of 7 years; OPEX 2% of initial investment and 2% annual increase; annual PV performance depredating by 0.3%.

Because the project lifetime is limited to 18 years in Mauritius, this value is the maximum shown here. The higher the Energy Sales Price, the shorter the break-even period, the higher the IRR and the lower the LCOE.

With the given parameters, an Energy Sales Price of more than € 0.15 per kilowatt hour is needed to make an Agrivoltaic project profitable.

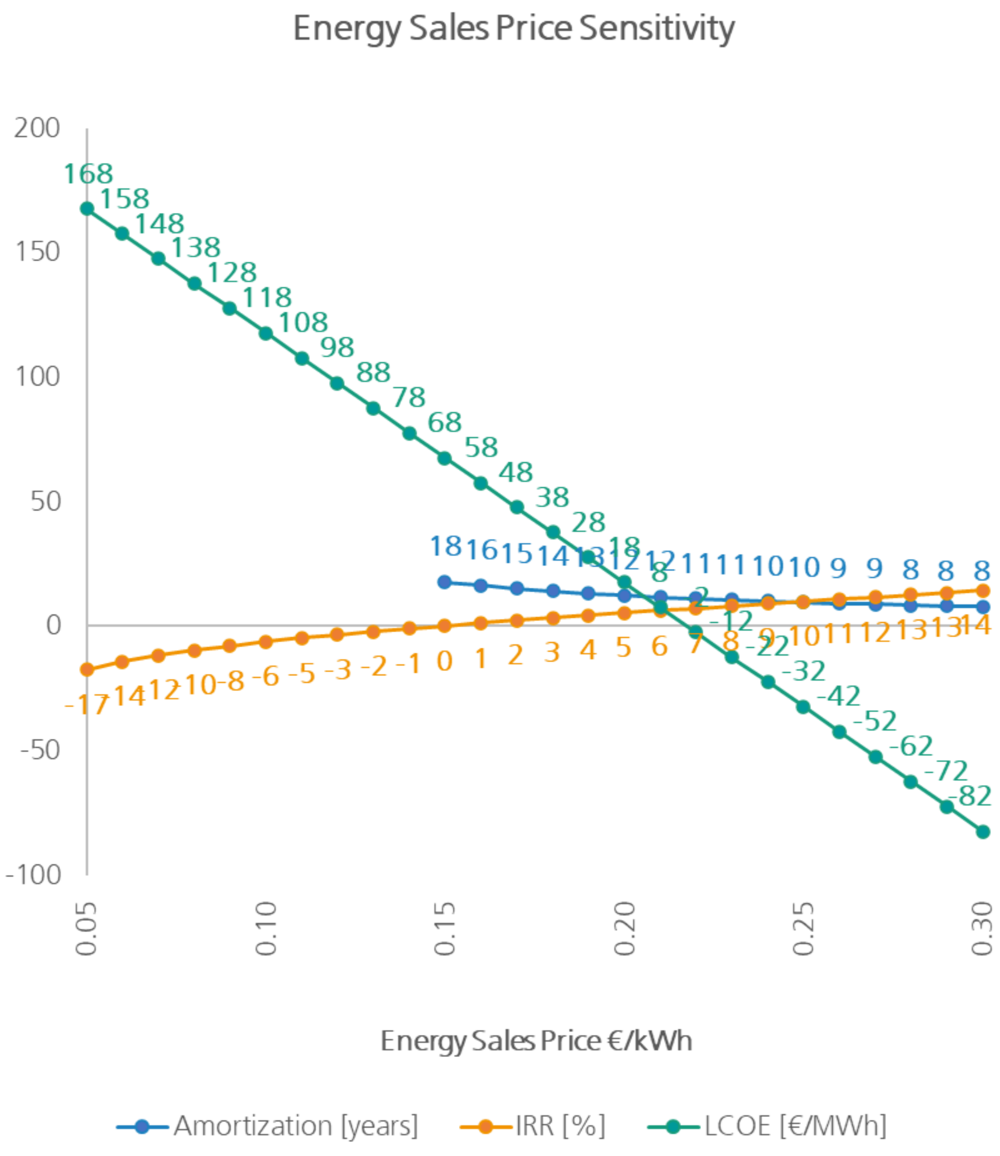


Figure 86: System Cost Sensitivity for an Agrivoltaic System in Mauritius with the given input parameters

8.6.4 Specific Yield Sensitivity

This ‘Specific Yield’ sensitivity analysis shows the dependency of Amortization in years, Internal Rate of Return (IRR) and the Levelized Costs of electrical Energy (LCOE), from the Specific Yield [kWh/kWp] of an Agrivoltaic system in Mauritius. The actual Specific Yield depends on different factors as: location, climate factors like irradiation (clouds), temperature (altitude of the site) and the module and inverter technology. For example, bifacial modules can achieve a higher specific yield by additional gains on the rear side of the modules from albedo (reflecting the sunlight from the surface below the module). Even the way of interconnecting the modules or minimizing shading effects by optimizing the module orientation can have an influence on the PV system performance and the specific annual yield.

More detailed and comprehensive, the specific yield of a photovoltaic (PV) system, measured in kWh/kWp, is influenced by various factors. These factors include:

- **Location:** The amount of sunlight a location receives affects the specific yield. Regions with higher solar irradiance will have a higher specific yield; coastal area have a higher solar irradiance than the Central plateau in Mauritius. The albedo also has an influence on the performance of bifacial modules. The albedo value is the measure of how well a surface reflects solar radiation and this reflected sunlight can generate electricity on the back of the bifacial modules.
- **Weather:** Weather conditions such as cloud cover, temperature, and precipitation can impact the amount of sunlight reaching the PV system, thereby affecting the specific yield.
- **Design and quality of equipment:** The efficiency and quality of the solar modules, inverters, and other system components (as cables, plugs) can influence the specific yield of a PV system. Tracking and bifacial gains increase the Specific yield.
- **Tilt angle and orientation:** The tilt angle and orientation of the solar modules affect the amount of sunlight they receive, thus impacting the specific yield.
- **Shading:** Shading from nearby objects such as trees or buildings can reduce the amount of sunlight reaching the solar modules, leading to a lower specific yield. Areas without such shading should be preferred.
- **Soiling:** Operations and maintenance (O&M) practices, such as regular cleaning and predictive maintenance, can impact the specific yield of a PV system.

By considering these factors, it is possible to optimize the design and location of a PV system to maximize its specific yield, thereby increasing its energy production efficiency.

In Mauritius PV GIS provides typical Specific Yield figures for a mono-facial fixed-tilt PV system between 1,350 in the central plateau and 1,650 kWh per kWp in the coastal area. To maximize the specific yield, the coastal area should be preferred, as it has higher solar radiation than the Central plateau of Mauritius and thus enables higher electricity yields. Simulation results from Fraunhofer ISE show that a tracked system in the coastal area with bifacial modules can achieve up to 2225.5 kWh/kWp per year. However, application of a tracking system will add some costs to the CAPEX of the Agrivoltaic system.

The optimal slope angle is 20°. A smaller module slope angle reduces the forces caused by cyclonic winds.

For Agrivoltaic systems a deviation of the ideal orientation might be chosen to allow better agricultural yield.

SUNFARMING expects that their fixed-tilt (20° slope angle North-oriented) bifacial glass-glass modules agrivoltaic system will have a specific yield of about 1,750 kWh/kWp.

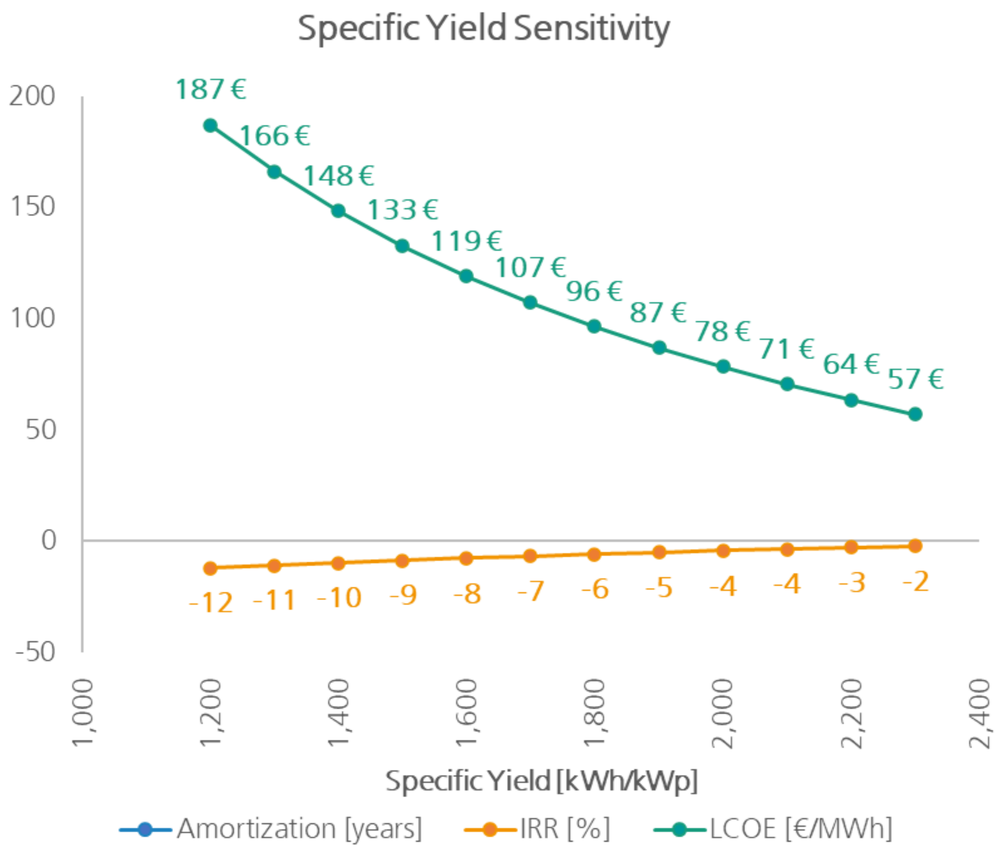


Figure 87: Sensitivity of the Specific Yield for an Agrivoltaic System in Mauritius with the given input parameters

Note: With the given input parameters, the amortization period is more than 18 years and is therefore not shown in the graph.

Input parameters (default values): 18 years system operation; Energy sale price 0.0849 EUR/kWh (= 4.2 MUR/kWh); CAPEX 1,600 €/kWp; interest rate 7% with 80% debt financing and a repayment period of 7 years; OPEX 2% of initial investment and 2% annual increase; annual PV performance depredating by 0.3%.

A higher specific annual yield for PV electricity generation shortens the years until the break-even point (amortization) is reached and the LCOE declines. With a higher specific annual yield, the IRR also rises, and the PV project becomes more profitable.

8.6.5 Debt Interest Rate Sensitivity

This 'Debt Interest Rate' sensitivity analysis shows the dependency of the Levelized Costs of electrical Energy (LCOE), from the Debt Interest Rate at 80 percent debt financing. The default interest rate for debt financing is 7% according to information form BusinessMauritius.

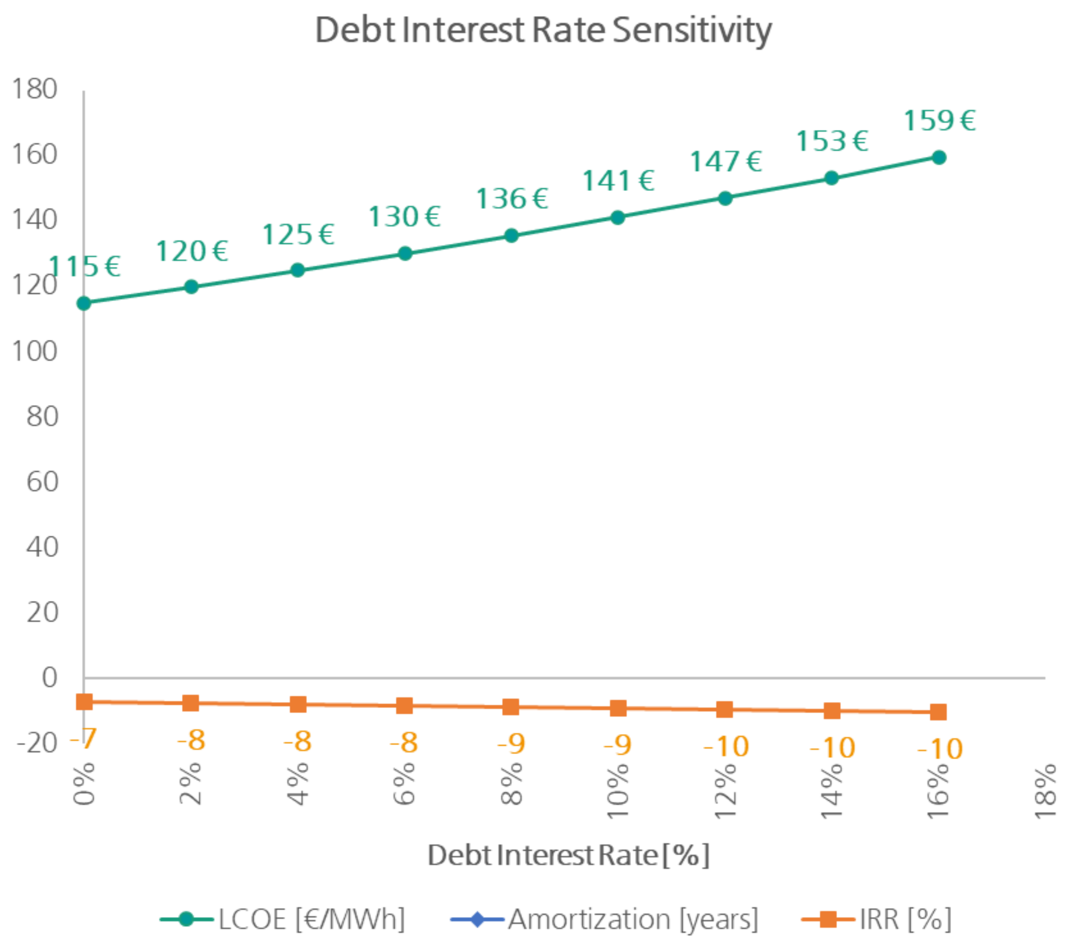


Figure 88: Sensitivity of the Debt Interest Rate for an Agrivoltaic System in Mauritius with the given input parameters

Note: With the given input parameters, the amortization period is more than 18 years and is therefore not shown in the graph.

<u>Input parameters (default values):</u> 18 years system operation; Energy sale price 0.0849 EUR/kWh (= 4.2 MUR/kWh); CAPEX 1,600 €/kWp; Specific yield 1,500 kWh/kWp; OPEX 2% of initial investment and 2% annual increase; annual PV performance depredating by 0.3%.

Increasing the interest rate for the debts leads to higher LCOE.
Even if the debt interest rate would be zero, the LCOE would be 133 € per MWh.

8.7 Agrivoltaics Suppliers

In the following we provide a (not comprehensive) list of agrivoltaics suppliers sorted by their location of the headquarters. In each region the companies are sorted in alphabetical order. As the agrivoltaics market is still a niche market, most of the suppliers mentioned in the following section are not exclusively in this market segment, but often offer products and services for ground-mounted systems (GM PV), floating PV (FPV) or building-integrated PV (BIPV).

8.7.1 Project Developers EPC Suppliers from Europe

Engineering, Procurement and Construction (EPC) companies are project developers who are able to offer all stages in the agrivoltaic value chain.

8.7.1.1 Altergie Développement et Râcines

ALTERGIE **Altergie** is a company that specializes in the development, implementation, and financing of solar photovoltaic (PV) power plants. Their business involves identifying potential sites for solar plants, conducting design and surveys, obtaining regulatory approval and permits, and securing demand through off-taker agreements. Additionally, Altergie manages its renewable power assets, which includes monitoring and controlling production, handling corporate and business management, and ensuring suppliers and equipment guarantees. They work both independently and in partnership on various projects[1].

8.7.1.2 Amarenco

Amarenco is a technology provider which built many greenhouses in France focusing rather on PV. They also offer a lending business model.

8.7.1.3 BayWa

BayWa **BayWa** was established in 1923 as an initiative to provide services to farmers and has since then grown into being of the leading agrivoltaic companies globally. BayWa AG's energy division focuses on renewable energy, including wind, solar, and bioenergy[2].

8.7.1.4 BomGroup

BomGroup is a Dutch technology provider, building own greenhouses (know-how substructure - project partner of BayWa for projects in NL).

8.7.1.5 DEEA

DEEA is a German based EPC and all-rounder in Renewable Energy scene with great interest in Agrivoltaics. They are currently active in the research and development project, APV-MaGa (https://www.bmbf-client.de/en/projects/apv-maga).

[1] Source : https://www.pv-magazine.com/2021/06/10/french-pv-companies-set-up-agrivoltaics-association/

[2] Source: https://www.verifiedmarketresearch.com/blog/top-agrivoltaic-companies/ [retrieved on 30.01.2024]

8.7.1.6 EDF Renouvables

EDF Renouvables is an EPC based in France. The are all-round group offering technology and power plant operation.

8.7.1.7 Enel Green Power

Enel Green Power was founded in 2008 and is headquartered in Rome, Italy. Headquartered in Italy, the multinational energy corporation Enel owns Enel Green Power. To make the most of available space and have a minimal negative impact on the environment, Enel Green Power has been investigating the idea of merging solar energy generation with agriculture[2].

8.7.1.8 Fa. Zimmermann PV-Stahlbau

Fa. Zimmermann PV-Stahlbau is based in Germany and offers substructures for BayWa systems in NL.

8.7.1.9 Goldbeck Solar

Goldbeck Solar is a French project developer.

8.7.1.10 Groenleven

Groenleven: Baywa re and Groenleven have developed a special monocrystalline solar module for five agrivoltaics pilot projects that they are realizing in the Netherlands.

8.7.1.11 Hilber Solar

Hilber Solar is a technology supplier from Austria.

8.7.1.12 IBC Solar

IBC Solar is based in Germany and as a wholesaler it offers hardware as bifacial modules but also performs service as an EPC.

8.7.1.13 InsoLight

InsoLight offers CPV modules with which a lot of diffuse light can be transmitted. InsoLight is based in Switzerland.

8.7.1.14 Kilowattsol

Kilowattsol[1] is a France based engineering company supporting professionals internationally as Technical Advisor.

8.7.1.15 Luxor Solar

Luxor Solar EPC, Solar Sharing Mounting Structures DE/JP https://luxor-solar.com/

8.7.1.16 Nex2Sun

Next2Sun The core idea behind the **Next2Sun** system concept is the vertical alignment of special solar modules with solar cells on both sides, exploiting insolation on both the front and back. These 'bifacial' modules are best facing east and west. This means that electricity is primarily produced in the morning and afternoon or early evening. Next2Sun's bifacial photovoltaics modules are particularly nature-friendly and agriculture-friendly and achieve high yields compared with conventional south-facing PV systems. Next2Sun headquarters are in Dillingen on the Saar (Germany) and Saalfelden in Pinzgau (Austria). The company has also offices in Berlin, Freiburg im Breisgau and Paris (France).

8.7.1.17 PVP Solar

PVP Solar is based in Switzerland and manufactures custom panels. PVP Solar has experience in greenhouse panels.

8.7.1.18 REM TEC

Relatively new in the field of agrivoltaic companies, **REM TEC** was founded in 2015 and is currently headquartered in Lombardia, Italy[2].

8.7.1.19 Schlaich Bergermann Partner (sbp) gmbh

sbp GmbH is an engineering and planning office in Germany. Among other things, they do engineering services for solar power plants worldwide.

8.7.1.20 SolarRack

SolarRack is an EPC, offering Solar Sharing Mounting Structures.

8.7.1.21 SunFarming

SunFarming is a German based EPC with Agrivoltiac projects in Africa. Their concept is to build a Agrivoltaic training system for capacity building. They esablihed such Agrivoltiac systems in Madagascar and Mauritius.

8.7.1.22 Sun'R

Sun'R is specialized in tracked systems and in particular active in viticulture in France.

8.7.1.23 TotalEnergies

Oil, petrol, and renewable energy production and distribution are the main priorities of the French global energy firm, **TotalEnergies**. As the Compagnie Française des Pétroles, it was established in 1924. The company's current headquarters are located in Paris, France. TotalEnergies is becoming a new name in agrivoltaic companies and has been exploring agrivoltaic technologies as a way to increase renewable energy production while also supporting agriculture[2].

8.7.1.24 Tenergie

Tenergie is a Frensch PV greenhouse manufacturer.

8.7.1.25 TubeSolar

TubeSolar is a German technology provider with an innovative solar module with PV tubes and is planning to found a project developer.

8.7.1.26 Volatalia

Volatalia is an EPC in France.

8.7.1.27 Volta Green Energy S.r.l.

Volta Green Energy S.r.l. has recently (09.2020) been working together with REM tec on agricultural PV systems in Italy.

8.7.1.28 WPD

WPD offers development, financing, construction and operation of wind and solar projects worldwide and is based in Germany.

8.7.1.29 Wynergy

Wynergy is an open field livestock focused mounting structure and EPC based in Austria.

8.7.2 EPC Suppliers from Asia

8.7.2.1 Jain Irrigation

Jain Irrigation is an Agrivoltaic project and irrigation and renewable energy hardware manufacturer covering also floating PV based in India.

8.7.2.2 Mackin Energy

A Japanese firm called **Mackin Energy Japan**. focuses on the creation of renewable energy projects including solar and wind power facilities. Tokyo, Japan serves as the company's headquarters. It was established in 2005. In Japan, the business has set up several agrivoltaic systems and is slowly becoming one of the promising agrivoltaic companies[2]. Mackin Energy is an EPC offering Solar Sharing Mounting Structures.

8.7.2.3 Sun Agri

Sun Agri was founded by Mr. Pankaj Kumar, who is a renewable energy enthusiast and entrepreneur. The company is currently headquartered in Vadodara, Gujarat, India. The use of solar panels above crops as part of Sun Agri's agrivoltaic technologies creates shade and boosts agricultural output. The business provides several services, such as design and installation[2].

8.7.2.4 Suntech Power Holdings

Suntech Power Holdings is a Chinese solar energy company that is primarily focused on the design, manufacture, and distribution of solar panels and related goods. The business is headquartered in Wuxi, Jiangsu, China, and was established in 2001[2].

An overview has been provided in Table 17 in the Annex at the end of this report.

8.7.3 EPC Suppliers from North America

8.7.3.1 Hyperion Systems LLLC

Hyperion Systems LLLC is a United States based EPC.

8.7.3.2 Soliculture

Soliculture is a Greenhouse Panel manufacturer based in USA.

8.7.3.3 sandbox Solar

sandbox Solar is a United States based EPC.

8.7.3.4 Agrivoltaic Solution

AGRIVOLTAIC SOLUTIONS Dr. Stephen J. Herbert founded **Agrivoltaic Solution**. The corporation is headquartered in Amherst, Massachusetts, in the United States. Agrovoltaic technologies also referred to as agrovoltaics or solar sharing, use PV panels to produce electricity while also shading crops. It is one of the global argivoltaic companies[2].

8.7.3.5 Boralex

BORALEX A corporation called **Boralex** specializes in the planning, building, and management of renewable energy projects, including wind, solar, hydropower, and biomass power plants. The organization's current headquarters is in Kingsey Falls, Quebec, where it was established in 1995[2].

8.7.3.6 Sunrise Power Solutions

sunrise power solutions clean energy contractors **Sunrise Power Solutions** was founded in the year 2007. The current headquarters are located in New York, USA. The company provides solar energy contractors for design and maintenance services. Though, still comparatively new, it is one of the promising agrivoltaic companies[2].

8.7.4 Module Suppliers (specialized for Agrivoltaics)

Depending on the location and the local situation of the system to be installed, it is important to consider whether bifacial double glass modules (also known as glass-glass modules) are best suited for such an installation. The bifaciality allows PV electricity to be generated from both sides of the module, which can lead to additional gain through indirect solar radiation (albedo); especially if there are bright areas below the PV module. Double glass modules are more robust than conventional modules with a plastic back sheet, as the encapsulation between two panes of glass protects the solar cell from moisture penetration and the cells are very well protected mechanically against breakage.

The module manufacturers listed here offer modules that are particularly suitable for Agrivoltaic. Some of them are semi-transparent, allowing more light to reach the plants and enabling more homogeneous photosynthesis under the PV modules.

SoliTek: https://www.solitek.eu/en

GRID PARITY next generation photovoltaic AgriPV GmbH, GridParity AG https://de.gridparityag.com/

Jinko Solar is a Top10 module supplier from China offering bifacial modules and stronger modules for BIPV.

An overview is provided in Table 18 in the Annex at the end of this report.

8.8 Conclusion of the Economic Analysis

To promote the agrivoltaic system market in Mauritius, a higher incentive is needed compared to standard utility-scale photovoltaic systems. As far as is known, the specific costs for the only large agrivoltaic system realized to date (200 kWp) are in the region of €1,600/kWp. This CAPEX is about 60% higher compared to typical utility-scale PV systems which has typical specific costs below €1,000/kWp.

The reason for the high CAPEX is that Agrivoltaic systems are typically elevated to allow agricultural production below the PV modules. Mauritius experiences cyclonic winds and the mounting structure must be strong enough to withstand these forces. The substructure must be firmly anchored to the ground to prevent strong winds from pulling it out - this is one cost driver.
Another is the fact that the cost of shipping hardware to Mauritius is higher than in regions served by container ships and where very large volumes are handled.

Due to economies of scale, a 1 MWp PV system is several percent cheaper in terms of specific investment costs (€/kWp) compared to a 200 kWp system. To reduce the specific investment cost of the project, the individual project should not be too small. Therefore, a size between 200 kWp and 1 MWp seems to be reasonable for agrivoltaic systems in Mauritius.

As the sensitivity analysis shows in chapter 8.6, the **Specific yield**, the **CAPEX** and the **System lifetime** of an agrivoltaic system has the highest influence on the LCOE, followed by the **Energy sales price** and the **Interest rate** for the 80% debt funding.

References

1. United Nations Development Programme. Mauritius NDC Status. Available at https://climatepromise.undp.org/what-we-do/where-we-work/mauritius#:~:text=Key%20highlights%20from%20the%20NDC,initial%20NDC%20target%20of%2030%25 (2023).
2. United Nations. Mauritius Renewable Energy Roadmap 2030.
3. Independent Evaluation Unit. Second Performance Review of the Green Climate Fund. Country case study report. Green Climate Fund, 2023.
4. Tsakok, I. Implications of Food Systems for Food Security During a Time of Multiple Crises: The Republic of Mauritius. Policy Brief. Policy Center for the New South.
5. FAO. GIEWS Country Brief Mauritius, 2020.
6. Agrivoltaics: Opportunities for Agriculture and the Energy Transition. A Guideline for Germany. Fraunhofer ISE, 2022.
7. Adolf Goetzberger and Armin Zastrow. On the Coexistance of Solar-Energy Conversion and Plant Cultivation, Pages 55-69 (1981).
8. Dupraz, C. *et al.* Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes. *Renewable Energy* **36,** 2725–2732; 10.1016/j.renene.2011.03.005 (2011).
9. Fraunhofer ISE. Photovoltaics Report. Available at https://www.ise.fraunhofer.de/en/publications/studies/photovoltaics-report.html#:~:text=The%20intention%20of%20the%20%C2%BBPhotovoltaics%20Report%C2%AB%20is%20to,energy%20payback%20time%20and%20price%20developments%20are%20present (2024).
10. JOËL SPAES. Agrivoltaics prevail in France’s tender for innovative PV technologies. Available at https://www.pv-magazine.com/2021/01/05/agrivoltaics-prevail-in-frances-tender-for-innovative-pv-technologies/?utm_source=dlvr.it&utm_medium=linkedin (2021).
11. Lim, C.-H. *et al. Recent R&D Trends and Status of Agri- photovoltaic System in South Korea* (2020).
12. Jung, D. & Salmon, A. Agrivoltaico: Protección de Cultivos, Agua y Clima con Paneles Fotovoltaicos. Fraunhofer Chile, 2020.
13. Eculume. Green Socioeconomics. Water, Energy and Food Security in the Semi-Arid Region of Pernambuco in the Face of Climate Change. Available at https://itcbio.org/pt/2020/09/10/projeto-ecolume-socioeconomia-verde-segurancas-hidricas-energeticas-e-alimentar-no-semiarido-de-pernambuco-frente-as-mudancas-climaticas/ (2020).
14. Aqua-PV: “SHRIMPS” Project Combines Aquaculture and Photovoltaics. Available at https://www.ise.fraunhofer.de/en/press-

media/news/2019/aqua-pv-project-shrimps-combines-aquaculture-and-photovoltaics.html.

15. APV-MaGa - Agrophotovoltaik und nachhaltige Stromproduktion durch integrierte Nahrungsmittel-, Energie- und Wassersysteme (Mali, Gambia). Available at https://www.fona.de/de/massnahmen/foerdermassnahmen/energieforschung-mit-afrika/apv-mager-agrophotovoltaik-nachhaltige-stromproduktion.php.
16. Bosch invests €500 million to develop hydrogen electrolyzers. Available at https://www.pv-magazine.com/2019/10/14/australian-agrivoltaics-start-up-aiming-for-eventual-1-gw-of-solar-capacity/ and https://www.pv-magazine-australia.com/2020/11/04/utility-scale-agrivoltaic-proposal-for-nsw-opens-for-public-exhibition/.
17. Harvesting the sun twice: Enhancing livelihoods in East African agricultural communities through innovations in solar energy. Available at https://app.dimensions.ai/details/grant/grant.8856758.
18. Fraunhofer ISE. Photovoltaics Report (2020).
19. Fraunhofer ISE. Agrivoltaics: Opportunities for Agriculture and the Energy Transition (2020).
20. Elamri, Y., Cheviron, B., Lopez, J.-M., Dejean, C. & Belaud, G. Water budget and crop modelling for agrivoltaic systems: Application to irrigated lettuces. *Agricultural Water Management* **208,** 440–453; 10.1016/j.agwat.2018.07.001 (2018).
21. Barron-Gafford, G. A. *et al.* Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands. *Nat Sustain* **2,** 848–855; 10.1038/s41893-019-0364-5 (2019).
22. Weselek, A. *et al.* Agrophotovoltaic systems: applications, challenges, and opportunities. A review. *Agron. Sustain. Dev.* **39**; 10.1007/s13593-019-0581-3 (2019).
23. Dinesh, H. & Pearce, J. M. The potential of agrivoltaic systems. *Renewable and Sustainable Energy Reviews* **54,** 299–308; 10.1016/j.rser.2015.10.024 (2016).
24. Agostini, A., Colauzzi, M. & Amaducci, S. Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment. *Applied Energy* **281,** 116102; 10.1016/j.apenergy.2020.116102 (2021).
25. Goolaup, P. First Biennial Update Report - Republic of Mauritius.
26. IEA. World Energy Outlook (2020).
27. IEA. Renewable electricity: A quick look back at 2020. Available at https://www.iea.org/reports/renewable-energy-market-update-2021/renewable-electricit (2021a).
28. Fortune Business Insights. Middle East & Africa Solar Photovoltaic (PV) Market Size, Share & COVID-19 Impact Analysis, By Technology (Monocrystalline Silicon, Multicrystalline Silicon, Thin Film, Others), By Grid Type (On-grid, Off-grid), By Installation (Ground Mounted, Rooftop, Others), By Application (Residential, Non-Residential, Utility) and Regional Forecasts,

2021-2028. Available at https://www.fortunebusinessinsights.com/middle-east-africa-solar-photovoltaic-pv-market-105691 (2021).

29. VDMA. International Technology Roadmap (ITRPV) 2021. Available at https://itrpv.vdma.org/download (2021).
30. Soliculture. Soliculture – Greenhouse Integrated Solar Photovoltaics. Available at http://www.soliculture.com/. (2022).
31. Zhang, Y., Samuel, I. D. W., Wang, T. & Lidzey, D. G. Current Status of Outdoor Lifetime Testing of Organic Photovoltaics. *Advanced science (Weinheim, Baden-Wurttemberg, Germany)* **5,** 1800434; 10.1002/advs.201800434 (2018).
32. Bellini, E. CPV panels for agrivoltaics. Available at https://www.pv-magazine.com/2020/08/04/cpv-panels-for-agrivoltaics/ (2020).
33. Chloride Exide Ltd. Kenya to use solar panels to boost crops by 'harvesting the sun twice'. Available at https://www.theguardian.com/global-development/2022/feb/22/kenya-to-use-solar-panels-to-boost-crops-by-harvesting-the-sun-twice (2022).
34. Trommsdorff, M. *et al.* Agrivoltaics: solar power generation and food production. In *Solar Energy Advancements in Agriculture and Food Production Systems* (Elsevier2022), pp. 159–210.
35. Yano, A. & Cossu, M. Energy sustainable greenhouse crop cultivation using photovoltaic technologies. *Renewable and Sustainable Energy Reviews* **109,** 116–137; 10.1016/j.rser.2019.04.026 (2019).
36. Marco Cossu *et al.* Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe (2018).
37. Gupta, R., Tiwari, G. N., Kumar, A. & Gupta, Y. Calculation of total solar fraction for different orientation of greenhouse using 3D-shadow analysis in Auto-CAD. *Energy and Buildings* **47,** 27–34; 10.1016/j.enbuild.2011.11.010 (2012).
38. Kozai, T. & Kimura, M. Direct solar light transmission into multi-span greenhouses. *Agricultural Meteorology* **18,** 339–349; 10.1016/0002-1571(77)90031-0 (1977).
39. Fraunhofer ISE. APV-MaGa – Agrivoltaics for Mali and Gambia: Sustainable Electricity Production by Integrated Food, Energy and Water Systems. Available at https://www.ise.fraunhofer.de/en/research-projects/apv-maga (2021).
40. Cossu, M. *et al.* Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe. *Renewable and Sustainable Energy Reviews* **94,** 822–834; 10.1016/j.rser.2018.06.001 (2018).
41. Amaducci, S., Yin, X. & Colauzzi, M. Agrivoltaic systems to optimise land use for electric energy production. *Applied Energy* **220,** 545–561; 10.1016/j.apenergy.2018.03.081 (2018).

42. Maximilian Vorast, Maximilian Trommsdorf, Subrahmanyam Pulipaka & Sachin Patwardhan. Agrivoltaics - International Experiences and Opportunities for India (2021).

43. Santra, P., Pande, P., Kumar, S., Mishra, D. & Singh, R. Agri-voltaics or solar farming: The concept of integrating solar PV based electricity generation and crop production in a single land use system. *International Journal of Renewable Energy Research* (2017).

44. Santra, P., Pande, P., Kumar, S., Mishra, D. & Singh, R. K. Agri-voltaics or solar farming: the concept of integrating solar PV based electricity generation and crop production in a single land-use system. *International Journal of Renewable Energy Research,* 694–699 (2017).

45. Bussey, A. *How to calculate gutter slope.* Available at https://bluerivergutters.com/how-to-calculate-gutter-slope/ (2020).

46. Fraunhofer ISE. APV-MaGa – Agrivoltaics for Mali and Gambia: Sustainable Electricity Production by Integrated Food, Energy and Water Systems - Fraunhofer ISE. Available at https://www.ise.fraunhofer.de/en/research-projects/apv-maga.html (2021).

47. Ali, M. H. *Practices of Irrigation & On-farm Water Management: Volume 2* (Springer New York, New York, NY, 2011).

48. Second Performance Review of the Green Climate Fund, 2023.

49. World Bank Group. Mauritius. Available at https://climateknowledgeportal.worldbank.org/country/mauritius/climate-data-historical#:~:text=The%20Republic%20of%20Mauritius%20enjoys,commonly%20known%20as%20transitional%20months.

50. macrotrends. Mauritius Population 1950-2023. Available at https://www.macrotrends.net/countries/MUS/mauritius/population#:~:text=The%20current%20population%20of%20Mauritius,a%200.08%25%20increase%20from%202020.

51. The World Bank. Climate Change Knowledge Portal. Country Mauritius. Available at https://climateknowledgeportal.worldbank.org/country/mauritius/climate-data-historical.

52. Statistics Mauritius. Digest of Agricultural Statistics 2018.

53. Meteoblue. Simulierte historische Klima- und Wetterdaten für Mauritius. Available at https://www.meteoblue.com/de/wetter/historyclimate/climatemodelled/mauritius_mauritius_934293.

54. Mauritius-Holidays-Discovery.com. Mauritius Weather – what is it like to go through a tropical cyclone? Available at https://www.mauritius-holidays-discovery.com/mauritius-weather.html#:~:text=Mauritius%20is%20prone%20to%20be,and%20ends%20on%2015%20May.

55. Swapna, P., Sreeraj, P., Sandeep, N. & Jyoti, J. Increasing Frequency of Extremely Severe Cyclonic Storms in the North Indian Ocean by Anthropogenic Warming and Southwest Monsoon Weakening. Available at https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021GL094650 (2021).

56. Mather, A. & Stretch, D. A Perspective on Sea Level Rise and Coastal Storm Surge from Southern and Eastern Africa: A Case Study Near Durban, South Africa. Available at https://www.researchgate.net/publication/276044391_A_Perspective_on_Sea_Level_Rise_and_Coastal_Storm_Surge_from_Southern_and_Eastern_Africa_A_Case_Study_Near_Durban_South_Africa (2012).
57. Japan International Cooperation Agency. Preparatory Survey Report on the Mauritius Meteorological Services Project in the Republic of Mauritius. Available at https://openjicareport.jica.go.jp/pdf/12083705_01.pdf (2012).
58. WorldData.info. Cyclones in Mauritius. Available at https://www.worlddata.info/africa/mauritius/cyclones.php.
59. Global Solar Atlas 2.0. Solar resource data: Solargis, 2020.
60. Proag, V. Water resources management in Mauritius, 2006.
61. YONATURE. Freshwater Sources of Mauritius. Available at https://www.yonature.com/freshwater-sources-of-mauritius/ (2018).
62. Water Utilisation, Island of Mauritius, 2020, 2020.
63. IEA. Mauritius Energy Mix. Available at https://www.iea.org/countries/mauritius/energy-mix.
64. globalEDGE. Mauritius: Economy. Available at https://globaledge.msu.edu/countries/mauritius/economy.
65. The World Bank. Agriculture, forestry, and fishing, value added (% of GDP). Available at https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS.
66. European External Action Service. The European Union and the Republic of Mauritius. Available at https://www.eeas.europa.eu/mauritius/european-union-and-republic-mauritius_en?s=110#:~:text=In%202020%2C%20despite%20the%20pandemic,with%2024.7%25%20of%20total%20trade (2021).
67. Statistics Mauritius. Digest of Agricultural Statistics 2022 (2023).
68. Mauritius Chamber of Agriculture. Homepage of Mauritius Chamber of Agriculture. Available at https://mauritius-chamber-of-agriculture.org/.
69. International Trade Administration US. Mauritius - Country Commercial Guide. Agricultural Sectors. Available at https://www.trade.gov/country-commercial-guides/mauritius-agricultural-sectors (2023).
70. Strategic Plan for the Food Crop, Livestock and Forestry Sectors. 2016 to 2020.
71. EU. DeSIRA. Available at https://capacity4dev.europa.eu/projects/desira/info/innovation-farei_en (2020).
72. EU delegates. Smart Agriculture Project: when food crop production and biodiversity tally. Available at https://www.eeas.europa.eu/delegations/mauritius/smart-agriculture-project-when-food-crop-production-and-biodiversity-tally_en?s=110 (2022).

73. Questionnaire in relation to Human Rights Council Resolution 47/24 on human rights and climate change, 2021.
74. SADRI. Drought Resilience Profiles Mauritius.
75. FAO. Pesticides use, pesticides trade and pesticides indicators. Global, regional and country trends, 1990–2020.
76. FAO. Production / Crops and livestock products - Metadata. Available at https://www.fao.org/faostat/en/#data/QCL/metadata (2023).
77. Republic of Mauritius. National Integrated Water Resources Management (IWRM) Plan.
78. FAO. Cereal supply and demand balances for sub-Saharan African countries - Situation as of October 2023 (2023).
79. West-East Ltd. Wheat cultivation a reality in Mauritius. Available at https://www.w-e-consult.com/news/2013_october_28_mauritius_wheat_cultivation_project.html#:~:text=Constraints%20to%20wheat%20production%20in,mechanisation%20of%20plantation%20and%20harvest. (2012).
80. Cirad. Sugarcane. Available at https://www.cirad.fr/en/our-activities-our-impact/tropical-value-chains/sugarcane/plant-and-uses (2023).
81. Marguery Villas. Sugarcane in Mauritius. Available at https://www.marguery-villas-resort.com/blog/en/sugarcane-in-mauritius/ (2018).
82. T. L. K. Y., James & Chang, K.-W. Comparative Energy and Greenhouse Gas Analysis (2013).
83. MSIRI. Recommendation Sheet No.156. Dual Row Planting (2006).
84. Kellogg, E. A. C4 photosynthesis. *Current biology: CB* **23,** R594-9; 10.1016/j.cub.2013.04.066 (2013).
85. Young African Leaders Initiative. Yali Voices: Sugarcane in Mauritius. Available at https://yali.state.gov/yali-voices-sugarcane-in-mauritius/ (2019).
86. World Bank. The Sugar Sector: Problems and Prospects, 1986.
87. Mauritius Meteorological Services. Seasonal Climate Forecast. Seasonal Outlook for Summer 2023-2024. Available at http://metservice.intnet.mu/climate-services/seasonal-climate-forecast.php (2023).
88. FasterCapital. Windbreaks: Protecting Crops with Windbreaks: The Role of Agroforestry. Available at https://fastercapital.com/content/Windbreaks--Protecting-Crops-with-Windbreaks--The-Role-of-Agroforestry.html (2023).
89. Kuhns, M. Modern Windbreaks Fight Drought. Available at https://extension.usu.edu/forestry/rural-forests/windbreaks/modern-windbreaks-fight-draught.
90. Stefani, M. A. & Felema, J. Agro photovoltaic: feasibility of synergistic system in the sugarcane bioenergy sector. *quaestum* **3,** 1–20; 10.22167/2675-441X-20220578 (2022).
91. Government Information Service of Mauritius. Transforming the Mauritian tea sector into a pillar of the economy. Available at

https://govmu.org/EN/newsgov/SitePages/Transforming-the-Mauritian-tea-sector-into-a-pillar-of-the-economy.aspx (2022).

92. Bathilde, S. & Bhugaloo, A. Tea in Mauritius: an industry with potential. Available at https://comstudies.wordpress.com/2017/02/25/tea-in-mauritius-an-industry-with-potential/ (2017).
93. Missouri Botanical Garden. Plantfinder. Available at https://www.missouribotanicalgarden.org.
94. Iplantz. Camellia sinensis. Available at https://www.iplantz.com/plant/303/camellia-sinensis/.
95. Palais des thes. The tea plantation. Available at https://www.palaisdesthes.com/en/understanding/tea-plantation/.
96. CORSON. The making of tea. Available at https://www.1886corsontea.com.
97. Tea Research Institute of Sri Lanka. Guidelines for the establishment of tea to facilitate mechanization of field operations **3** (2019).
98. Mohotti, A. J. Shade in tea is it beneficial. *S.L.J Tea Sci.,* 27–39 (2004).
99. Wijeratne, T., Mohotti, A. J. & Nissanka, S. P. Impact of Long-Term Shade on Physiological, Anatomical and Biochemical Changes in Tea. *Tropical Agricultural Research,* 376–387 (2008).
100. Philip O Owuor, Caleb O Othieno, George E Howard, Janet M Robinson, Rodney D Cooke. Studies on the use of shade in tea plantations in Kenya: Effects on chemical composition and quality of made tea. *Journal of Food and Agriculture* (1988).
101. Fang Z-T, Jin J, Ye Y, He W-Z. Effects of Different Shading Treatments on the Biomass and Transcriptome Profiles of Tea Leaves (Camellia sinensis L.) and the Regulatory Effect on Phytohormone Biosynthesis. *Front. Plant Sci.* **2022**.
102. Marguery Villas. History of tea in Mauritius. Available at marguery-villas-resort.com.
103. World Bank. Global Solar Atlas. Solar resource maps of Mauritius. Available at https://solargis.com/maps-and-gis-data/download/mauritius (2020).
104. *AGRIVOLTAICS2020 CONFERENCE: Launching Agrivoltaics World-wide* (AIP Publishing, 2021).
105. PRPV. Agricultural commodities exported by Mauritius. Available at http://cordemoy.cirad.fr/index.php/en/reglementation/importer_exporter_des_vegetaux/importer_exporter_a_maurice/informations_pratiques/agricultural_commodities_exported_by_mauritius (2024).
106. Nakasone, H. Y. & Kamemoto, H. Anthurium Culture. With emphasis on the effects of some induced environments on growth and flowering (1962).
107. ICAR. Anthurium crop. Available at https://ccari.icar.gov.in/dss/Anthurium.html.

108. FAO. FAO Crop Calendar. Information Tool for Crop Production. Available at https://cropcalendar.apps.fao.org (2021).

109. Setyorini, D., Sugito, Y., Aini, N. & Tyasmoro, S. Y. Lycopene, beta-carotene and productivity of tomato varieties at different shade levels under medium land of Indonesia. *Journal of Applied Horticulture* (2018).

110. Masabni, J., Sun, Y., Niu, G. & Del Valle, P. Shade Effect on Growth and Productivity of Tomato and Chili Pepper. *hortte* **26,** 344–350; 10.21273/HORTTECH.26.3.344 (2016).

111. El-Gizawy, A. M., Abdallah, M., Gomaa, H. M. & Mohamed, S. S. Effect of different shading levels on tomato plants. *Acta Hortic.,* 349–354; 10.17660/ActaHortic.1993.323.32 (1993).

112. Kittas, C., Katsoulas, N., Rigakis, V., Bartzanas, T. & Kitta, E. Effects on microclimate, crop production and quality of a tomato crop grown under shade nets. *The Journal of Horticultural Science and Biotechnology* **87,** 7–12; 10.1080/14620316.2012.11512822 (2012).

113. Kavitha, Natarajan, M. S. & Pugalendhi, L. Effect of Shade and Fertigation on Growth and Yield Attributes of Tomato. *Int.J. Curr.Microbiol. App.Sci* **9,** 2281–2288; 10.20546/ijcmas.2020.912.270 (2020).

114. Haifa Group. Cucumber.

115. Patil, M. A. & Bhagat, A. D. Yield response of cucumber (Cucumis sativus L.) to shading percentage of shade net. *International Journal of Agricultural Engineering* **7** (2014).

116. Naraghi, M. & Lotfi, M. (eds.). *Effect of Different Levels of Shading on Yield and Fruit Quality of Cucumber (Cucumis sativus)* (2010).

117. Smith, I. E., Savage, M. J. & Mills, P. Shading Effects on Greenhouse Tomatoes and Cucumbers. *Acta Hort.* **148** (1984).

118. Weselek, A. *et al.* Agrivoltaic system impacts on microclimate and yield of different crops within an organic crop rotation in a temperate climate. *Agron. Sustain. Dev.* **41**; 10.1007/s13593-021-00714-y (2021).

119. Vanessa S. Schulz, Sebastian Munz, Kerstin Stolzenburg, Jens Hartung & Sebastian Weisenburger and Simone Graeff-Hönninger. Impact of Different Shading Levels on Growth, Yield and Quality of Potato (Solanum tuberosum L.).

120. Kuruppuarachchi, D. S. P. Intercropped potato (Solanum spp.)" Effect of shade on growth and tuber yield in the northwestern regosol belt of Sri Lanka. *Elsevier Science Publishers B.V.* (1990).

121. Sugiartini, E., Eris, F. R., Pancaningsih, E., Nurviani, O. & Herawati, N. Studies on Cultivation of Several Varieties of Onion (Allium ascalonicum L.) under Plastic Shade during Rainy Season in Jakarta. *IOP Conf. Ser.: Earth Environ. Sci.* **715,** 12044; 10.1088/1755-1315/715/1/012044 (2021).

122. Dan Drost and Wade Bitner. Carrots in the Garden, 2020.

123. Barmon, N. C., Bala, P., Roy, U. K. & Azad, A. K. Growth and Yield of Carrot Influenced by Shading Characteristics. *Eco-friendly Agril. J.* (2012).

124. Marrou, H., Wery, J., Dufour, L. & Dupraz, C. Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. *European Journal of Agronomy* **44,** 54–66; 10.1016/j.eja.2012.08.003 (2013).

125. Ministry of Agro Industry and Fisheries. Blueprint for a Sustainable Diversified Agri Food Strategy for Mauritius 2008-2015 (2008).

126. Golchin, A., Mofrad, F. & Moghadam Igdelou, N. K. Effect of shadow and different levels of nitrogen on growth and essential oil content of peppermint (Mentha piperita L.); 10.22059/jci.2019.280170.2206 (2019).

127. Palani Kumar, M. Performance of mint (Mentha Spp.) under the humid tropical conditions of Kerala.

128. Murillo-Amador, B. *et al.* Physiological, morphometric characteristics and yield of Origanum vulgare L. and Thymus vulgaris L. exposed to open-field and shade-enclosure. *Industrial Crops and Products* **49,** 659–667; 10.1016/j.indcrop.2013.06.017 (2013).

129. Li, Y. Effect of light level on the growth and essential oil production of two herbs: sage (Salvia officinalis) and thyme (Thymus vulgaris), 1996.

130. L'express. Mauritius: end of the ginger production season. Available at https://www.freshplaza.com/europe/article/9046410/mauritius-end-of-the-ginger-production-season/ (2018).

131. Ravindran, P. N. & Nirmal Babu, K. *Ginger. The genus Zingiber* (CRC Press, Boca Raton, 2005).

132. Gokool, A., Abeeluck, D., Dooblad, V. & Facknath, S. Investigation on the use of trapping in the management of the banana weevil, Cosmopolites Sordius (Germnay) in Mauritius. *University of Mauritius Research Journal* (2010).

133. Muhidin, Nurmas, A., Sadimantara, G. R., Leomo, S. & Yusuf, D. N. The growth performance of dwarf banana Cavendish from SE Sulawesi under natural shading. *IOP Conf. Ser.: Earth Environ. Sci.* **807,** 42038; 10.1088/1755-1315/807/4/042038 (2021).

134. Hortology. Musa Acuminata Dwarf Cavendish. Available at https://hortology.co.uk/products/musa-acuminata-dwarf-cavendish-banana-plant#:~:text=Height%20%26%20Growth%20Rate,around%202%20to%203%20metres.

135. Da Ferro Silva, I. *et al.* Phenotypic plasticity of leaves and yield of pineapple grown under shade conditions. *Revista Verde de Agroecologia e Desenvolvimento Sustentável* (2017).

136. Kishore, K., Rupa, T. R. & Samant, D. Influence of shade intensity on growth, biomass allocation, yield and quality of pineapple in mango-based intercropping system. *Scientia Horticulturae* **278,** 109868; 10.1016/j.scienta.2020.109868 (2021).

137. Weselek, A., Bauerle, A., Zikeli, S., Lewandowski, I. & Högy, P. Effects on Crop Development, Yields and Chemical Composition of Celeriac (Apium graveolens L. var. rapaceum) Cultivated Underneath an Agrivoltaic System. *Agronomy* **11,** 733; 10.3390/agronomy11040733 (2021).

138. Yasoda, P. G. C., Pradheeban, L., Nishanthan, K. & Sivachandiran, S. Effect of Different Shade Levels on Growth and Yield Performances of Cauliflower. *IJEAB* **3,** 948–955; 10.22161/ijeab/3.3.30 (2018).

139. Xenia Y. Wolff and Robert R. Coltman. "Productivity Under Shade in Hawaii of Five Crops Grown as Vegetables in the Tropics".

140. Y. Shahak, K. Ratner, Y.E. Giller, N. Zur, E. Or E.E. Gussakovsky, R. Stern, P. Sarig, E. Raban, E. Harcavi, I. Doron and Y. Greenblat-Avron. Improving Solar Energy Utilization, Productivity and Fruit Quality in Orchards and Vineyards by Photoselective Netting. *Acta Hortic.* **772** (2008).

141. García-Sánchez, F. *et al.* Shade screen increases the vegetative growth but not the production in 'Fino 49' lemon trees grafted on Citrus macrophylla and Citrus aurantium L. *Scientia Horticulturae* **194,** 175–180; 10.1016/j.scienta.2015.08.005 (2015).

142. Abd El-Naby, S. K. M., Esmail, A. M. A. M., Baiea, M. H. M., Amin, O. A. E.-F. & Abdelkhalek Ahmed Mohamed, A. MITIGATION OF HEAT STRESS EFFECTS BY USING SHADE NET ON WASHINGTON NAVEL ORANGE TREES GROWN IN AL-NUBARIA REGION, EGYPT. *asphc* **19,** 15–24; 10.24326/asphc.2020.03.02 (2020).

143. da Silva, I. F. *et al.* Phenotypic plasticity of leaves and yield of pineapple grown under shade conditions. *Revista Verde de Agroecologia e Desenvolvimento Sustentável* **12**; 10.18378/rvads. v12i4.5010 (2017).

144. Kim, S., Kim, S. & Yoon, C.-Y. An Efficient Structure of an Agrophotovoltaic System in a Temperate Climate Region. *Agronomy* **11,** 1584; 10.3390/agronomy11081584 (2021).

145. Sano, T., Horie, H., Matsunaga, A. & Hirono, Y. Effect of shading intensity on morphological and color traits and on chemical components of new tea (Camellia sinensis L.) shoots under direct covering cultivation. *Journal of the science of food and agriculture* **98,** 5666–5676; 10.1002/jsfa.9112 (2018).

146. Oliveira, R. d. S. V., Salomão, L. C., Morgado, H. S., Sousa, C. M. & Oliveira, H. F. E. de. Growth and production of basil under different luminosity and water replacement levels. *Hortic. Bras.* **38,** 324–328; 10.1590/s0102-053620200314 (2020).

147. Li, Y. Effect of light level on the growth and essential oil production of two herbs: sage (Salvia officinalis) and thyme (Thymus vulgaris) /. Master thesis. University of Massachusetts Amherst, 1996.

148. Hassanien, R. H. E., Ibrahim, M. M., Ghaly, A. E. & Abdelrahman, E. N. Effect of photovoltaics shading on the growth of chili pepper in controlled greenhouses. *Heliyon* **8,** e08877; 10.1016/j.heliyon. 2022.e08877 (2022).

149. Hassanien, Emam Hassanien, R. & Ming, L. Influences of greenhouse-integrated semi-transparent photovoltaics on microclimate and lettuce growth. *International Journal of Agricultural and Biological Engineering* **10,** 11–22; 10.25165/j.ijabe.20171006.3407 (2017).

150. Ureña-Sánchez, R., Callejón-Ferre, Á. J., Pérez-Alonso, J. & Carreño-Ortega, Á. Greenhouse tomato production with electricity generation by

roof-mounted flexible solar panels. *Sci. agric. (Piracicaba, Braz.)* **69,** 233–239; 10.1590/S0103-90162012000400001 (2012).

151. EL-SAWY, A. M., WADID, M. M., EL-BEHAIRY, O. A., ZOCCHI, Z. G. & ABOU-HADID, A. F. Response of Strawberry Plants to Shortening Day Length, Shading and Coold Storage under Egyptian Conditions. *Egyptian Journal of Agricultural Research* **89,** 673–686; 10.21608/ejar.2011.176055 (2011).

152. Nelkin, J. B. & Schuch, U. K. Retractaible roof greenhouse production of of basil (ocimum basilicum) and lemon grass (cymbopogon citrates) in a semi-arid climate. *Acta Hortic.,* 113–120; 10.17660/ActaHortic.2004.659.13 (2004).

153. Babu, S. *et al.* Impact of shade net condition on growth, rhizome and yield characters of ginger. *Journal of Pharmacognosy and Phytochemistry* (2019).

154. Solar Building Tech. Remodeling to Solar Photovoltaic Greenhouse & Sunroof. Available at http://www.solarbuildingtech.com/Greenhouse_Sunroof_Remodeling/greenhouse_solar_pv_sunroof_remodeling.htm (2023).

155. Russell Persyn, A Porter, Dana O. Rainwater Harvesting. In *Texas A&M AgriLife Extension*, Vol. B-6153.

156. Seyfi şevik & Ahmet Aktaş. RAINWATER HARVESTING IN A 600 kW SOLAR PV POWER PLANT (2021).

157. http://metservice.intnet.mu. Available at http://metservice.intnet.mu/ (2024).

158. Raja, N. B. & Aydin, O. Regionalization of precipitation in Mauritius: a statistical approach. *Meteorological Applications* **26,** 711–719; 10.1002/met.1798 (2019).

159. https://wgbis.ces.iisc.ac.in/energy/water/paper/drinkingwater/rainwater/calculation.html. Available at https://wgbis.ces.iisc.ac.in/energy/water/paper/drinkingwater/rainwater/calculation.html (2022).

160. Bussey, A. How to Calculate Gutter Slope. *Blue River Gutters* (2020).

161. editor. Above Ground Vs Underground Water Tanks. *Sydney Water Tanks* (2019).

162. Hygiene, Water, Sanitation & Health. Guidelines for drinking-water quality, 3rd edition: Volume 1 - Recommendations incorporating the first and second addenda. *World Health Organization* (2008).

163. Hedrick, H. The Benefits of Installing Gutter Guards. Available at https://www.hedrickconstructioninc.com/blog/gutter-guard-installation-benefits (2024).

164. Greenhouse Emporium. Greenhouse Irrigation - What's the best watering system? Available at https://greenhouseemporium.com/greenhouse-irrigation-systems/ (2021).

165. Bushman Tanks. Water Tank Prices: Cost of Rainwater Tanks | Bushman Tanks. Available at https://www.bushmantanks.com.au/information/water-tank-prices (2023).

166. Miller, M. How Much Does Gutter Installation Cost in 2024? *This Old House* (2022).

167.FAO. Crop Calender Mauritius. Information Tool for Crop Production. Available at https://cropcalendar.apps.fao.org/#/home?id=MU&crops=0027,0065,0073,0078,0090,0091,0111,0119,0132,0202,0247,0274,0283,0285,0334,0356 (2021).
168.BNA, "EEG-För-de-rung und -För-der-sät-ze," 2024. https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/ErneuerbareEnergien/EEG_Foerderung/start.html.

169. Maschinenringe Deutschland GmbH, "Das bringt das Solarpaket 1 für Landwirte," 2023. https://www.maschinenring.de/blog/das-bringt-das-solarpaket-1-fuer-landwirte.

170. PV Magazine, "France announces new FIT rates for PV systems up to 500 kW," 2024. https://www.pv-magazine.com/2024/01/04/france-announces-new-fit-rates-for-pv-systems-up-to-500-kw/.

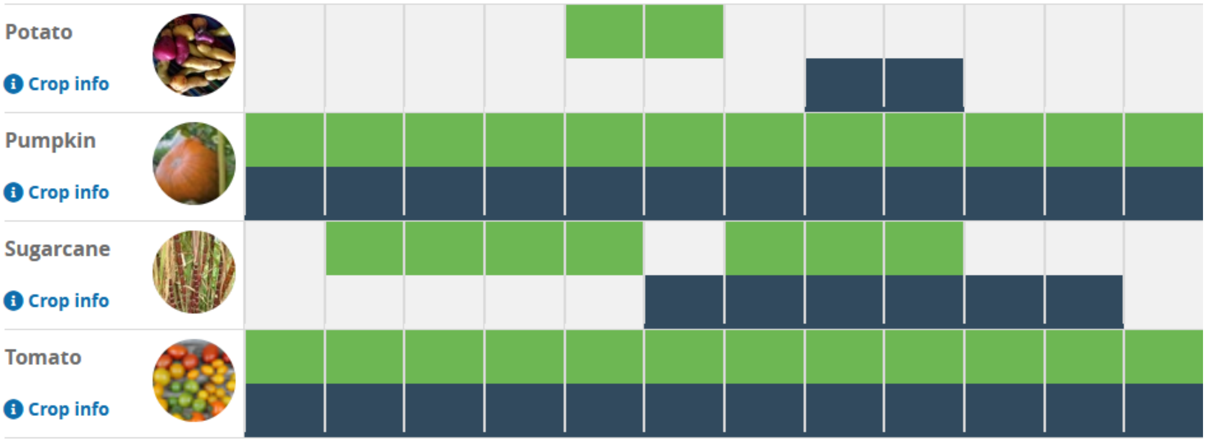
171. PV Magazine, "France unveils new FIT rates for PV systems up to 500 kW," 2023. https://www.pv-magazine.com/2023/07/26/france-unveils-new-fit-rates-for-pv-systems-up-to-500-kw-2/.

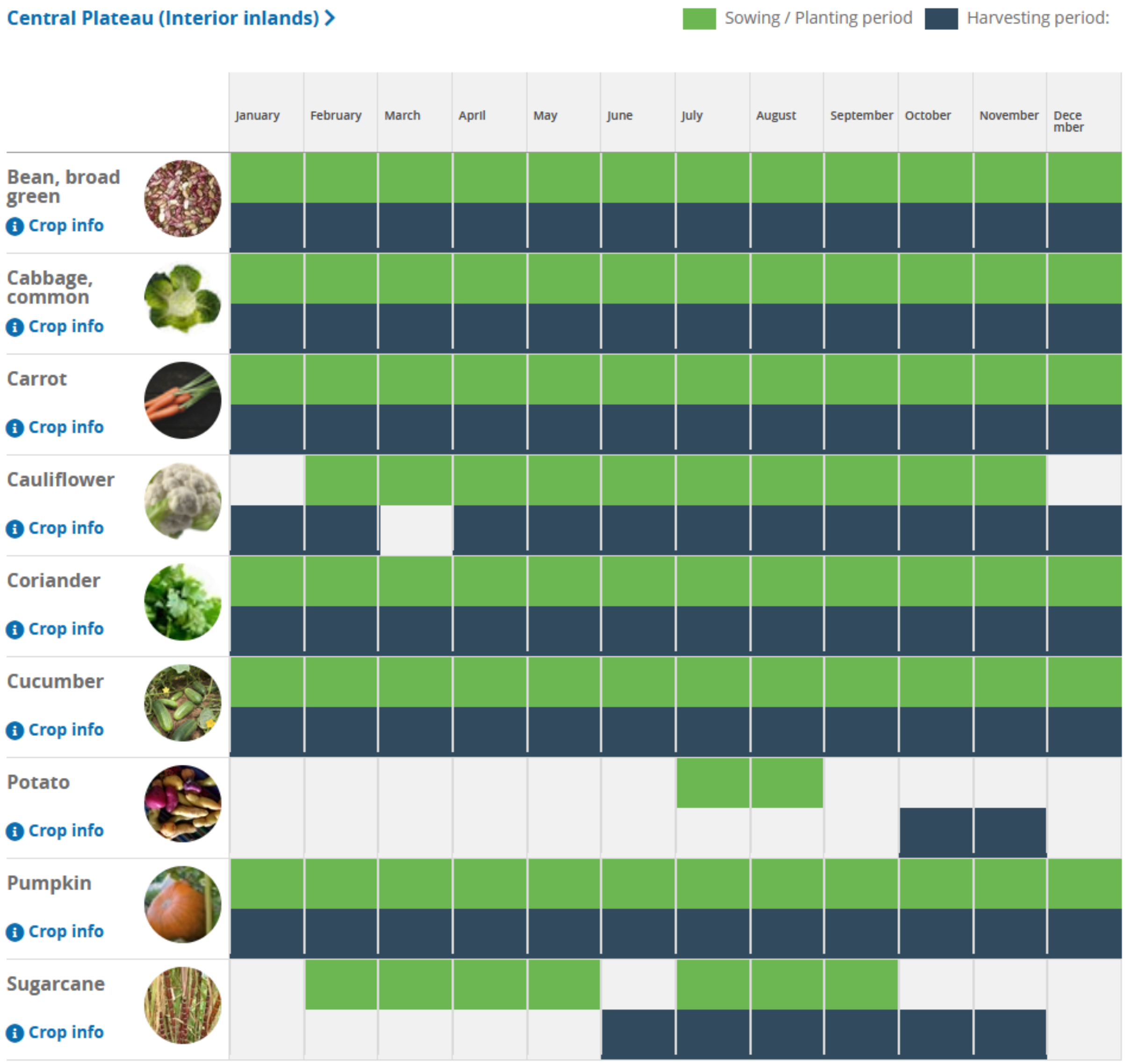
172. M. Bolinger and G. Bolinger, "Land Requirements for Utility-Scale PV An Empirical Update on Power and Energy Density," *IEEE J. Photovoltaics*, Vol. 12, No. 2, 2022, pp. 589–594. doi:10.1109/jphotov.2021.3136805.

Annexes

Annex 1:

Table 15: Crop Calendar for Mauritius.[167]


Potato
Crop info
Pumpkin
Crop info
Sugarcane
Crop info
Tomato
Crop info


Central Plateau (Interior inlands)
Sowing / Planting period
Harvesting period:
January
February
March
April
May
June
July
August
September
October
November
Dece mber
Bean, broad green
Crop info
Cabbage, common
Crop info
Carrot
Crop info
Cauliflower
Crop info
Coriander
Crop info
Cucumber
Crop info
Potato
Crop info
Pumpkin
Crop info
Sugarcane
Crop info

Coastal Belt >

Sowing / Planting period   Harvesting period:

Annex 2:

Table 16: Components needed to implement a rainwater harvesting system within an agrivoltaic system.

1 Rainwater harvesting		
1.1 Gutter system		
1.1.1	Guttering (including corners and outlets)	Vinyl, aluminum or steel, minimum 117mm width
1.1.2	Hangers and brackets	Vinyl, aluminum or steel
1.1.3	Downpipe	Vinyl, aluminum or steel
1.1.4	End caps	Vinyl, aluminum or steel
1.1.5	Sockets and elbows	Vinyl, aluminum or steel
1.1.6	Flashing	If required, to be specified by contractor
1.1.7	Fasteners (screws, nuts and bolts)	Galvanized
2 Pumping and water storage system		
2.1 Pump unit set		
2.1.1	Manufacturer	To be specified by Contractor
2.1.2	Series	To be specified by Contractor
2.1.3	Motor type	AC Motor or Brushless DC
2.1.4	Material of pumping equipment	Corrosion-resistant stainless steel AISI 304 or higher
2.1.5	Daily flow rate	According to water needs and water availability
2.1.6	Total Head	Guaranteed at duty point
2.2 Controller		
2.2.1	Manufacturer	To be specified by Contractor
2.2.2	Series	To be specified by Contractor
2.2.3	Water and dust protection	Minimum IP65
2.2.4	Motor protections	Dry run, over and under voltage, overload protection, temperature protection
2.2.5	Cable	UV resistant
2.2.6	Efficiency	Minimum 95%
2.3 Deposit and piping		
2.3.1	Deposit water capacity	Minimum 50,000L
2.3.2	Height of deposit installation	According to irrigation scheme
2.3.3	Water piping material	PVC (including manual valves)
2.3.4	Water piping DIN	Dimensioned according to water desired flow

The following list presents a selection of mostly European project planners. It is not considered to be fully comprehensive.

Annex 3:

Table 17: List of Project Developer for Agrivoltaic Systems

Company	Country	URL
Amarenco	FR	https://amarencogroup.com/
BayWa	DE	https://www.baywa-re.com/en.html
BomGroup	NL	https://bomgroup.nl/en
DEEA	DE	https://www.deea-solutions.com/en
EDF Renouvables	FR	https://www.edf-renouvelables.com/en
Fa. Zimmermann PV-Stahlbau	DE	https://www.pv-stahlbau.de/en/
Goldbeck Solar	FR	https://goldbecksolar.com/en/
Groenleven	DE/NL	https://groenleven.nl/english/
Hilber Solar	AT	https://www.hilbersolar.com/en/
Hyperion Systems LLLC	USA	https://hyperionsystemsllc.com/
IBC Solar	DE	https://www.ibc-solar.com/
InsoLight	CH	https://insolight.ch/
Jain Irrigation	IN	https://www.jains.com/
Luxor Solar	DE/JP	https://luxor-solar.com/
Mackin Energy	JP	https://www.mackin-energy.co.jp/en/
Next2Sun	DE	https://www.next2sun.com/
PVP Solar	CH	
Sandbox Solar	USA	https://sandboxsolar.com/
sbp gmbh	DE	https://www.sbp.de/en/
SolarRack	CN/JP	https://solarrack.de/kontakt/
Soliculture	USA	https://soliculture.com/
SPB	DE	https://www.spb.com.sa/
SunFarming	DE	https://www.sunfarming.de/en/
Sun'R	FR	https://www.sunr.com/
Tenergie	FR	https://www.tenergie.fr/en/
TubeSolar	DE	https://tubesolar.de/
Volatalia	FR	https://www.voltalia.com/index
Volta Green Energy S.r.l.	IT	https://volta-energy.com/en/
WPD	DE	https://www.wpd.de/en/
Wynergy	AT	https://www.wynergy.at/

Annex 4:

The following list offers a selection of module manufacturers that offer special modules such as semi-transparent modules that are particularly suitable for agrivoltaic projects. Depending on the application, standard modules can also be used. For quality reasons, Tier 1 suppliers with a warranty should be preferred. The list is not considered to be fully comprehensive.

Table 18: Suppliers of Agrivoltaic modules / special modules

Company	Country	Contact Info	URL
Aleo Solar	DE	info@aleo-solar.de	https://www.aleo-solar.de/en/solartechnologie
Almaden	CN	info@almaden.ma	https://www.almaden.ma/products/#1565818162610-d5ad3238-406e
Atersa	ES	atersa@elecnor.com	https://www.atersa.es/en/products-services/photovoltaic-modules/special-modules/
Axsun Solar	DE	info@axsun.de	https://www.axsun.de/solarmodule
Bisol	SVN	info@bisol.com	https://www.bisol.com/
BYD	CN	bydpv@byd.com	https://pv.byd.com/sites/sune/index.html
Das Energy	AT	office@das-energy.com	https://das-energy.com/en/products
Gridparity	DE	info@gridparity.ag	https://www.gridparityag.com/glass-technology
Hannover Solar	DE	info@hanoversolar.de	https://www.hanoversolar.de/?lang=de
Hermes Solar	BG	office@hermessolar.com	https://www.hermessolar.com/
HT-SAAE	CN	pvmarketing@ht-saae.com	http://www.ht-saae.com/en/coreEnergy.aspx?id=74
Irex	VN	info@irex.vn	https://irex.vn/en/product/irm48b1-265-3/
Jains Bewässerungssysteme	IN	customercare@jains.com	http://www.jains.com/Solar/module/jain_BIPV_solar_PV_Modules.htm
Jinko Solar	CN	contact.eu@jinkosolar.eu	https://www.jinkosolar.com/en/site/bifacial
KIOTO Solar	AT	office@sonnenkraft.com	https://www.kiotosolar.com/de/unsere-produkte/doppelglas-module/doppelglas-modul-mit-rahmen.html

Company	Country	Contact Info	URL
Luxor	DE	info@luxor-solar.com	https://www.luxor-solar.com/en/solar-modules/special-line/special-line-m-p.html
Megasol	CH	info@megasol.ch	https://megasol.ch/en/produkt/solar-modules/special-module-laminate/
Novergy	IN	enquiry@novergy.net	https://www.novergysolar.com/products/solar-panels/solar-bipv-module/
RAYTECH	CN	ruwenwen@raytm.cn	https://www.raytech-energy.com/Products/transparentm.html
Risun solar	CN	sales@risunsolar.com	http://www.risunsolar.com/en/list/?21_1.html
Solarwatt	DE	info@solarwatt.com	https://www.solarwatt.com/solutions/our-products/product-overview/panels
Solitek	LT	info@solitek.eu	https://www.solitek.eu/en/solar-panels
Solvis	HR	sales@solvis.hr	https://solvis.hr/en/
CS Wismar Sonnen-stromfabrik	DE	maximilian.wacker@sonnenstrom-fabrik.com	https://www.sonnenstromfabrik.com/de/produkte/brilliant/
Sunovation	DE	info@sunovation.de	https://sunovation.de/en/products/eFORM_clear
Swelect	IN	info@swelectes.com	https://swelectes.com/solar-pv-module/
ZNShine Solar	CN	gerhard.bittner@znshinesolar.de	https://www.znshinesolar.de/speziall%C3%B6sungen
SUNSET Solar	DE	info@sunset-solar.com	https://www.sunset-solar.de/de/
Heckert Solar	DE	info@heckert-solar.com	https://www.heckertsolar.com/
Meyer Burger	DE	mbtinfo@meyerburger.com	https://www.meyerburger.com/de/
CETC Solar Energy	CN	info@cetcsolarenergy.com	http://cetcsolarenergy.com/

Annex 5: Site Evaluation Matrix

Research Station	Weighting Factor	Belle Vue Experiment Station	Nouvelle Decouverte	Barkly Experiment Station Ministry	FAREI Head Office Research Station
Lat/Long		-20.20222222,57.4208333	-20.19625409,57.59239329	-20.226210542449,57.4605090836631	´-20.14051, 57.293646
Agricultural	**3,5**				
Type of research		Seeds	Seeds	Seeds	Production
Are two 1000m² fields available with flat land?		1	0	1	1
Do relevant crops grow there?		1	1	1	1
Is farming possible all the year?		0	1	1	1
Is water accessible?		1	0	1	1
Depth of soil (on top or rock)		0	0	1	1
		10,50	**7,00**	**17,50**	**17,50**
Monitoring	**1**				
Laboratory		0	0	0	1
Meteorlogical Station		1	1	1	1
Sensors		0	0	0	1
Internet connection		1	1	1	1
		2,00	**2,00**	**2,00**	**4,00**
Power Supply	**1,5**				
Grid Connection without extensive extension work		1	0	0	1
		1,50	**0,00**	**0,00**	**1,50**
Security	**1**				
The station is fenced?		1	1	1	1
Security guards		1	1	1	1
		2,00	**2,00**	**2,00**	**2,00**
Personnel	**2,5**				
Supervision		1	1	1	1
Research		0	0	0	1
		2,50	**2,50**	**2,50**	**5,00**
Decentralized portfolio	**0,5**				
Empowerment of less equipped sites		1	1	0	0
		0,50	**0,50**	**0,00**	**0,00**
Total (30,5)		***19,00***	***14,00***	***24,00***	***30,00***