PLANNING AND ESTIMATION OF A PILOT PROJECT ON AGRIVOLTAIC SYSTEM FOR RARS PATTAMBI

By

ARCHANA I B (2020-02-012)

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY TAVANUR- 679573,

MALAPPURAM, KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfilment of the requirements for the degree of

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DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING
AND TECHNOLOGY TAVANUR- 679573,

MALAPPURAM, KERALA, INDIA

2024

DECLARATION

We hereby declare that this project report entitled "**PLANNING AND ESTIMATION OF A PILOT PROJECT ON AGRIVOLTAIC SYSTEM FOR RARS PATTAMBI**" is a bonafide record of project work done by us during the course and that this report has not previously formed on the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place: Tavanur

Date:

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CERTIFICATE

Certified that this project report entitled **“PLANNING AND ESTIMATION OF A PILOT PROJECT ON AGRIVOLTAIC SYSTEM FOR RARS PATTAMBI”** is a record of project work done jointly by **Ms. Archana I B, Mr. Akshay Parameswaran, Ms. Abhirami Bhaskar and Ms. Archana A,** under our guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

Abbreviation/ Notation	**Description**
%	Percentage
°	Degree
A	Ampere
AE	Agro-ecological
Ag	Silver
Agrl.	Agricultural
Al	Aluminum
Al_2O_3	Aluminium oxide
APV	Agri-Photovoltaic
ARC	Anti-Reflective Coating
Asst.	Assistant
Avg.	Average
AVS	Agrivoltaic System
BSF	Black Surface Field
℃	Degree Celsius
CA	Closed agrivoltaics system
cm	Centimetre(s)
CO_2	Carbon dioxide
CS	Concentrated Shadow
CT	Controlled Tracking

Dept.	Department
E	East
EIA	Environmental Impact Assessment
Engg.	Engineering
et al.	And others
etc.	Et cetera
FD	Full Density
Fig.	Figure
FMPE	Farm Machinery and Power Engineering
FS	Full Sun
GWh/ a	Giga Watt Hour per area
ha	Hectare
HD	Half Density
hr	Hour
ie.	That is
KAU	Kerala Agricultural University
KCAET	Kelappaji College of Agricultural Engineering and Technology
kg	Kilogram
kgm^{-2}	Kilogram per square metre
kgm^{-3}	Kilogram per cubic metre
km	Kilo metre(s)
KVK	Krishi Vigyan Kendra

kW	Kilo Watt
kWp	Kilo Watt Peak
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
LER	Land Equivalent Ratio
m	Metre(s)
m^2	Metre square
m^3	Cubic metre(s)
mm	Millimetre(s)
ms^{-1}	Metre per second
MWh	Mega Watt Hour
N	North
Nm^{-2}	Newton per square metre
OPV	Organic Photovoltaic
P3HT	Regioregular poly(3-hexylthiophene)
PAR	Photosynthetically Active Radiation
PERC	Passivated Emitter and Rear Cell
PV	Photovoltaic
PVR	Photovoltaic Ratio
q	Quintal
RARS	Regional Agricultural Research Station
Rs.	Rupees
Si	Silicon

SIA	Social Impact Analysis
SiN_x	Silicon Nitride
SME	Small and Medium Enterprises
SR	Shading Ratio
SS	Scattered Shadow
ST	Solar Tracking
TiO_2	Titanium dioxide
V	Volt
VF	Vertical farm
W	Watt

INTRODUCTION

CHAPTER I

INTRODUCTION

In a context of climate change and a growing world population, agriculture is facing new challenges in producing food. On the one hand, global food production is expanding to meet increasing demand, while the global land area allocated has stabilised in recent years. On the other hand, global warming of +1.5 ^{O}C is highly likely in the near future due to human activities and extreme weather events such as heatwaves, droughts, and heavy precipitation will become more frequent.

In addition, increase in world population, and rising living standards and industrialisation are driving global energy demand. It is estimated that by the middle of the 21st century, global energy consumption will have doubled, of which 50 % could be for electricity alone. To meet sustainable development goals and energy demand, the energy sector must be transformed by deploying low-emission energy sources and increasing the share of renewable energy. Among renewable energies, solar energy is the most important exploitable resource. It is estimated that more than 40% of the renewable energy produced in the world in 2050 will come from photovoltaic installations. Although today, solar installations occupy only a fraction of lands in the world, current scenarios show that their development may increase competition for lands and resources, especially with the agricultural sector.

To address competition for land, it is possible to combine the installation of a solar photovoltaic (PV) plant with agricultural production on the same area. The convergence of agriculture and renewable energy technologies has evolved a novel concept known as Agrivoltaics, a sustainable solution aimed at maximizing land use efficiency while addressing the pressing challenges of food security and renewable energy generation.

This new production system was first devised and proposed in the 1980s to allow additional use of agricultural land. This concept, known as agrophotovoltaics, agroPV, agrivoltaics, solar sharing or PV agriculture, depending on the country, is one of the new agricultural techniques under development where research has increased significantly in recent years.

Three types of agrivoltaics have been developed. The first one consists in using the space between the crop rows to install solar panels (Interspersed PV arrays), while for the other two the PV modules are installed above the crops, either by replacing part of the greenhouse cover with panels (Greenhouse-mounted PV arrays) or by mounting them on an open-air structure (Stilt-mounted PV arrays). The solar panels can be installed in a fixed way on the structure (Static panels) or in a dynamic way (Dynamic panels) by modifying their inclination according to the sunshine and the management of the crops (Widmer *et al*., 2024). If the produced electricity is directly used on site, agrivoltaics could also contribute to reducing the carbon footprint of the farming unit (Trommsdorff *et al*., 2022).

Thus, agrivoltaics can increase the productivity of the farmland and aid in enhancing the overall income of the farmers. It may also contribute towards diversifying the income of the farmers by facilitating the growth of various crops under the installed PV modules and the revenue generated from electricity sales or land lease rents from the owner of the agrivoltaics system. Some of the major advantages by incorporating agrivoltaics into our farms are increased land use efficiency, enhanced crop yield and quality, water conservation, renewable energy production, economic benefits, improved biodiversity and soil health, climate resilience, technology synergy, community and social benefits and policy and incentive alignment.

The Kerala Agricultural University, which extends over a network of institutions spread throughout Kerala State consisting of 9 Colleges, 6 Regional Agricultural Research Stations, 16 Research Stations and 7 Krishi Vigyan Kendra is one of the suitable site for the implementation of agrivoltaic system.

KAU has lots of farm areas, ponds, buildings and unused land or free areas, which can successfully be incorporated with agrivoltaics. This not only will ensure the availability of green power for entire KAU but also brings about the integration of advanced technology to the farms. The zero carbon farming goals and carbon neutral farming can be achieved by this system. The produced power can be used for farm activities, electrical needs for buildings etc. The adoption of agrivoltaics will also contribute to smart farming and futuristic farming.

This report delves into the principles and practices of Agrivoltaics, illustrating how the integration of solar photovoltaic systems with agricultural activities can not only bolster renewable energy generation but also improve crop yields, conserve water resources, and mitigate climate risks. It highlights the potential synergy between solar energy production and agricultural activities in diverse agro-climatic zones across KAU.

In conclusion, this project aims to shed light on the potential of Agrivoltaics in KAU by examining its relevance, challenges, and opportunities.

This project was undertaken with the following objectives:

1. To find suitable sites in KAU for the implementation of agrivoltaics system by collecting crop area data.
2. To design APV system for selected area.
3. To prepare a pilot project plan and estimation of APV system for the selected site.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

In this chapter, the comprehensive review of the literature referring to the analysis of agrivoltaics carried out by many researches on different aspects were briefly summarized.

The review has been organised objective wise under the following sub heads:

1. Solar energy in agriculture
2. Opportunities of agrivoltaics
3. Productivity of crops according to shade tolerance
4. Crop production

2.1 SOLAR ENERGY IN AGRICULTURE

Rodriguez *et al*. (2023) examined the potential electricity generation of photovoltaic greenhouses, emphasizing the significance of agrivoltaics in land-scarce regions. Their findings indicated that optimal photovoltaic ratio (PVR) values varied based on crop light requirements, ranging from 0% for high light-requirement crops in low solar radiation areas to 74% in the best-case scenario. Medium and low light-requirement crops were less sensitive to PVR changes. For the Canary Islands, with a total greenhouse area of 7284 ha, the potential power output varied significantly with greenhouse material transmittance (τG), reaching up to 1607 MW (τG: 0.8) or 2940 MW (τG: 0.9). Corresponding annual energy production ranged from 2480 GWh/a to 4497 GWh/a. With energy storage systems, agrivoltaics supplied 31% of the region's annual energy demand (τG: 0.8) or up to 56% (τG: 0.9). Even in the worst-case scenario (τG: 0.7), agrivoltaics could meet 8% of regional electricity demand.

Ma-Lu *et al*. (2024) developed and evaluated models for decomposing photosynthetically active radiation (PAR) in agrivoltaic systems. Their research aimed to optimize the distribution of light under solar panels to enhance both photovoltaic and agricultural productivity. The study introduced various PAR decomposition models that predicted how solar radiation was distributed in agrivoltaic setups, considering factors like panel orientation and spacing. Field experiments conducted in Italy demonstrated that the models could accurately simulate light conditions, aiding in the design of agrivoltaic systems that maximized crop yields while maintaining efficient solar energy production.

The authors highlighted the importance of precise PAR management to ensure crops receive adequate light for photosynthesis.

Weselek *et al*. (2021) assessed the impact of different agrivoltaic system configurations on crop yield and energy production in Germany, focusing on barley and clover grass. Their study found out that agrivoltaic systems with adjustable solar panels improved light conditions for crops, resulting in higher yields and increased energy production compared to fixed panel systems. The research underscores the benefits of adjustable panels in optimizing light for crops while maximizing solar energy capture. The study concluded that agrivoltaic systems, especially with adjustable panels, hold significant promise for boosting agricultural productivity and renewable energy generation in temperate regions, warranting further research and development.

Barron *et al*. (2019) found out that PV panels in a traditional ground-mounted array were significantly warmer during the day and experienced greater within-day variation than those over an agrivoltaic understorey. They attributed these lower daytime temperatures in PV panels in the agrivoltaic system to the greater balance of latent heat energy exchange from plant transpiration relative to sensible heat exchange from radiation from bare soil. Across the core growing season, PV panels in an agrivoltaic system were ~8.9+0.2 °C cooler in daylight hours. This reduction in temperature lead to an increased in system performance.

Lee *et al*. (2023) examined agrivoltaic systems (AVSs) and its dual impact on agriculture. They found out that PV module installation reduced solar radiation, which hindered crop growth, but also prevented excessive insolation that lowered photosynthetic efficiency and increased moisture evaporation. Optimized PV placement enhanced crop growth. Additionally, PV modules offered protection from intense precipitation, snowfall, and cold winds. The surplus solar energy generated boosted farm revenue. The study also inferred that AVSs have lower water consumption and greenhouse gas emissions than traditional rice fields, presenting a sustainable agricultural alternative.

2.2 OPPORTUNITIES OF AGRIVOLTAICS

Elamri *et al.* (2018) investigated the effects of dynamic agrivoltaic systems, where solar panels can be adjusted based on crop growth stages and weather conditions. Their research focused on the cultivation of irrigated lettuces under these adjustable solar panels. The study demonstrated that dynamic agrivoltaic systems enhanced both crop yields and energy production efficiency. The researchers found out that adjusting the panels based on the specific needs of the crops and prevailing weather conditions allowed for optimal light distribution and reduced water stress, leading to improved growth and productivity. The study recommended further development of automated systems to optimize the balance between agricultural and energy outputs, suggested that dynamic agrivoltaic systems offer a promising solution for maximizing the benefits of agrivoltaics in various agricultural settings.

Aurela Qamili and Silva Kapia (2024) examined PV usage in Albania’s energy sector, highlighting its opportunities and challenges. They noted that southern and central Albania received higher solar radiation than northern areas. In the first quarter of 2023, available electricity decreased by 9.7%, with only 0.6% of the 2,787 GWh net domestic production from photovoltaics. The country's broad terrain, especially in coastal and central regions, is suitable for PV system installations. Adopting PV systems offers substantial environmental benefits, aligning with Albania’s commitment to sustainability. PV technology also uses minimal water, beneficial for a country facing occasional water scarcity.

Gustavo *et al.* (2023) conducted a study in Chile, a country with significant renewable energy resources, to explore the potential of agrivoltaic systems. These systems aimed to enhance renewable energy use, reduced fossil fuel dependence, and combat CO_2 emissions, thus creating a synergy between energy production and agriculture. The study proposed an agrivoltaic system for agricultural land in Temuco, Araucanía region, and assessed its viability. In 2017, three pilot plants were installed on crops in El Monte, Lampa, and Curacaví, each with a 13 kWp capacity, generating up to 20.8 MWh/year and reducing CO_2 emissions by 8.8 tons/year. These projects demonstrated significant CO_2 reductions and energy savings for crop irrigation, particularly during dry seasons. Chile's Netbilling Law (Law 20,571) further encouraged interest in such systems by allowing consumers, including households and SMEs, to act as "prosumers"—both producers and consumers of electricity—thereby improving operational cost efficiency.

Thomas *et al*. (2023) reviewed the impacts of solar parks and its mitigation mechanism through agrivoltaics and techno-economic analysis. He reviewed the agrivoltaic plants in India, and concluded that the focus was to look into the economics of the agrivoltaic plant to lure the farmers to practice. The present study considered agrivoltaics as a mitigation mechanism of EIA (Environmental impact analysis) and SIA (Social impact analysis) and looked into the techno-commercial viabilities of the same. Three livelihood mechanisms were considered and technical and economic feasibilities were carried out. It was identified that a mix of medicinal plants and poultry was beneficial and the breakeven was achieved in 17 years for an additional capital investment of 80% and operational expenses of 2.5%. However, considering the breakeven of 17 years may not attract investors, for a 70:30 debt equity ratio with a term interest of 10%, the inclusion of subsidies and green billing was considered and it was found that the LCOE could be brought down to Rs. 41/kWh from Rs. 53/kWh, thus bringing the better breakeven.

Rodriguez *et al*. (2024) conducted a study to demonstrate the functionality that was added to agricultural land by combining it with solar parks. These projects allowed the reduction of carbon dioxide (CO_2) into the atmosphere and significant energy savings related to crop irrigation, especially considering the dry season that occurs in the country.

Lama and Jeong (2024) designed and analyzed foldable solar panels for agrivoltaic systems, aimed to optimize light distribution for crops and solar energy generation. Using lightweight, flexible photovoltaic materials, the panels featured adjustable folding mechanisms for various tilt angles and configurations. Field tests showed improved crop yields by 15-20% due to reduced heat stress and better water retention. Energy efficiency was slightly lower than fixed panels, but the levelized cost of energy (LCOE) was competitive, ranging from Rs. 9 to Rs. 13 per kWh. The study concluded that foldable panels enhance agrivoltaic system functionality by adapting to crop needs and environmental conditions, promoting sustainable agricultural practices and efficient energy production.

Jaiyoung Cho *et al*. (2020) investigated crop growth in a rain-shield facility in Ongjin-Gun, Republic of Korea. The photovoltaic system, designed with a 30% shading rate, included normal, transparent, and bifacial solar panels to compare cultivation environments and product quality. Over seven months, power generation was 25.2 MWh for normal, 21.6 MWh for bifacial, and 25.7 MWh for transparent panels. The transparent module performed best due to its direction, not inherent superiority. Soil temperature was higher in spring and winter at the test site, but grape coloring and growth were delayed due to reduced solar radiation and temperature changes from the solar modules.

Pascaris *et al*. (2024) conducted a life cycle assessment (LCA) to analyze the environmental impacts and energy usage of pasture-based agrivoltaic systems integrating rabbit production. Their research assessed the emissions and energy consumption associated with various stages of rabbit production, considering factors such as feed production, housing, and manure management. The study found out that integrating rabbit production with agrivoltaic systems significantly reduced greenhouse gas emissions and energy consumption compared to conventional rabbit farming practices. Agrivoltaic systems provided shading and microclimate benefits for rabbit welfare while generating renewable energy. The research highlighted the potential of agrivoltaics to enhance the sustainability and resilience of agricultural systems by simultaneously producing food and renewable energy.

Handler and Pearce (2022) conducted a life cycle analysis (LCA) to evaluate the environmental impacts of integrated sheep agrivoltaic systems. Their research assessed the sustainability of combining sheep grazing with solar energy production, considering factors such as land use, feed production, and energy generation. The study found out that integrated sheep agrivoltaic systems offered significant environmental benefits, including reduced greenhouse gas emissions, lower land footprint, and enhanced ecosystem services compared to conventional sheep farming and standalone solar installations. Grazing sheep in agrivoltaic systems helped to maintain vegetation under solar panels, reduced the need for mechanical mowing and herbicide use. The findings suggested that integrating sheep with solar energy production contributed to sustainable land management and renewable energy generation.

2.3 PRODUCTIVITY OF CROPS ACCORDING TO SHADE TOLERANCE

Ortega *et al*. (2021) assessed lettuce growth under different photovoltaic shading types: Concentrated Shadow (CS), Scattered Shadow (SS), and Full Sun (FS). The experiment took place on a rooftop with nine cultivation containers, each 81 cm long, 48 cm wide, and 20 cm high, arranged in a grid. The study was conducted in spring and summer, with planting dates of May 2 and June 16, 2021. Results showed that the SS treatment significantly outperformed CS and FS. In spring, SS was 46.4% more productive than CS and 68.8% more than FS. In summer, SS showed even greater increases, with 61.2% higher productivity than CS and 87.6% more than FS. The superior growth in SS-treated lettuces was due to more leaves, greater lengths, and larger roots, highlighting SS as the most effective shading type.

Valle *et al*. (2017) developed an agrivoltaic prototype with orientable photovoltaic panels at the IRSTEA site near Montpellier, comparing full-sun (FS), half-density (HD), and full-density (FD) stationary systems, as well as solar tracking (ST) and controlled tracking (CT) panels. Two lettuce varieties, Kiribati and Madelona, were planted in autumn, spring, and summer. The study found out that less transmitted radiation generally led to better biomass conversion, except in spring for Madelona. The CT system showed no difference in biomass per unit light transmitted compared to FS conditions in summer and spring. Conversely, the HD and ST systems produced more biomass per unit of transmitted radiation.

Sekiyama and Akira (2019) investigated the performance of agrivoltaic systems for corn production. They assessed the sensitivity of corn yield per square meter to varying shading levels under PV modules. The study measured the fresh weight of corn crops and the biomass of corn stover. Results demonstrated the feasibility of growing corn, a shade-intolerant crop, under agrivoltaic PV panels. The biomass of corn stover under PV modules spaced at 0.71 m intervals was at least 96.9% compared to corn without PV modules. Interestingly, the biomass of corn stover under PV modules spaced at 1.67 m intervals exceeded that of corn without PV modules by 4.9%. Moreover, the corn yield per square meter in the low-density configuration surpassed both the high-density and no-module control configurations by 5.6%.

Gonocruz *et al*. (2021) analysed rice yield under an Agrivoltaic System. They considered four case study sites as their proximity allowed meaningful comparisons by eliminating differences in solar irradiance. In this study, they controlled the fertilizer applied to each plot. The grain weights of the control and shaded plots were compared. Subsequently, panicle number, spikelet number per panicle, percentage of ripened grain, and thousand grain weight were measured as the four components of grain yield. The results showed that the grain weight on all the farms decreased with increasing shading rate. The decrease in grain yield owing to shading was primarily caused by the decrease in panicle number.

Scarano *et al*. (2024) examined the impact of agrivoltaic systems on the production of tomatoes (Solanum lycopersicum L.). Their study aimed to understand how shading from solar panels affects tomato growth, yield, and quality. The experimental design included various shading configurations provided by the solar panels. The results revealed that moderate shading from the panels enhanced tomato production by mitigating heat stress and improving soil moisture retention. Tomatoes grown under the agrivoltaic system exhibited a 10-15% increase in yield and better quality compared to those grown in full sunlight. The study also noted improvements in fruit size and color uniformity under the shaded conditions. Economically, the integration of solar panels did not significantly increase production costs, while the dual use of land for both energy and crop production added value.

Hermelink *et al*. (2024) conducted a meta-analysis on berry crops in agrivoltaic systems to assess shade tolerance. They found out that differing shade tolerances among berry varieties, some showed better growth and yield retention under partial shading. Factors like cultivar characteristics and light requirements influenced shade tolerance. Understanding these was crucial for optimizing agrivoltaic system design to support berry cultivation while maximizing solar energy production. The findings offered insights into crop selection and management, enhancing the sustainability and productivity of agrivoltaic systems by integrating berry production with renewable energy generation.

2.4 CROP PRODUCTION

Dinesh and Pearce (2016) conducted a life cycle analysis of agrivoltaic systems, revealed its significant environmental and economic benefits compared to conventional farming and standalone solar power generation. The study highlighted reduced greenhouse gas emissions and water usage, emphasizing the potential for improved land use efficiency by combining food and energy production. Site-specific designs, considering factors like climate and crop selection, were deemed crucial for optimizing agrivoltaic system benefits. Overall, the findings underscored agrivoltaics' pivotal role in advancing sustainable agriculture and renewable energy, crucial for climate change mitigation and resource conservation.

Zotti *et al*. (2024) investigated the effectiveness of semi-transparent, spectrally selective thin film solar panels in agrivoltaic applications. The study employed a multi-experimental and multi-specific approach, focusing on various light sources, configurations impacting light irradiation, and growth effects on different photosynthetic organisms. Results demonstrated excellent growth of algae, tomato, and basil under thin film panels tilted at 30 degrees, with increased biomass, leaf count, and shoot length across all crops.

Zisis *et al*. (2019) experimented with semi-transparent Organic PV(OPV) modules utilizing a P3HT photoactive layer, achieving up to 19.4% transparency in the PAR region. They found out that these modules were suitable for combined cultivation and energy generation on the same land. Plants grown under the shading of OPV devices exhibited enhanced performance, displayed longer central stems and increased pepper fruit yields. The shading provided by OPV modules offered protection from UV radiation, contributing to the favourable growth of shaded plants. Additionally, while plants convert sunlight into biomass, OPV modules generate electricity, which can directly power greenhouse systems, thereby reducing operational costs.

Widmer *et al*. (2024) examined current knowledge and future prospects of agrivoltaics, aimed to identify existing installations and assess changes in plant production. Among the 50 agrivoltaic setups mentioned, only 37 provided total area information. Most installations (23 out of 37) were smaller than 1000 m^2, with only one exceeding 0.8 ha. About 79% shaded a ground area equal to or less than 40% of the total surface. Reports suggested that up to 25% coverage does not significantly affect plant growth, but exceeding 50% may. Additionally, a study on lamb production showed no impact from agrivoltaic systems on daily weight gain.

Cossu *et al*. (2023) quantified the increase of land productivity derived from the integration of an experimental vertical farm (VF) for baby leaf lettuce inside a pre-existing commercial closed agrivoltaics system (CA). The mixed system increased the yield by 13 times compared to the CA. The original agrosystem integrated an experimental VF inside a pre-existing CA (VFCA) with a PV cover ratio of 100 %. The VFCA increased the yield up to 13 times compared to the sole CA and the CO_2 emissions decreased by 12 %, whereas the land productivity increased with a Land Equivalent Ratio (LER) up to 1.60 on the green varieties

Barron *et al*. (2019) evaluated the impact of irrigation water savings under an agrivoltaic system compared to traditional methods. They found out that the greatest influence of agrivoltaics on soil moisture retention when irrigating every 2 days, with soil moisture remaining approximately 15% higher than in the control setting before subsequent irrigation. Even with daily irrigation, the agrivoltaic system maintained 5% higher soil moisture levels before the next irrigation event compared to the control. Importantly, soil moisture in the agrivoltaic system after 2 days exceeded the driest points observed in the control after daily irrigation, suggesting potential for further reduced irrigation in agrivoltaics. This highlighted substantial water use reduction potential in agrivoltaics, necessitating further research, particularly considering future rainfall uncertainties.

Barron *et al*. (2019) explored the impact of agrivoltaic systems on plant productivity, water-use efficiency, and microclimate in a dryland region. They cultivated crops like chiltepin pepper, jalapeño, and cherry tomato under solar panels, finding improved water-use efficiency due to reduced evapotranspiration rates. Moreover, crops grown under the panels yielded more than those in open-field conditions. This research showed agrivoltaics' potential to enhance agricultural sustainability in arid regions by optimizing water use and increasing crop productivity. The dual benefits of agrivoltaics, providing food and energy from the same land, address the food-energy-water nexus in drylands.

MATERIALS AND METHODS

CHAPTER III
MATERIALS AND METHODS

This chapter includes primary materials involved in agrivoltaics design such as site selection, description of selected site, design considerations, meteorological data and planning and layout.

3.1 SITE SELECTION CRITERIA FOR AGRIVOLTAICS

This section details the location of the agrivoltaics installation sites, specifying the various regions of Kerala Agricultural University, according to the agroecological units in Kerala, India. Coordinates and AE units of all the stations under KAU are given in Table 3.1.

Table 3.1. Co-ordinates and AE units of site

Sl. No.	Name	Co-ordinates	AE units
	Northern region		
1	Regional Agricultural Research Station, Pilicode	13 ^{0}N/ 75 ^{0}E	VI
2	Pepper Research Station, Panniyur	12.0809 ^{0} N/ 75.3991^{0} E	V
	High range zone		
3	Regional Agricultural Research Station, Ambalavayal	11.6168 ^{0}N/ 76.2141^{0}E	XIII
4	Cardamom Research Station, Pampadumpara	9^{0} 47’56’’N/ 77^{0} 9’42’’E	XIII
	Central zone		
5	Regional Agricultural Research Station, Pattambi	10.8114 ^{0}N/ 76.1904 ^{0}E	IV
6	Agronomic Research Station, Chalakudy	10.3105 °N/ 76.3357 °E	IV
7	Cashew Research Station, Madakkathara	10.5504 ^{0}N/ 76.2658 ^{0}E	IV
8	Agricultural Research Station, Anakkayam	11.08986 ^{0}N/ 76.12038 ^{0}E	VI

9	Aromatic & Medicinal Plants Research Station, Odakkali	10.0870 °N/ 76.3885 °E	IV
10	Pineapple Research Station, Vazhakulam	9.9435 ^{0}N/ 76.3684 ^{0}E	IV
11	Agricultural Research Station, Mannuthy	10^{0}32’ N / 76^{0}16’ E	IV
12	Plant Propagation & Nursery Management Unit, Vellanikkara	10.5492 °N/ 76.2188 °E	IV
13	Banana Research Station, Kannara	10 ^{0}N/ 76 ^{0}E	IV

Special zone of problem areas

14	Regional Agricultural Research Station, Kumarakom	9^{0}3’ N/ 76^{0}3’ E	XI
15	Rice Research Station, Vyttila	9.97 ^{0}N/ 76.32 ^{0}E	IV
16	M.S. Swaminathan Rice Research Station, Moncompu	9.7240 °N/ 76.3452 °E	XI
17	Agricultural Research Station, Thiruvalla	9^{0}24’ N/ 76^{0}41’ E	III

Onattukara zone

18	Onattukara Regional Agricultural Research Station, Kayamkulam	9.1790 °N/ 76.5000 °E	I

Southern zone

19	Regional Agriculture Research Station, Vellayani	8^{0}25’45’’ N/ 76^{0}59’18’’ E	III
20	Integrated Farming Systems Research Station, Karamana	8.4736 ^{0}N/ 76.9614 ^{0}E	III
21	Coconut Research Station, Balaramapuram	8.4 ^{0}N/ 77.0291^{0}E	III
22	Farming Systems Research Station, Sadanandapuram	8.9815 ^{0}N/ 76.8109 ^{0}E	III

Colleges

23	College of Agriculture, Vellayani	8^{0}25’45’’ N/ 76^{0}59’18’’ E	III
24	College of Agriculture, Vellanikkara	10^{0}32’53’’ N / 76^{0}16’58’’ E	IV

25	College of Agriculture, Padannakkad	12^{0}15’30’’ N/ 75^{0}07’ E	VI
26	College of Forestry, Vellanikkara	10^{0}32’53’’ N / 76^{0}16’58’’ E	IV
27	College of Co-operation, Banking & Management, Vellanikkara	10^{0}32’53’’ N / 76^{0}16’58’’ E	IV
28	Kelappaji College of Agricultural Engineering & Technology, Tavanur	10^{0} 51’ N/ 75^{0} 58’ E	VI
29	College of Climate Change and Environmental Science, Vellanikkara	10^{0}32’53’’ N / 76^{0}16’58’’ E	IV
30	Institute of Agriculture Technology & RARS, Pattambi	10.8114 ^{0}N/76.1904 ^{0}E	IV
31	College of Agriculture, Wayanad	11.6168 ^{0}N/ 76.2141^{0}E	XIII

(AE units are appended in appendix I)

3.2 DESCRIPTION OF SELECTED SITES

Out of all the institutes of Kerala Agricultural University (KAU), the selected sites for agrivoltaics are RARS Pattambi and KCAET Tavanur. The sites at RARS Pattambi and KCAET Tavanur were chosen for agrivoltaics based on several key factors such as sunshine hours, available area, crops, etc., both locations benefit from approximately 5-6 hours of daily peak sunshine, ensuring optimal conditions for photovoltaic (PV) energy production. Ample area was available at these sites which allows for the installation of a substantial PV system, accommodating both ground-mounted panels and potentially rooftop installations on existing structures like poly houses and rain shelters. Moreover, the presence of plain topography facilitates the effective deployment and operation of the agrivoltaic system, maximizing energy output and agricultural productivity. These factors collectively contribute to the suitability of RARS Pattambi and KCAET Tavanur for implementing agrivoltaics, effectively meeting the energy requirements of the respective campuses while promoting sustainable practices and research within Kerala Agricultural University (KAU).

Site 1: Regional Agricultural Research Station Pattambi, (10.8114 °N, 76.1904 °E)

The Regional Agricultural Research Station (RARS) located in Pattambi, Kerala, covering an area of 64.1435 ha, has a prominent agricultural research facility for the development of innovative farming practices and technologies suited to the region's unique agro-climatic conditions. This station is situated in the Palakkad district, this research station covers extensive agricultural land, strategically chosen for its diverse soil types and favorable climate, which were representative of the typical farming conditions in Kerala.

RARS Pattambi specializes in a variety of crops, with significant focus on rice, coconut, and a range of horticultural plants. The station encompasses a variety of research plots, greenhouses, and experimental fields where advanced agronomic techniques were tested and refined.

The Regional Agricultural Research Station (RARS) in Pattambi, Kerala, presents a promising site for the implementation of agrivoltaics, integrating solar energy production with agricultural activities. Pattambi experiences a tropical climate with abundant sunshine, especially during the non-monsoon months. The high levels of solar irradiance are ideal for photovoltaic (PV) panel efficiency, ensuring substantial energy production throughout the year. The integration of solar panels with agricultural activities can enhance land use efficiency, provide renewable energy, and support sustainable agricultural practices, contributing to the overall goal of sustainable development in the region.

Here, no roof area is available for the installation of solar panels. The extensive farm area features a 1.7 km long canal as shown in Fig.3.1, offering an ideal location for the installation of an agri-photovoltaic (APV) system. This innovative system holds significant potential for energy production while simultaneously reducing evaporation losses from the canal. By harnessing solar power in this dual-purpose manner, the farm can enhance its sustainability and resource efficiency. The APV system was designed according to the requirement of RARS Pattambi.

Fig.3.1 Google Earth picture of 1.7 km long canal in RARS Pattambi

Site 2: KCAET Tavanur

Kelappaji College of Agricultural Engineering and Technology (KCAET) is located in Tavanur village (10^0 51’ North latitude and 75^0 58’ East Longitude) in Malappuram district. The campus covers a vast area of 40 hectares. It is located near the Bharathapuzha river and has a wide variety of crops. This place is 7 km west of Kuttippuram Railway Station and 12 km north of Ponnani. The campus is characterized by a sloped topography and has sandy loam soil. The campus area is covered by academic block, labs, ground, volleyball court, KVK Malappuram, KCAET farm, ponds, polyhouses, rain shelters, hostels, staff quarters and areas covered with trees.

Fig.3.2 Google Earth picture of KCAET

Fig.3.3 Google Earth picture of farm area

The major crops in farm includes paddy, coconut, vegetables (okra, spinach, ginger, turmeric, beans, cucumber, bottle gourd, fodder crops etc.). It also has a nursery with a variety of fruits and vegetables. Cattle farm is also present here. Crops chosen for the study were selected based on their compatibility with partial shading conditions. Common crops included leafy greens, root vegetables, and legumes. Standard agricultural practices were followed, including soil preparation, planting, irrigation, and pest management. Crop growth, yield, and health were monitored regularly to evaluate the impact of the PV panels on agricultural productivity. The suitable area for agrivoltaic implementation in KCAET was identified as shown in Fig.3.2 and Fig.3.3.

3.3 DESIGN CONSIDERATION

Following are the components and design considerations regarding crop cultivation conditions from agronomic aspects for agrivoltaics systems.

3.3.1 Components of agrivoltaics system

The agrivoltaic system is comprised of several essential components that work to ensure the efficient working of solar energy production and agricultural activities. These components include solar panels, mounting structures, inverters, monitoring systems, etc., each playing a crucial role in maximizing land productivity and optimizing resource utilization.

3.3.1.1 Solar panel

A solar panel is a device that converts sunlight into electricity through the photovoltaic effect. There are various types of solar panels available having varying characteristics like efficiency, power, durability, warranty, size, area, power per square meter, weight, and cost.

3.3.1.1.1 Photovoltaic effect

The process of conversion of light to electricity is called the photovoltaic effect. The photovoltaic effect can be defined as being the appearance of a potential difference (voltage) between two layers of a semiconductor slice in which the conductivities are opposite, or between a semiconductor and a metal, under the effect of a light stream (Fig.3.4).

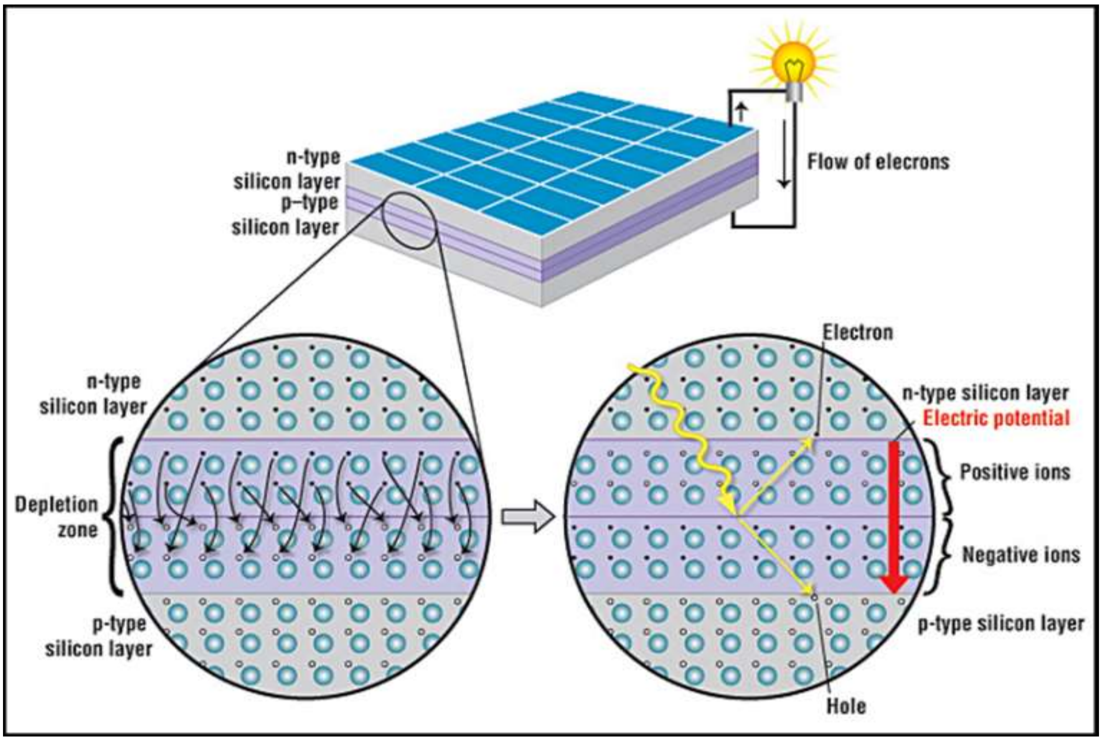


Fig.3.4 Photovoltaic effect

3.3.1.1.2 PV Cell, Modules, Arrays

A single PV device is known as a cell. An individual PV cell is usually small (1 or 2 watts of power) and it is made of different semiconductor materials. Cells are sandwiched between protective materials in a combination of glass and/or plastics. To boost the power output of PV cells, they are connected together in chains to form larger units known as modules or panels and arrays.

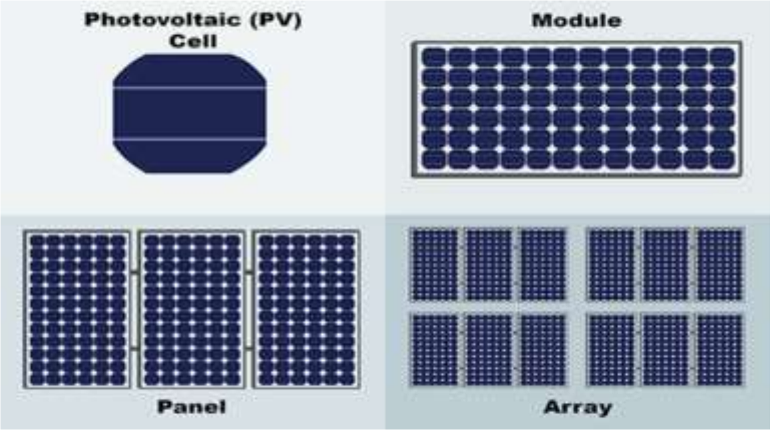


Fig.3.5 PV Cells, Module, Arrays and Panels

3.3.1.1.3 Types of Si solar cell

There are mainly three types of solar cells which are namely crystalline silicon solar cell, amorphous silicon solar cell and polycrystalline silicon solar cell. Crystalline Silicon solar cell have repeating arrangements of atoms which have equal spacing between the atoms. Amorphous Silicon solar cell have no such repetitive arrangement is there between the atoms. Atoms are randomly arranged. Polycrystalline Silicon solar cell have crystalline phases in patches separated by grain boundaries.

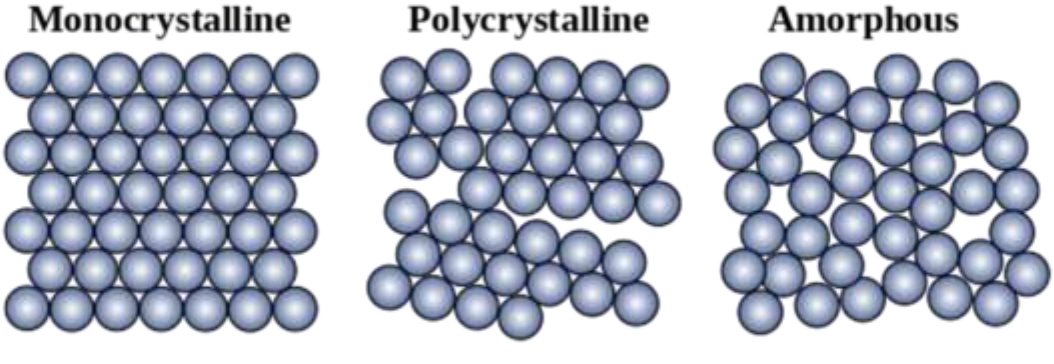


Fig.3.6 Types of Si solar cells

Crystalline Silicon solar cells are composed of silicon atoms bonded together to form a crystal lattice structure. This arrangement allows them to efficiently capture and convert sunlight into electricity through the photovoltaic effect. There are two main types of silicon solar cells: polycrystalline silicon and monocrystalline silicon.

Polycrystalline silicon cells are fabricated by melting multiple silicon crystals together, resulting in a material with varied crystal orientations. In contrast, monocrystalline silicon cells are made from a single, continuous crystal structure, ensuring uniformity throughout the material. While both types harness the photovoltaic effect to generate electricity, monocrystalline silicon cells typically exhibit higher efficiency and better performance in low-light conditions due to their uniform crystal structure.

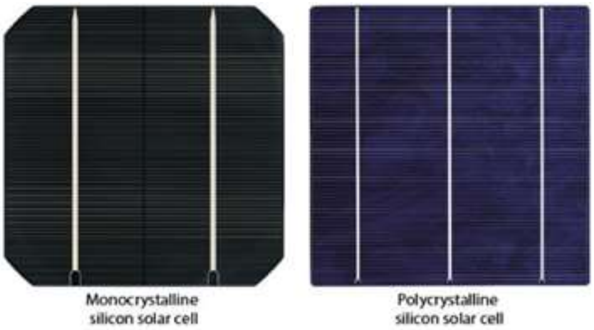


Fig.3.7 Types of crystalline solar cells

Nowadays more efficient cells are in the market like Mono PERC (Passivated Emitter and Rear Cell) solar cells. These cells enhance the efficiency and performance of standard monocrystalline solar panels. PERC technology involves adding a passivation layer to the rear side of the solar cells. This layer reflects some of the light that passes through the cell back into it, giving the cell a second chance to convert that light into electricity. This process enhances the overall efficiency of the cell.

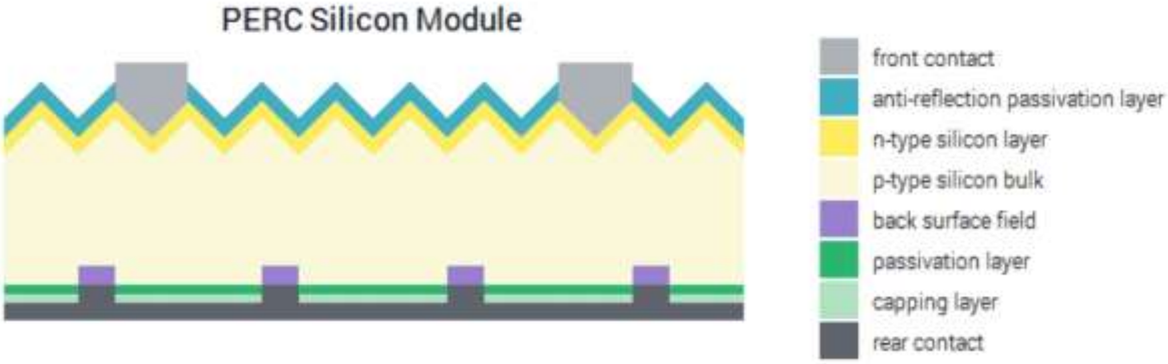


Fig.3.8 Structure of Mono PERC solar cell

Following layers are present in the Mono PERC solar cell:

1. Front Contact (Grid or Fingers): Collects and transports the electric current generated by the cell. Material used are Silver (Ag) or aluminum (Al).

2. Anti-Reflective Coating (ARC): Reduces the reflection of sunlight off the cell surface, increasing the amount of light absorbed by the silicon. Material used are Silicon nitride (SiN_x) or titanium dioxide (TiO_2).

3. Emitter Layer: Creates a p-n junction with the base layer, essential for the cell’s operation. This layer is very thin. Material used are heavily doped n-type silicon (for n-type cells) or p-type silicon (for p-type cells).

4. Base Layer: Forms the main body of the cell where most light absorption and electron-hole pair generation occur. This layer is thicker, typically a few hundred micrometers. Material used are lightly doped p-type silicon (for p-type cells) or n-type silicon (for n-type cells).

5. Passivation Layer: Reduces surface recombination of carriers (electrons and holes), improving the cell's efficiency. Material used are Silicon dioxide (SiO_2) or aluminum oxide (Al_2O_3).

6. Back Surface Field (BSF) Layer: Reduces recombination of charge carriers at the back surface and reflects minority carriers back into the base layer, enhancing efficiency. Material used are heavily doped p-type or n-type silicon.

7. Back Contact: Collects and conducts the current generated by the cell to the external circuit. This layer covers the entire backside of the cell. Material used are Aluminum (Al) or silver (Ag).

Table 3.2 Specifications of selected panel

Cell type	210 mm-12 BB Mono PERC crystalline
Dimension	2384 x 1096 x 35 mm
Weight	28.25 kg
P_{max} (Maximum Power)	555 W
Efficiency	21.25 %
Model	CS-QU555-110
V_{oc} (Open Circuit Voltage)	37.85 V
V_{mp} (Max. Power Voltage)	31.90 V
I_{mp} (Max. Power Current)	17.45 A
I_{sc} (Short Circuit Current)	18.55 A

3.3.1.1.4 Types of grid system

Currently three grid systems are followed which are on grid, off grid and hybrid grid systems.

1. On grid

These are connected to the power grid. This system is ideal for balancing power production. Solar energy fluctuates based on weather conditions, time of day. If solar energy is low, user can use the energy grid to power their home. If solar produces excess energy, user can send this energy back to the grid for a credit on their electric bill.

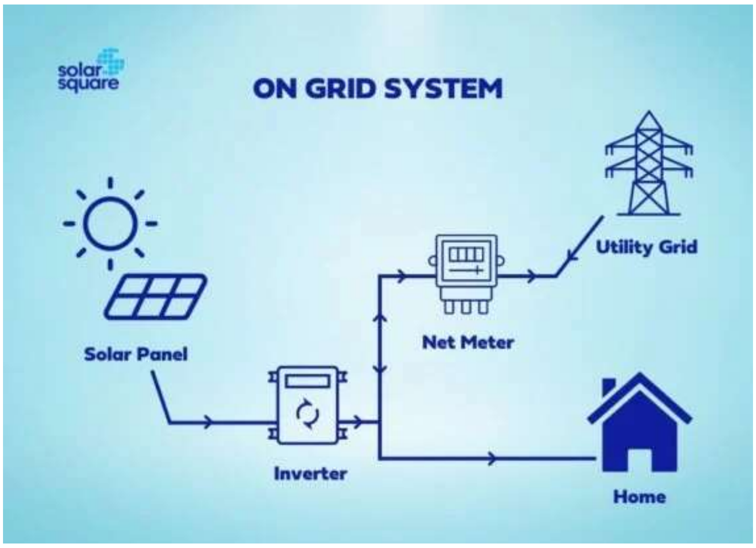


Fig.3.9 On Grid system

2. Off grid

Off-grid solar systems are not connected to an electric grid, and utilize battery storage systems to balance energy demands. Houses with off-grid systems rely entirely on solar energy. Batteries are necessary with such systems. The battery system stores excess electricity produced during the day, which can then be used at night to keep the lights on. Off-grid systems offer complete energy independence.

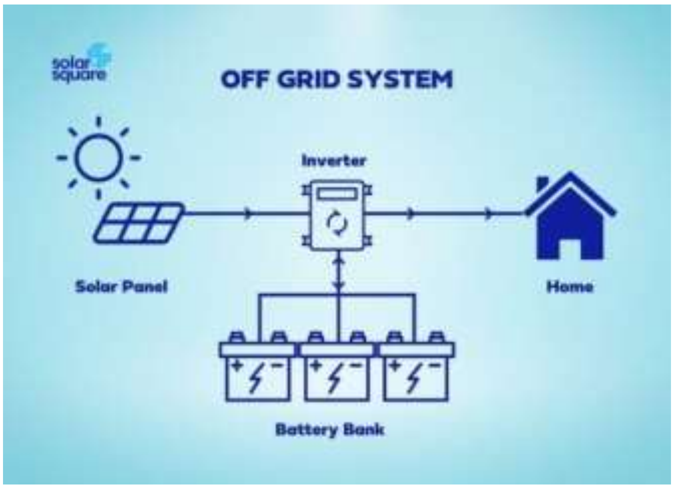


Fig.3.10 Off Grid system

3. Hybrid solar system

A hybrid solar system is a combination of grid tied and off grid. These systems are connected to the power grid and come equipped with their own battery storage system. Hybrid systems are the most flexible option available, offering the ability to draw energy from the grid or from the battery when needed.

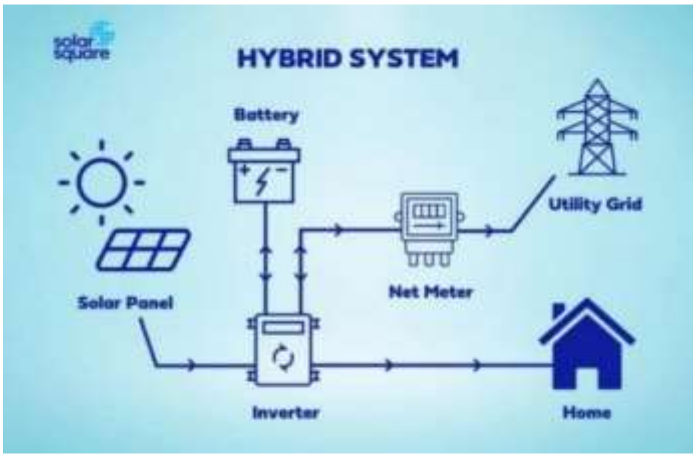


Fig.3.11 Hybrid system

3.3.2 Design parameters

When designing an APV System, it is crucial to take into account several key design parameters to ensure optimal performance and efficiency. These considerations include land equivalent ratio, shading ratio, crop planting distance, farm work under the system, tilt angle and solar panel.

3.3.2.1 Land Equivalent Ratio

LER is an index used to evaluate the dual-use efficiency of land for crop cultivation and solar energy generation

$$\text{LER} = \frac{FM_{AVS}}{FM_C} + \frac{E_{AVS}}{E_C}$$

Where, FM_{AVS} and FM_C are the fresh biomass in the AVS and control (conventional cultivation in open field), respectively, and E_{AVS} and E_C are the electricity production in the AVS and control, respectively. LER should be maximised for the development of an AVS in a smart farm that optimises land-use efficiency. Its value should be greater than 1.0, typically between 1.2 and 1.5 (Lee *et al*., 2023).

3.3.2.2 Shading ratio (SR)

The amount of solar radiation reaching the ground is reduced when an AVS is installed, which can decrease crop production as these two factors are strongly correlated. The solar radiation under AVSs depends on SR, which is defined as the ratio between the area of PV modules (A_{PV}) and farmland area in the system (A_{system}):

$$\text{SR} = \frac{A_{PV}}{A_{System}}$$

SR may be derived differently depending on the tilting angle of the PV module as it is calculated using the area of modules projected vertically on the ground surface in some cases (Lee *et al*., 2023).

3.3.2.3 Crop planting distance

Each crop type has a recommended planting distance; hence, it is necessary to determine the column spacing of the AVS structure based on these planting distances. In upland fields, spacing should be set according to the size of the furrows in the paved planting area. In orchards, it is essential to design a system that is suitable for planting distances because the fruit trees are maintained for several years after planting. Additionally, the column spacing should be adjusted during detailed design and on-site construction (Lee *et al*., 2023).

3.3.2.4 Farm work under the system

The column spacing and height must be adjusted to enable the use of machines for agricultural work. In particular, turning should be possible for tractors under the system. Weselek *et al*. reviewed several studies and concluded that a column distance between 4 and 5 m is required for large combine harvesters to pass (Lee *et al*., 2023).

3.3.2.5 Tilt angle

The optimal tilt angle of a solar panel basically depends on two factors i.e., the latitude of the installation place geographically and the season with more energy requirement.

When the solar panel is placed perpendicular to the sun, it produces more electricity. Certainly, the best position in the countries of southern hemisphere is facing the NORTH, and in the countries of the northern hemisphere, it is south. The maximum energy is produced when the sun reaches its highest altitude on the horizon. To determine the parameters for positioning the solar panel based on latitude, it is necessary to know the longest and the shortest sunny days. The optimal tilt angle is determined by adding 15 degrees to the area's latitude in the winter and subtracting 15 degrees from the area's latitude in the summer (Anonymous, 2015).

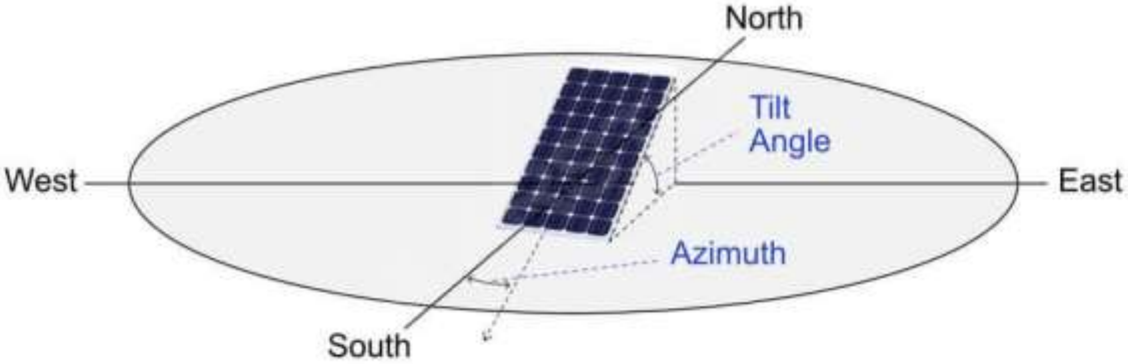


Fig.3.12 Southern orientation of panels

3.4 METEOROLOGICAL DATA

Meteorological data plays a crucial role in the study and implementation of agrivoltaic system. Understanding the local climate conditions is essential for optimizing both crop growth and photovoltaic efficiency. This section includes the climatic conditions of the region such as temperature, precipitation and sunshine hours.

These factors directly influence both plant physiology and the performance of photovoltaic panels. For instance, solar radiation affects photosynthesis and energy generation, while temperature and humidity impact crop health and panel efficiency. Wind speed and precipitation data are also vital for designing resilient agrivoltaics systems that can withstand extreme weather conditions.

3.4.1 Hours of sunshine

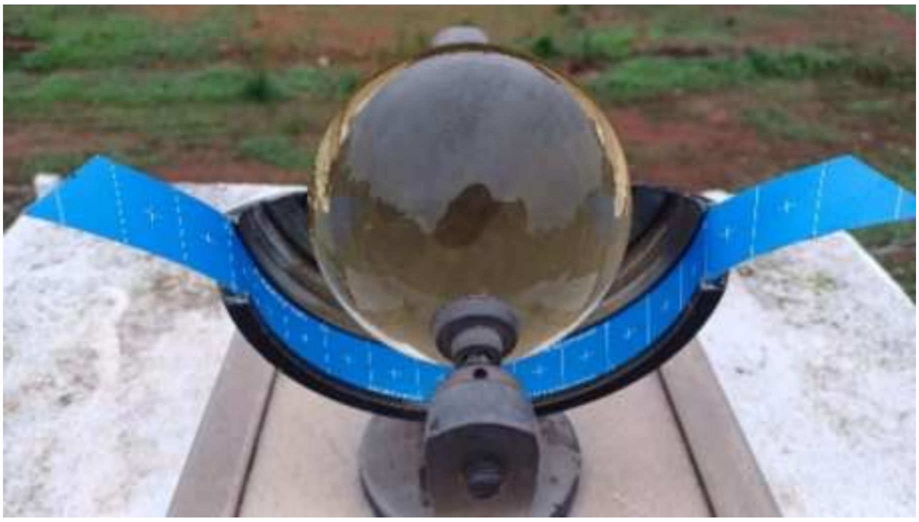


Plate.3.1 Sunshine recorder

Sunshine hours directly influence both solar energy production and crop growth. Adequate sunshine ensures optimal photovoltaic panel performance, maximizing energy yield. Simultaneously, crops require sufficient sunlight for photosynthesis, impacting their health and productivity.

In agrivoltaic system, careful management is essential to balance the shading effects of solar panels with the light needs of crops. Monitoring and optimizing sunshine hours are thus key to the successful integration of agrivoltaics. A sunshine recorder is a device that records the amount of sunshine at a given location or region at any time.

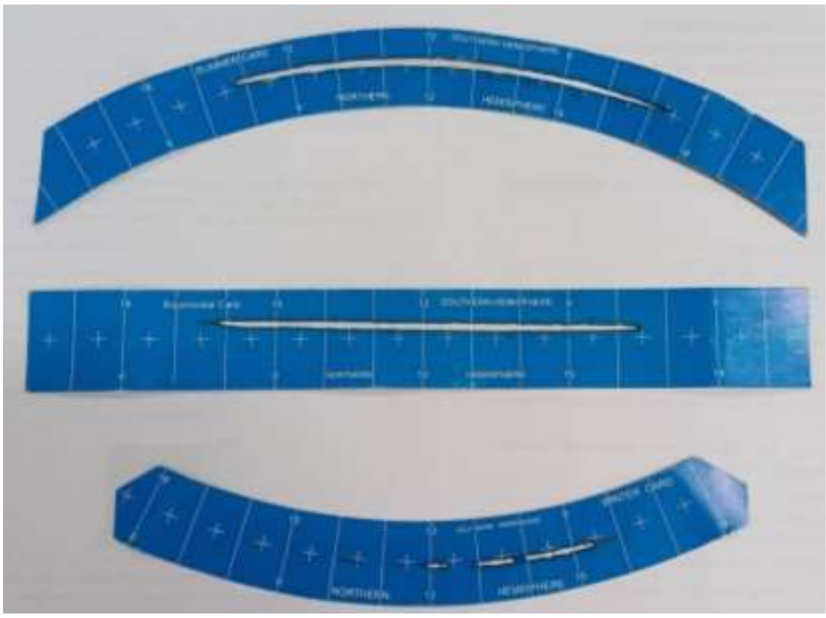


Plate.3.2 Sunshine recorder card

3.4.2 Temperature

Temperature management is essential for optimizing crop growth and energy generation. Elevated temperatures can influence crop physiology, potentially affecting photosynthesis, respiration, and water uptake. Additionally, excessive heat can lead to stress and reduced yield in certain crops. Conversely, PV panels are sensitive to temperature changes, with their efficiency decreasing as temperatures rise. High temperatures can cause thermal losses and reduce the electrical output of the panels.

3.4.3 Precipitation

Heavy and persistent rainfall may reduce solar irradiance, thereby decreasing power generation. Optimal agrivoltaic design should consider local precipitation patterns to balance water needs for crops and maximize solar energy production, promoting sustainable dual land use.

3.5 PLANNING AND LAYOUT

This section of the report analyses the design principles essential for optimizing land use, ensuring both crops and photovoltaic panels operate efficiently and sustainably. Based on the preliminary study conducted at RARS Pattambi and KCAET Tavanur, it was observed that the necessity for this system was greater at RARS Pattambi. At

KCAET, a proposal for a 100 kW PV system had already been approved, and the system is about to be installed. Therefore, we mainly focused our study on RARS Pattambi.

3.5.1 Design of Agrivoltaic System for RARS Pattambi

The proposed design for the Regional Agricultural Research Station (RARS) in Pattambi aims to optimize both crop yield and energy generation. It includes load calculation and design of PV system for the bank of a canal which is the only available area.

3.5.1.1 Load calculation

The dead load, live load and wind load were calculated to ensure that the structural stability of the structure to ensure it is strong enough to support the entire system. The design of the supporting structure was done based on the load parameters.

3.5.1.1.1 Dead load calculation

The dead load includes loads that are relatively constant over time, including the weight of the structure itself. Dead loads are also known as permanent or static loads. The weight of solar panel is dominant dead load in design of solar mounting structure. This calculation of load is invariant hence can be calculated accurately. Clamps, bolts, weight were in negligible amount hence the clamping equipment’s weight is neglected (Panjawani *et al*., 2020).

Dead load on the purlin and rafter = Weight of one solar panel x No. of solar panel

3.5.1.1.2 Live load calculation

Live load is a civil engineering term that refers to a load that can change over time. The weight of the load is variable or shifts locations, such as when people are walking around in a building. Anything in a building that is not fixed to the structure can result in a live load, since it can be moved around. So, the live load on solar panel is also needed to be considered for design calculations (Panjawani *et al*., 2020).

3.5.1.1.3 Wind load calculations

Wind load on the structure is calculated by using following formula

$$P_{wind} = 0.6 \text{ x } V^2$$

Where, V is the basic wind velocity which is obtained from map of India showing basic wind speed given in Fig.3.13.

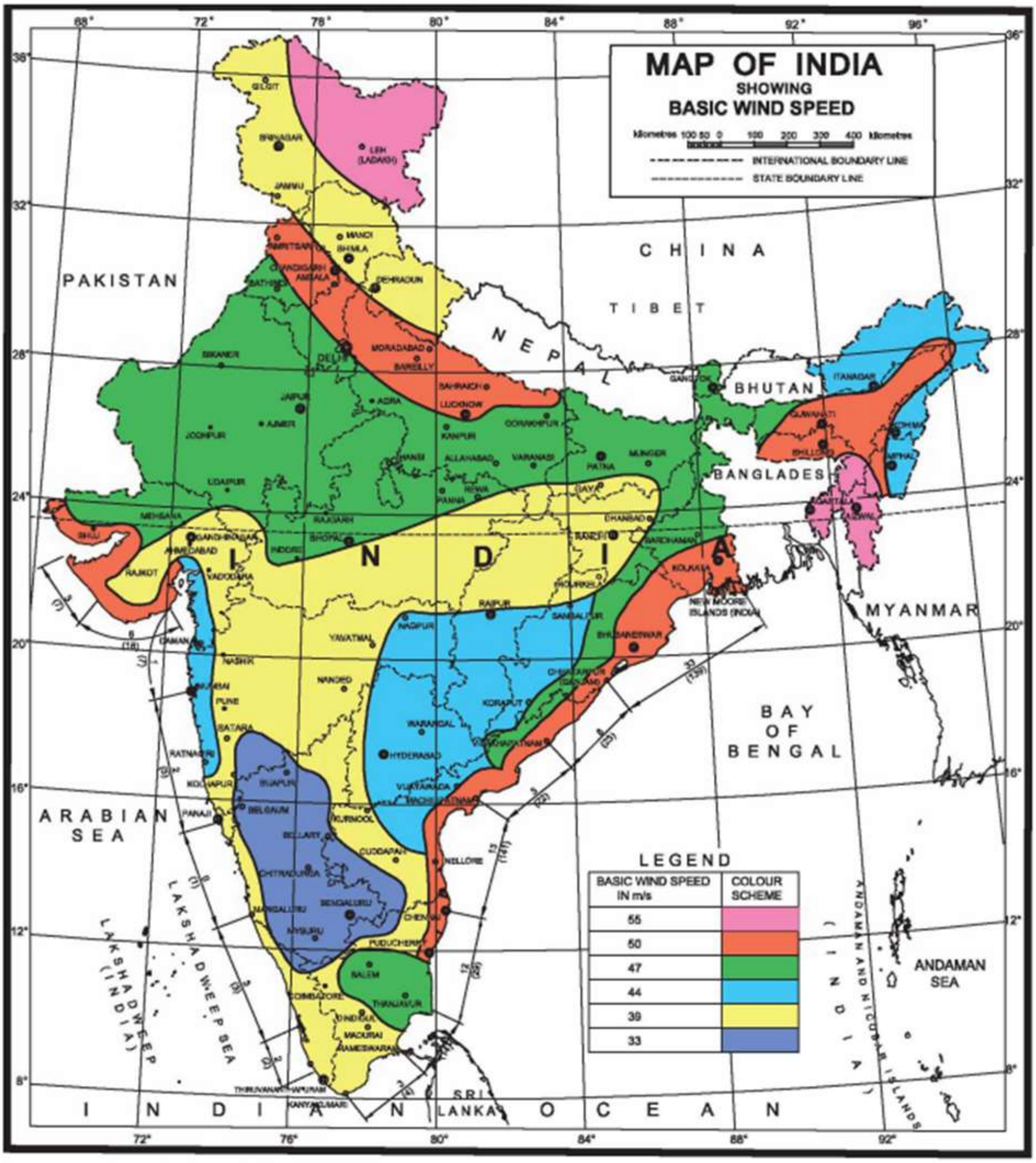


Fig.3.13 Map of India showing basic wind speed

3.5.1.1.4 Design velocity

Design velocity for a structure typically refers to the maximum expected wind speed that the structure is designed to withstand. This is crucial for determining the structural integrity and safety of buildings, bridges, towers, and other constructions against wind loads.

Design velocity, V_d can be calculated by using the equation

$$V_d = k_1 \times k_2 \times k_3 \times V$$

From IS: 875 (part 3) – 1987, values of k_1, k_2 and k_3 were taken.

k_1 =Risk coefficient or probability factor.

k_2 = Terrain, height and structure size factor.

k_3 = Topography factor. Its value is taken as unity, if the slope of ground is $< 3^0$.

While calculating design velocity the k_3 is taken as unity.

Design velocity, $V_d = k_1 \times k_2 \times k_3 \times V$

Projected area, $Ae = A \times \sin\alpha$

$$F_{wind} = Ae \times P_{wind}$$

3.5.1.1.5 Total load

Partial factor of safety for loads, for limit states Limit state is a condition just before collapse. A structure designed by limit state should give proper strength and serviceability throughout its life. In limit state method, the limit state of collapse deals with the safety of structure and limit state of serviceability deals with the durability of structure. Serviceability refers to the conditions under which a building is still considered useful. Should these limit states be exceeded, a structure that may still be structurally sound would nevertheless be considered unfit (Panjawani *et al.*, 2020).

$$TL = DL + LL + WL$$

3.5.1.2 Solar PV System Design

Following assumptions were made for designing the APV system regarding its operational parameters and efficiency factors. It was assumed that the daily sunlight available for PV panel operation would be approximately 5 hours, representing peak radiation conditions. The PV panels themselves are rated at 555 Wp (watt peak), which denotes their peak power output under ideal conditions. The operational hours for the PV panels were set at 5 hours per day. To estimate the actual output from the PV modules, an operating factor was applied, typically ranging between 0.60 and 0.90. This factor indicates that the output power could be 60% to 90% lower than the rated output power, depending on factors such as temperature variations and the presence of dust on the panels. Additionally, the overall efficiency of the system, including both the inverter and battery, was considered as the product of their individual efficiencies. These assumptions collectively inform the design and expected performance of the solar energy system under normal operating conditions.

3.5.1.2.1 ON Grid system

The determination of total capacity in a plant is based on dividing the total unit consumption per day by the average daily production. It establishes the amount of energy needed relative to what can be reliably generated. Given that 1 kW of energy can typically be produced from 2 panels, the calculation for the total number of panels required involves multiplying the total capacity in a plant by 2. This ensures that the plant can effectively meet its energy demands with adequate production capacity.

3.5.1.2.2 OFF Grid system

The total energy requirement of the PV panel system, or total load, is calculated by multiplying the total connected load (in watts) by the operating hours. This yields the total watt-hours rating of the system, reflecting the amount of energy needed over the specified period. To determine the actual power output of a PV panel, multiply its peak power rating by the operating factor, which accounts for real-world conditions such as temperature and dust affecting performance. Since the combined efficiency of the system, which includes both the inverter and battery, results in some energy loss, the power available for end use is reduced. This adjusted power output of a panel is then multiplied by the combined efficiency factor to estimate the usable energy.

The daily energy production of one 555 Wp panel is calculated by multiplying its actual power output by the equivalent of 5 hours of peak sunlight per day. To determine the number of solar panels required to meet a given estimated daily load, divide the total watt-hour rating of the daily load by the daily energy produced by a single panel. This calculation ensures that the system is designed to reliably meet the daily energy demands while accounting for real-world efficiency and operational factors. An ON Grid system is ideal for RARS Pattambi.

3.7 ESTIMATION OF NUMBER OF SOLAR PANELS REQUIRED

A Python program was developed to calculate the number of solar panels required to meet a specific plant capacity. This program takes the total unit consumption per day (in kilowatts) as input and computes the number of panels needed accordingly.

The program prompts the user to input the total unit consumption of the plant in kilowatts. It then calculates the plant capacity by dividing the total connected load by 4. To ensure a whole number of panels, the program rounds up the plant capacity to the nearest whole number.

This tool is designed to facilitate the planning and implementation of solar energy systems by providing an accurate and efficient method for calculating the required number of solar panels. It aids decision-makers in evaluating the feasibility and scale of solar installations, promoting the adoption of sustainable energy practices.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

4.1 SITE SELECTION CRITERIA FOR AGRIVOLTAICS

The data on various crops and the cultivated areas at different stations under KAU was collected to identify suitable crops and available space for the installation of agrivoltaic systems. Table 4.1 provides a comprehensive overview of these agricultural research stations across different regions, highlighting their respective crop areas in hectares (ha). This information was vital for planning and optimizing resource allocation, crop management, and research initiatives, ultimately enhancing agricultural productivity and sustainability for agrivoltaics.

Table 4.1 Crop area data of sites

Sl. No.	Name	Crop Area (ha)
1	Regional Agricultural Research Station, Pilicode	57.87
2	Pepper Research Station, Panniyur	
3	Regional Agricultural Research Station, Ambalavayal	
4	Cardamom Research Station, Pampadumpara	
5	Regional Agricultural Research Station, Pattambi	66
6	Agronomic Research Station, Chalakudy	2.145 (Paddy 0.66, Cowpea 0.663, ridgegourd/ashgourd 0.20, snakegourd 0.200, Pumpkin 0.354, cucumber 0.068)
7	Cashew Research Station, Madakkathara	47 ha Cashew: 36.42
8	Agricultural Research Station, Anakkayam	10 ha (Cashew Coconut polyhouse 1:0.15 polyhouse 2: 0.07)

9	Aromatic & Medicinal Plants Research Station, Odakkali	12.5
10	Pineapple Research Station, Vazhakulam	
11	Agricultural Research Station, Mannuthy	28
12	Plant Propagation & Nursery Management Unit, Vellanikkara	
13	Banana Research Station, Kannara	17.3
14	Regional Agricultural Research Station, Kumarakom	44.76 (Coconut, Banana, Pepper)
15	Rice Research Station, Vyttila	8.91
16	M.S. Swaminathan Rice Research Station, Moncompu	8.57
17	Agricultural Research Station, Thiruvalla	9.2 (Sugarane: 5 Snake gourd: 0.2 Bitter gourd: 0.2 Cow pea: 0.2 Spinach: 0.2, Brinjal: 0.2, Chilli: 0.2)
18	Onattukara Regional Agricultural Research Station, Kayamkulam	
19	Regional Agriculture Research Station, Vellayani	
20	Integrated Farming Systems Research Station, Karamana	7.6 ha (Rice: 4, Banana, coconut, banana, vegetable terrace: 0.1)
21	Coconut Research Station, Balaramapuram	14.13
22	Farming Systems Research Station, Sadanandapuram	8.96

4.2 DESCRIPTION OF SELECTED SITE

The selected site for implementing agrivoltaics at RARS Pattambi was well-suited due to its expansive landscape and favorable tropical climate. Spanning 3.201 acres at KCAET Tavanur, the site offered ample space to integrate solar panels with agricultural activities, maximizing land use efficiency. Google Earth images of both selected sites are shown in Fig. 4.1. The region experienced abundant sunshine, particularly during non-monsoon months, which was ideal for photovoltaic (PV) panel efficiency and ensured consistent energy production throughout the year. The integration of agrivoltaics there not only addressed the energy requirements of the entire campus, including the farm and academic block, but also presented opportunities to cultivate plants suitable for growing under and around solar panels. This dual-use approach optimized land productivity while promoting sustainable energy practices.

Fig.4.1 Google Earth image of location of site

4.3 METEOROLOGICAL DATA

Sunshine hours, temperature, and precipitation data of Palakkad for the year 2023 was collected. This data was thoroughly analyzed for the design and integration of the solar photovoltaic system into agriculture.

4.3.1 Sunshine hours

To find suitable areas for agrivoltaics, the annual sunshine duration was measured using a sunshine recorder. This device recorded the amount of sunshine at a given location or region, providing information about the weather, climate, and temperature of a geographical area. The sunshine duration in hours for 2023 is shown in Fig. 4.2.

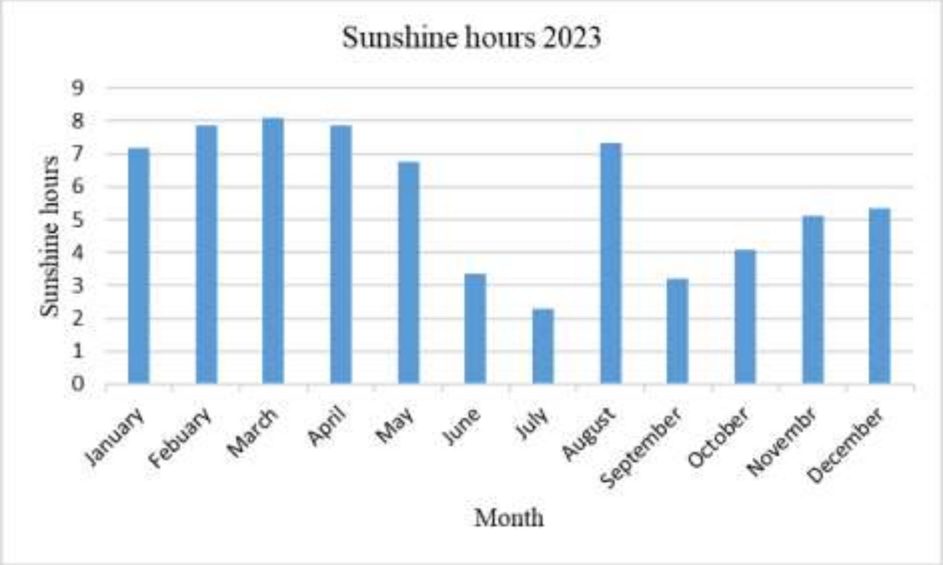


Fig.4.2 Average sunshine hours of the year 2023

From the graph, it was observed that the maximum hours of sunshine was obtained in the months of February, March, and April, while the least was obtained in June and July. The energy production by agrivoltaics was maximized during the months with the highest sunshine hours and decreased with the reduction in hours of peak sunshine.

4.3.2 Temperature

According to data from the Indian Meteorological Department (IMD) shown in Fig. 4.3, the temperature in Palakkad for the year 2023 showed seasonal variations. July had the lowest temperature, while February, March, April, and May had the highest temperature. On an annual basis, temperature showed slight variation.

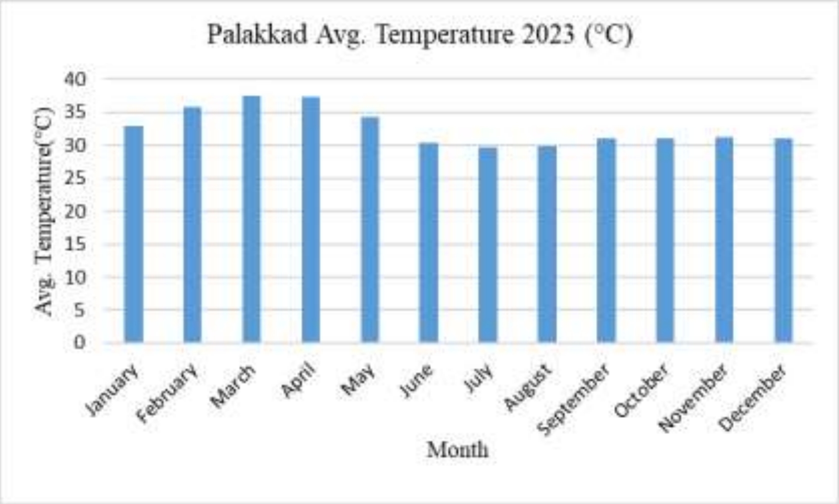


Fig.4.3 Temperature data of Palakkad

The temperature has a negative effect on energy production. As the temperature increases above optimum working temperature, the efficiency of panels will also reduce at a rate of 0.05% per ^{0}C increase of temperature.

4.3.3 Precipitation

The precipitation data of Palakkad district for the year 2023 is shown in Fig.4.4.

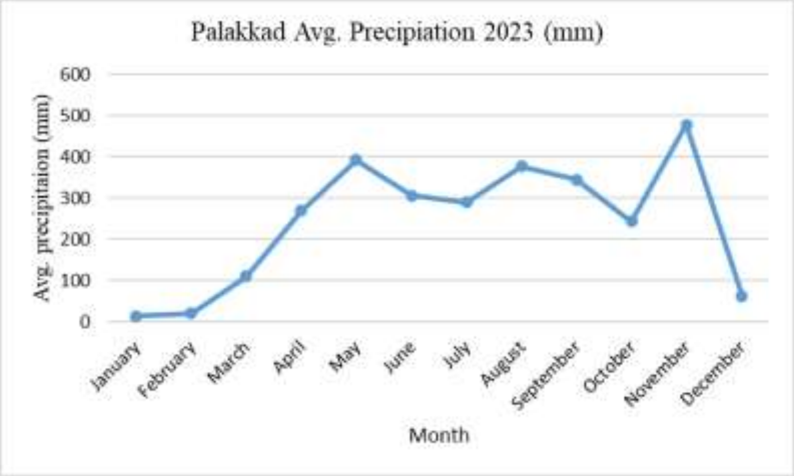


Fig.4.4 Precipitation data of Palakkad

It was observed from the graph that May and November were notable for their frequent rainfall, while February and March typically experienced fewer rainy days. The precipitation data provided information about cloud cover, which affected solar radiation and energy production. This allowed for better financial and operational planning. From the graph, it was observed that the months of February and March had less cloud cover and would give the highest energy output.

4.4 PLANNING AND LAYOUT

The design of agrivoltaic system was done by estimating the number of solar panels required by considering the total energy requirement and the estimation of the total load of the system. Operational efficiency, ability of the system to meet the energy requirement and structural stability was ensured by designing in accordance with the energy requirement and total system load.

4.4.1 Solar PV System Design

The estimation of the number of panels required was done by considering the total energy that needed to be produced by the system. For this, annual power consumption was taken and the system was designed to meet this energy requirement. The total energy requirement of the system (total load), i.e., total unit consumption per annum was 156,810 units. (Energy requirement i.e., total load value was obtained from the energy audit of RARS Pattambi appended in appendix II)

(1 unit = 1000 W)

From this, the average energy requirement per day was calculated by the formula,

Energy required for 1 day = Annual energy consumption / 365

Energy required for 1 day = 156810/ 365 = 429.61 kW ≈ 500 kW

Average daily production in a plant = 4 kWh

The total required capacity of the plant was calculated using daily energy requirement and average daily production of the plant.

Total capacity of the plant = Energy required for 1 day / Average daily production

Total capacity of the plant = 500/ 4 = 125 kW

The power output of 1 panel is 555 W. 1 kW energy could be produced from 2 panels.

So, the total number of panels required to meet the demand = 125 x 2 = 250 panels.

The methodology employed to estimate the number of solar panels needed to meet the energy requirements of RARS Pattambi was thorough and based on the detailed energy audit provided in Appendix II. The calculations ensured that the average daily energy requirement was accurately determined and matched with the average production capacity of the solar panels. To satisfy the energy needs of RARS Pattambi, a solar plant with a capacity of 125 kW, consisting of 250 solar panels, was required. This ensured that the energy requirement was met efficiently through renewable solar energy, contributing to sustainable and cost-effective energy solutions.

4.4.2 Load calculation

The self-weight or the dead load of the solar panels was calculated to ensure structural stability, structural integrity, safety, and efficiency of the installation.
Weight of individual solar panel = 28.25 kg

Dimension of solar panel = 2.4 m x 1.1 m x 0.035 m

Number of solar panels used = 250

Area of solar panel = 2.64 m^2

Total area of solar panel = 660 m^2

Dead load on the purlin and rafter = Weight of one solar panel x no. of solar panel

= 28.25 x 250 = 7062.5 kg

Taking 1 kg = 9.81 N,

Total dead load of solar panels = 7062.5 x 9.81 =69283.125 N

Factor of safety = 1.5

Factor of safety (FoS) was used to ensure that structure can support load beyond the expected maximum, providing a margin of safety to account for uncertainties.

Load after considering factor of safety = 103924.69 N

4.4.2.1 Live load calculations

Live loads refer to temporary or dynamic loads that the system experience during its lifetime. These loads are not constant and can vary significantly, influencing the design and structural integrity of the PV system.

For this system, live load was considered as 20 Nm^{-2}.

4.4.2.2 Wind load calculations

The wind load was calculated using local IS codes and standards to determine load exerted by wind on the system. It was done by considering factors such as wind speed, panel tilt angle, building height, and surrounding terrain.

Area of solar panel = 2.64 m^2

Dimension of solar panel = 2.4 m x 1.1 m x 0.035 m

Total area of solar panel array = 660 m^2

Wind press on the structure is calculated by using following formula,

$$P_{\text{wind}} = 0.6 \times V^2$$

To select the basic velocity of air, the India wind zone map was studied. It showed that the maximum speed in different regions of India could reach up to 33 m/s to 50 m/s. Specifically, in Kerala state, the speeds varied between less than 33 m/s to 39 m/s.

Upon analyzing the data, for ensuring the satisfactory performance of structures in such critical conditions of maximum air velocity, particularly during storms, it was necessary to design them to withstand this force. The basic velocity of air V was determined to be 39 m/s.

4.4.2.3 Design velocity

Design velocity is the wind speed that the system is designed to withstand, considering the worst-case scenarios anticipated for the location of the installation. This ensures that the PV system can safely endure extreme weather conditions without structural failure. Design velocity was calculated based on local wind data, considering factors such as the terrain, surrounding buildings, and the height of the structure.

Table 4.2 Risk coefficients for different classes of structures in different wind speed zones

Class of structure	Mean probable design life of structure (years)	k_1 factor for basic wind speed					
		33	39	44	47	50	55
All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
Temporary shed, structures	5	0.82	0.76	0.73	0.71	0.70	1.67
Building and structures presenting a low degree of hazard to life and property in the event of failure	25	0.94	0.92	0.91	0.90	0.90	0.89
Important buildings and structure such as hospitals, communication towers, etc.	100	1.05	1.06	1.07	1.07	1.08	1.08

Design velocity, V_d= k1 x k2 x k3 x V

k_1 = For all general building and structures with a wind velocity of 39 ms^{-1}, it is 1. Various values of k_1 are given in Table 4.2.

k_2 = For terrain category 1 and class A structures, it is 1.05. A value of this coefficient is given in Table 4.3. Category 1 exposed open terrain with a few or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m. Class A are the structures and/or their components such as cladding, roofing etc., having maximum dimensions is less than 20 m above ground surface.

Table 4.3 k_2 factors to obtain design wind speed variation with height in different terrains

Height (z) (m)	Terrain and height multiplier (k_2)			
	Terrain Category 1	**Terrain Category 2**	**Terrain Category 3**	**Terrain Category 4**
10	1.05	1	0.91	0.8
15	1.09	1.05	0.97	0.8
20	1.12	1.07	1.01	0.8
30	1.15	1.12	1.06	0.97
50	1.2	1.17	1.12	1.1
100	1.26	1.24	1.2	1.2
150	1.3	1.28	1.24	1.24
200	1.32	1.3	1.27	1.27
250	1.34	1.32	1.29	1.28
300	1.35	1.34	1.31	1.3
350	1.37	1.36	1.32	1.31
400	1.38	1.37	1.34	1.32
450	1.39	1.38	1.35	1.33
500	1.4	1.39	1.36	1.34

k_3 = Topography factor. Its value is taken as unity, if the slope of ground is $< 3^0$.

While calculating design velocity the k_3 was taken as unity.

Design velocity $V_d = k_1 \text{ x } k_2 \text{ x } k_3 \text{ x } V$

$= 1 \text{ x } 1.05 \text{ x } 1 \text{ x } 39$

$= 40.95 \approx 41$

Wind pressure, $P_{wind} = 0.6 \text{ x } Vd^2 = 1008.6 \text{ Nm}^{-2}$

Tilt angle was selected according to the geological location of Kerala.

α (tilt angle) = $15^{\,0}$

Projected area $Ae = A \text{ x } \sin\alpha = 660 \text{ X } 0.259 = 170.94 \text{ m}^2$

$F_{wind} = Ae \times P_{wind} = 170.94 \times 1008.6 = 172410.084$ N

($V_d = 41\ ms^{-1}$)

From above the maximum force that will be induced on solar panel structure due to wind load was calculated as 172410.084 N. This is a critical wind load condition for storm like situation.

4.4.2.4 Total Load

The total load comprises the sum of dead load, live load, and wind load, calculated as follows.

Table 4.4 Total Load

	Limit state of strength			Limit state of serviceability		
	DL	LL	WL	DL	LL	WL
DL+LL+WL	1.5	1.2	1.2	1.0	0.8	0.8
Load with FOS (N)	103924.69	15840 (20x 660x 1.2)	206892.1	69283.125	10560	137928.07

Here, the value of limit state of serviceability was found to be less than the value of limit state of strength, which indicated that the structure can withstand the load acting on it. Therefore, the structure is stable.

4.5 COST ESTIMATION OF PV SYSTEM

The total cost of installation of the system was estimated by multiplying the unit cost of installation of the system per kW and multiplying it by the plant capacity.

Cost of installation, Rs. per kW = Rs. 70,000

Total plant capacity = 125 kW

So, total cost of installation= 125×70,000 = Rs. 87,50,000

The estimated cost for the PV system was found to be Rs. 91,87,500.

(Additionally, Rs. 4,37,500 was allocated for the construction of supporting structure to ensure the structural integrity. The additional cost should not exceed 5% of the total system cost.)

Estimated cost for the construction of retaining wall= Rs. 63,14,863

(Cost estimation of retaining wall is appended in appendix IV)

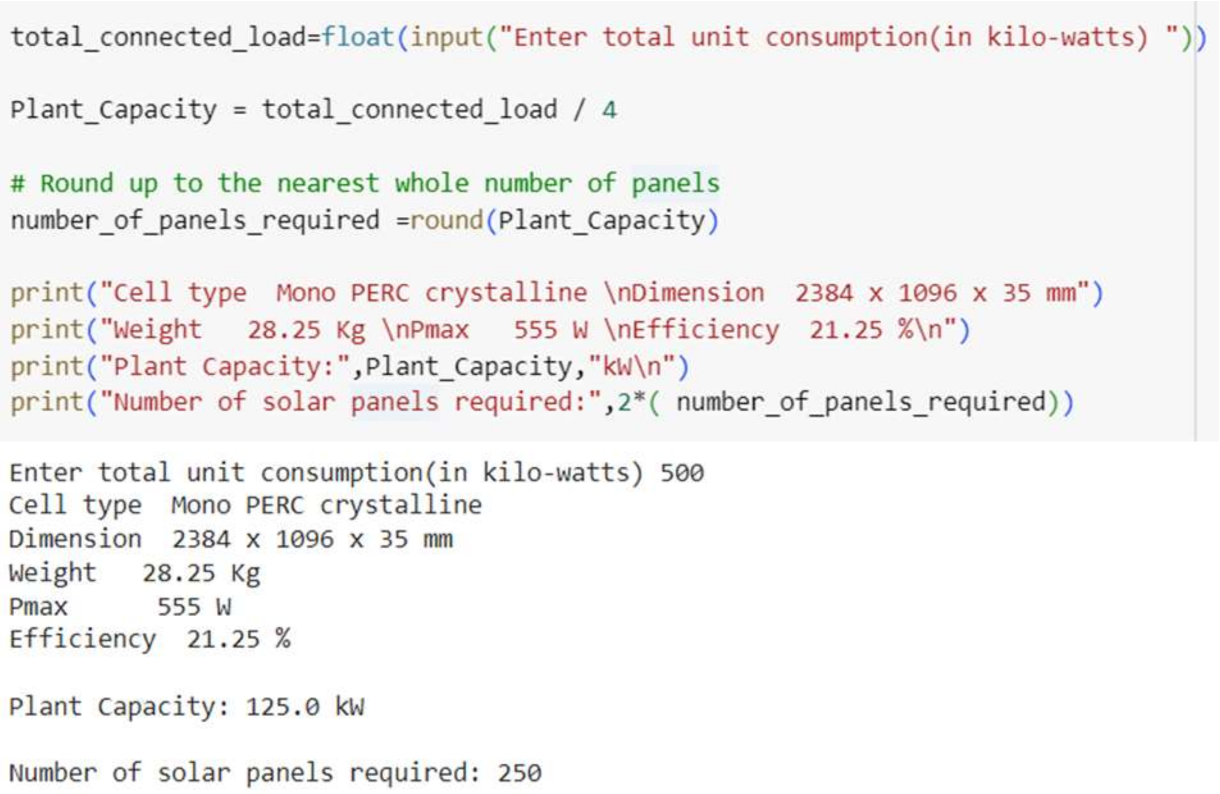
Total estimated cost for entire system = Rs. 63,14,863 + Rs. 91,87,500

= Rs. 1,55,02,363

The comprehensive cost analysis for the installation of the agrivoltaics system revealed a detailed breakdown of expenses. The installation cost, calculated at Rs. 70,000 per kW for a total plant capacity of 125 kW, amounted to Rs. 87,50,000. Alongside, the PV system's estimated cost stood at Rs. 91,87,500, which included an additional allocation of Rs. 4,37,500 for the construction of a supporting structure, ensuring structural integrity without exceeding the permissible 5% of the total system cost. Summing up these figures, the total estimated cost for the entire PV system was Rs. 1,55,02,362.8, inclusive of all components and considerations, providing a comprehensive financial overview for the project's execution.

4.6 ESTIMATION OF NUMBER OF SOLAR PANELS REQUIRED

Python code for the estimation of number of solar panels required to fulfil the requirement is given below:



```
total_connected_load=float(input("Enter total unit consumption(in kilo-watts) "))

Plant_Capacity = total_connected_load / 4

# Round up to the nearest whole number of panels
number_of_panels_required =round(Plant_Capacity)

print("Cell type  Mono PERC crystalline \nDimension  2384 x 1096 x 35 mm")
print("Weight   28.25 Kg \nPmax   555 W \nEfficiency  21.25 %\n")
print("Plant Capacity:",Plant_Capacity,"kW\n")
print("Number of solar panels required:",2*( number_of_panels_required))
```

```
Enter total unit consumption(in kilo-watts) 500
Cell type  Mono PERC crystalline
Dimension  2384 x 1096 x 35 mm
Weight   28.25 Kg
Pmax      555 W
Efficiency  21.25 %

Plant Capacity: 125.0 kW

Number of solar panels required: 250
```

This program, developed to determine the required number of solar panels for a specified total unit consumption, demonstrated the efficiency and capabilities of Mono PERC crystalline panels. With a total unit consumption of 500 kW, the calculated plant capacity was 125 kW, utilizing panels with dimensions of 2384 x 1096 x 35 mm, a weight of 28.25 kg, and a maximum power output (Pmax) of 555 W with an efficiency of 21.25%. Based on these parameters, the total number of solar panels required to meet the consumption needs was 250. This calculation ensured that the energy requirements were met efficiently, leveraging the high-performance characteristics of the selected solar panels.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

This project has comprehensively explored the planning and estimation required for the successful implementation of an agrivoltaics system for RARS Pattambi. The findings indicate that agrivoltaics systems present a viable and beneficial solution for optimizing land use by simultaneously producing agricultural crops and generating renewable energy. The key benefits identified include increased land-use efficiency, enhanced crop yields due to the microclimate created by the photovoltaic panels, and the provision of a reliable source of clean energy. These benefits align well with sustainable development goals, addressing critical issues such as food security, energy sustainability, and environmental conservation.

The installation of agrivoltaics system with a capacity of 125 kW including 250 panels will ensure energy supply for entire RARS Pattambi campus. It will be the perfect solution for the energy requirements of the farm as well as the academic block. The system will be suitable to the area because of its landscape and large area available for placing solar panels, tropical climate with abundant sunshine, especially during the non-monsoon months and high levels of solar irradiance are ideal for photovoltaic (PV) panel efficiency, ensuring substantial energy production throughout the year.

However, the study also highlighted several challenges, including high initial setup costs, the need for specific technological adaptations, and potential ecological impacts. An initial cost of Rs. 91,87,500 will be required for the installation of system, which is the biggest challenge. Addressing these challenges requires ongoing research, innovative solutions, and supportive policy frameworks.

To advance the adoption and optimization of agrivoltaic systems, it is recommended that policymakers develop incentives and subsidies to lower financial barriers for farmers and investors. Additionally, pilot projects and field trials should be conducted to gather more data and refine system designs. Collaboration among agricultural scientists, energy experts, and stakeholders is crucial to develop integrated strategies and supportive regulations. Future research should focus on improving photovoltaic technology, developing crop varieties adapted to agrivoltaic conditions, and studying the socio-economic impacts on rural communities. Continuous innovation and field evaluations will be essential to maximize the benefits of agrivoltaic systems and ensure their long-term viability.

In conclusion, installing an agrivoltaics system at RARS Pattambi is a great solution for meeting the energy needs of both the farm and the academic block. The landscape of the selected area and abundant sunshine make it perfect for solar panels, ensuring reliable energy production throughout the year. A Mono PERC solar panel rated at 555 Wp was chosen for agrivoltaic installation along a 1 km canal bank, the sole available land for this purpose in RARS Pattambi. The total capacity of the plant was 125 kW, utilizing 250 panels measuring 2384 x 1096 x 35 mm each. However, there are challenges to overcome. The initial setup cost of Rs. 91,87,500 is substantial, and it needed specific technologies and careful planning to address potential ecological impacts.

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APPENDIX-I

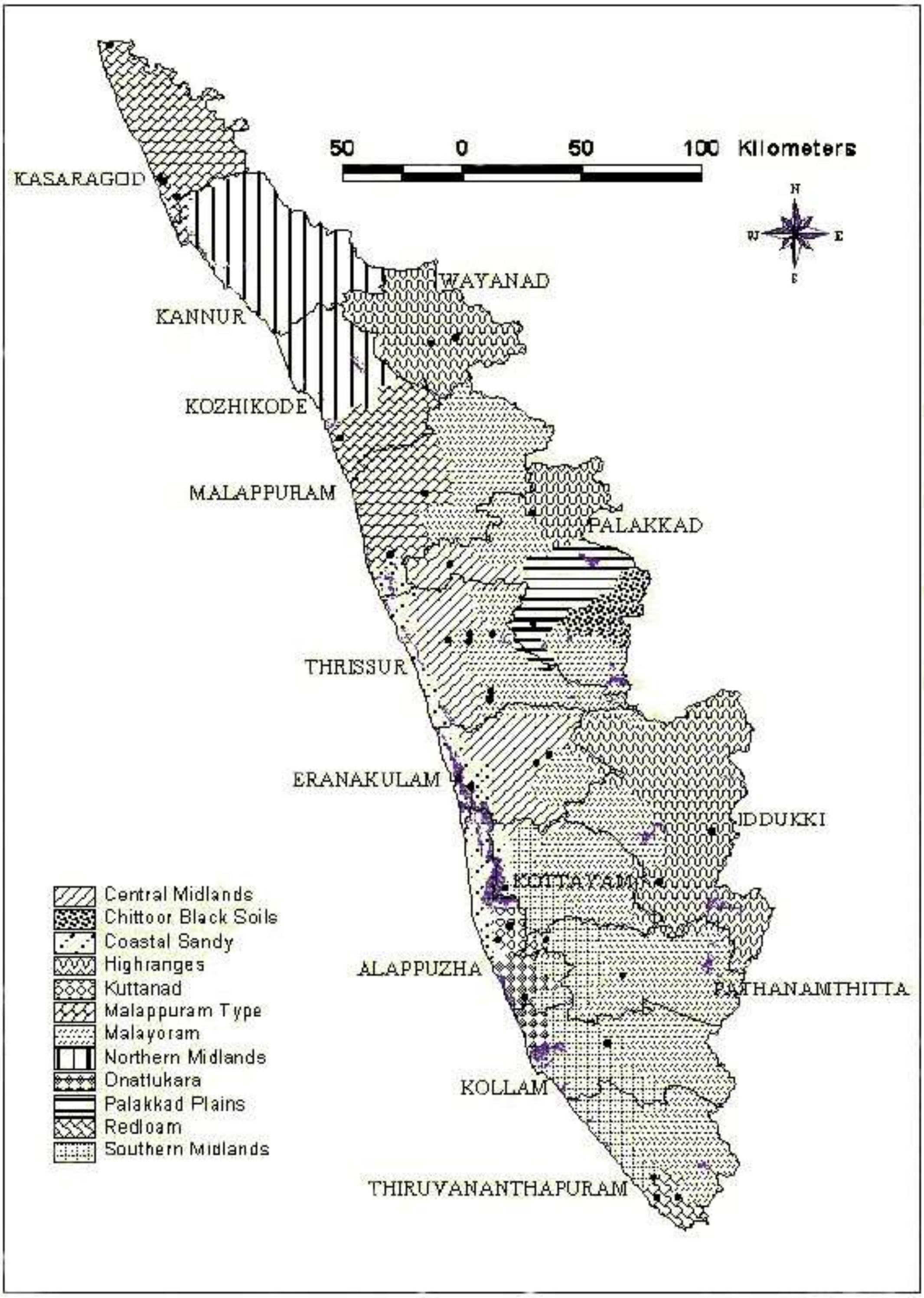

Fig. Agroecological zones of Kerala (source: KAU, 2002)

Agro-ecological zones of Kerala: main features (source: KAU, 2002)

Zones No.	Name	Soil type	Topographic class
I	Onattukara	Sandy loam	I
II	Coastal sandy	Sandy loam	I
III	Southern midlands	Laterite without B horizon	III
IV	Central midlands	Laterite	IIa
V	Northern midlands	Laterite	IIb
VI	Malappuram type	Laterite	IIc
VII	Malayoram	Laterite without B horizon	III
VIII	Palakkad plains	Red loam	II
IX	Red loam	Red loam	III
X	Chittoor black soil	Black soil	IIa
XI	Kuttanad	Peat (kari)	I
XII	Riverbank alluvium	Alluvium	I
XIII	High ranges	Red loam	III

APPENDIX-II

ENERGY AUDIT OF RARS PATTAMBI

Sl. No.	**Consumer no.**	**Connected Load**	**Bill Date**	**Units**	**Cost**	**Average cost per unit**
1	1165369001173	49880	04-01-2023	3832	35010	9.136221294
			05-01-2023	2534	24780	9.779005525
			06-01-2023	3177	27584	8.682404784
			07-01-2023	2308	23086	10.00259965
			10-01-2023	2013	20732	10.29905614
			11-01-2023	2404	23882	9.934276206
			01-01-2024	2218	23144	10.43462579
			02-01-2024	2250	23391	10.396
			03-01-2024	2993	29384	9.81757434
			Total	**23729**		0
2	115363023066	982	14/3/2024	284	1512	5.323943662
			13/5/2023	130	520	4
			14/9/2023	153	616	4.026143791
			14/11/2023	187	773	4.13368984
			13/1/2024	314	1785	5.684713376
			Total	**1068**		0
3	1165361001174	60016	04-01-2023	580	6883	11.86724138
			05-02-2023	720	7077	9.829166667
			06-01-2023	840	7434	8.85
			07-01-2023	680	6741	9.913235294
			08-01-2023	600	5884	9.806666667
			10-05-2023	560	5603	10.00535714
			11-01-2023	320	2735	8.546875
			01-01-2024	360	3325	9.236111111
			02-01-2024	480	4533	9.44375
			03-01-2024	480	4535	9.447916667

			Total	**5620**		0
4	1165366001175	97656	04-01-2023	2487	5909	2.375954966
			05-01-2023	2487	5925	2.38238842
			06-01-2023	2487	5574	2.241254524
			07-01-2023	2487	7235	2.909127463
			10-01-2023	2487	24881	10.004423
			11-01-2023	2487	6183	2.486127865
			01-01-2024	2487	6649	2.673502211
			02-01-2024	2100	7007	3.336666667
			03-01-2024	3068	7736	2.521512386
			Total	**22577**		0
5	1165369029422	30000	04-01-2023	4740	40457	8.535232068
			05-01-2023	5260	44699	8.497908745
			06-01-2023	11680	92342	7.905993151
			07-01-2023	9260	77232	8.340388769
			10-01-2023	3780	33183	8.778571429
			11-01-2023	4380	38016	8.679452055
			01-01-2024	3980	35259	8.859045226
			02-01-2024	5240	45394	8.662977099
			03-01-2024	9620	80690	8.387733888
			Total	**57940**		0
6	1165368029423	99964	04-01-2023	6960	13860	1.99137931
			05-01-2023	4700	9895	2.105319149
			06-01-2023	5060	10160	2.007905138
			07-01-2023	4500	15549	3.455333333
			10-01-2023	2400	6023	2.509583333
			11-01-2023	2560	6323	2.469921875
			01-01-2024	2380	6489	2.726470588
			02-01-2024	3140	7907	2.518152866
			03-01-2024	4300	10079	2.343953488

			Total	**36000**		0
7	1165367023080	13357	04-01-2023	1	1286	1286
			05-01-2023	0	1282	0
			06-01-2023	154	2305	14.96753247
			07-01-2023	1	1441	1441
			10-01-2023	2	1292	646
			11-01-2023	3	1300	433.3333333
			01-01-2024	0	1489	#DIV/0!
			02-01-2024	0	1488	#DIV/0!
			03-01-2024	0	1489	#DIV/0!
			Total	**161**		0
8	1165360023083	14605	06-01-2023	597	5644	9.453936348
			10-01-2023	420	4451	10.59761905
			07-01-2023	516	5519	10.69573643
			03-01-2024	557	6082	10.91921005
			05-01-2023	444	4597	10.3536036
			01-01-2024	465	5008	10.76989247
			02-01-2024	599	6418	10.71452421
			11-01-2023	368	4071	11.0625
			04-01-2023	485	4881	10.06391753
			Total	**4451**		0
9	1165368033362	22673	04-01-2023	553	5725	10.35262206
			05-01-2023	258	3314	12.84496124
			06-01-2023	377	3125	8.289124668
			07-01-2023	321	3733	11.62928349
			10-01-2023	304	3625	11.92434211
			01-01-2023	282	3482	12.34751773
			01-01-2024	384	4383	11.4140625
			02-01-2024	399	4479	11.22556391
			03-01-2024	429	4678	10.9044289

			Total	**3307**		0
10	1165369020820	1062	19/4/2023	17	105	6.176470588
			Total	**17**		0
11	1165361023081	6960	13/5/2023	0	1310	
			14/7/2023	0	1051	
			14/9/2023	0	1295	
			14/11/2023	0	1345	
			13/1/2024	0	1505	
			Total	**0**		
12	1165366023061	1758	13/5/2023	0	44.12	
			14/7/2023	0	15.12	
			14/9/2023	0	44.12	
			14/11/2023	0	47.12	
			13/1/2024	0	54.12	
			Total	**0**		
13	1165369023070	1818	13/5/2023	0	44.12	
			14/7/2023	0	21.12	
			14/9/2023	0	44.12	
			14/11/2023	0	47.12	
			13/1/2024	0	54.12	
			Total	**0**		
14	11653650304419	7790	13/5/2023	0	1475	
			14/7/2023	0	1475	
			14/9/2023	4	1505	376.25
			14/11/2023	112	2354	21.01785714
			13/1/2024	680	6707	9.863235294
			Total	**796**		0
15	1165360023056	920	19/6/2023	140	1140	8.142857143
			18/8/2023	154	1133	7.357142857
			17/2/2024	166	1443	8.692771084

			Total	**460**		0
16	1165365021447	2590	18/8/2023	15	92	6.133333333
			17/2/2024	39	201	5.153846154
			Total	**54**		0
17	1165364021443	1082	18/8/2023	75	7	0.093333333
			17/2/2024	114	501	4.394736842
			Total	**189**		0
18	1165364029038	1417	19/6/2023	140	1465	10.46428571
			17/2/2024	190	1675	8.815789474
			18/8/2023	107	1071	10.00934579
			Total	**437**		0
19	1165364023059	1706	17/02/2024	0	78	
			Total	0		
20	1165362020823	1075	17/2/2024	0	54	
			18/10/2023	3	55	18.33333333
			Total	**3**		**0**
21	1165365023068	1850	18/08/2023	1	47	47
			Total	**1**		**0**
Total		419161 W= 419.161 kW			**1067696**	

APPENDIX-III

ENERGY AUDIT OF KCAET

Sl. No.	Consumer Number	Building name	Present sanctioned load (kW)
1	1168526005582	Pump house	5.595
2	1165826000023	PHT block	76.850
3	1165820006941	Training complex	10
4	1165826006767	Academic block	80.950
5	1165822000148	Electrical lab	28.120
6	1165828001210	Pump house-1	11.936
7	1165822019865	Food engineering	51.700
8	1165829006443	Trainers hostel	18.400
9	1165826000147	SM lab	23.930
10	1165827000004	Street light/LH	0.490
11	1165823000145	SM lab	2.920
12	1165822000026	Physics lab	7.400
13	1165821002285	Auditorium	9.410
14	1165829000146	Electrical lab	1.510
15	1165826020517	New pump house	2.238
16	1165820018130	Pump house-3	3.730
17	1165828005976	FIM lab	25.485
18	1165821000126	PFDC	12.360
19	1165820000001	Workshop	50.902
20	1165824000003	Library	15.170
21	1165821022890	Men’s hostel	35.650
22	1165820000027	DITAT	48.251

The energy cost has been analysed in below table with the available data from the college for the period from October-22 to September-23.

Energy Cost

Sl. No.	Consumer Number	Quantity (kWh/Annum)	Avg. Cost per unit	Annual cost (Rs./Annum)	% Cost
1	1168526005582	5	2.26	11	0.001
2	1165826000023	3543	7.81	27667	3.3
3	1165820006941	1043	7.24	7551	0.9
4	1165826006767	22240	6.93	154123	18.6
5	1165822000148	238	7.24	1723	0.2
6	1165828001210	37845	6.41	245614	29.6
7	1165822019865	16920	7.2	121824	14.7
8	1165829006443	4670	6.82	31849	3.8
9	1165826000147	374	7.21	2697	0.3
10	1165827000004	620	7.24	4489	0.5
11	1165823000145	528	7.25	3828	0.5
12	1165822000026	1606	7.16	11499	1.4
13	1165821002285	1917	7.02	13457	1.6
14	1165829000146	208	7.36	1531	0.2
15	1165826020517	6648	7.15	47533	5.7
16	1165820018130	936	2.53	2368	0.3
17	1165828005976	2259	7.29	16471	2.0
18	1165821000126	4246	7.31	31038	3.7
19	1165820000001	1217	7.26	8835	1.1
20	1165824000003	3325	7.24	24073	2.9
21	1165821022890	8100	7.86	63666	7.7
22	1165820000027	1216	7.26	8828	1.1
	TOTAL	**119704**		**830678**	**100**

APPENDIX IV

DESIGN OF RETAINING WALL

For the installation of solar panels, the side walls of the canal must be strengthened to prevent collapsing during adverse climatic conditions. So, retaining wall was designed for one side of the canal.

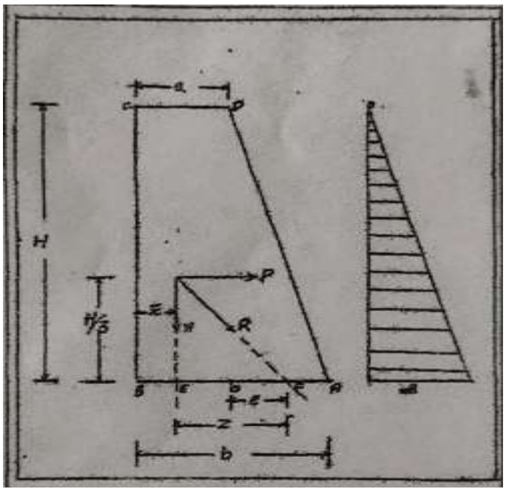

Fig. Retaining Wall

Design a Retaining wall with the following Considerations.

a. Height of the retaining wall = 2 m

b. Angle of repose of laterite soil (Φ) = 30°

c. Coefficient of friction (μ) = 0.5

d. Density of D.R masonry = 2400 kgm^{-3}

e. Density of laterite soil (ρ) = 1800 kgm^{-3}

f. Maximum compressive strength of D.R masonry = 20,000 kgm^{-2}

Steps:

1. Height of the structure (Depend on the column of the earth to be retained) = 2 m
2. Top width = 50 cm = 0.5 m
3. Base width = 0.8 m
4. Weight per length 0f retaining wall, W = $(\frac{a+b}{2}) \times H \times w$

$$= \frac{(0.5+0.8)}{2} \times 2 \times 2400$$

$$= 3120 \text{ kg}$$

5. P = $\frac{(wH^2)}{2} \times \frac{(1-\sin 30)}{(1+\sin 30)}$

$= \frac{(1800\ x\ 2^2)}{2} \times \frac{(1-\sin 30)}{(1+\sin 30)}$

= 1200 kgm

6. Centroid of the cross section, x̄ = $\frac{a^2+ab+b^2}{3(a+b)}$

$= \frac{0.5^2+(0.5\ x\ 0.8)+0.8^2}{3(0.5+0.8)}$

= 0.33 m

7. Shift of reaction, Z

Z= $\frac{pH}{W\times 3}$

$= \frac{1200\ x\ 2}{3120\times 3}$

= 0.256

8. Eccentricity, e = x̄ + Z - $\frac{b}{2}$

= 0.33 + 0.256 - $\frac{0.8}{2}$

= 0.186 ≈ 0.19 m

9. Resultant force, R = $\sqrt{(P^2 + W^2)}$

= $\sqrt{(1200^2 + 3120^2)}$

= 3342.81 kg

10. Testing against failures

i. Test against sliding μ W > P

μ W = 0.5 x 3120 kg = 1560 > 1200, which is P

Factor of safety, f = $\frac{\mu W}{P}$

$= \frac{1560}{1200}$

= 1.3 > 1

ii. Test against overturning`

W × EA > $\frac{PH}{3}$

EA= $\frac{b}{2}$ ± e

EA= $\frac{0.8}{2}$ ± 0.19 = 0.59 m

$W \times EA = 3120 \text{ x } 0.59 = 1840.8$

$\frac{PH}{3} = \frac{1200 \, x \, 2}{3} = 800$

$W \times EA > \frac{PH}{3}$

iii. Test against crushing

f max < permissible compressive strength of masonry

For laterite soil the permissible compressive strength is 25,000 kgm^{-2}

$f_{max} = \frac{w}{b} (1+ \frac{6e}{b})$

$f_{max} = \frac{3120}{0.8} (1+ \frac{6 \, x \, 0.19}{0.8})$

$= 9457.5 < 25000 \; kgm^{-2}$

iv. Test against tensile strength

The resultant ´R´ should pass through middle 1/3 of base.

$\bar{x} = 0.33$ m

e = 0.19 m

$\bar{x} + e = 0.52$ m

The middle 1/3 of base 0.8 m is from 0.5 to 0.52 m lies in the middle 1/3 of base. Hence the structure is safe against tensile strength.

COST ESTIMATION OF RETAINING WALL

Details of measurement and calculation of quantities

Sl. No.	**Description of items of work**	**No.**	**Dimension**			**Quantity**	**Remarks**
			Length (m)	**Breadth (m)**	**Height (m)**		
1	Site clearance	1	1000	1		1000 m^2	
2	Earthwork excavation of sides	1	1000	0.8	2	1600 m^3	
3	DR masonry for foundation	1	1000	0.8	0.6	480 m^3	

4	Super structure						
	For 1st 1m from base	1	1000	0.725	1	725 m^3	B=0.8+0.65 /2
	For next 1m from GL to 0.9 m	1	1000	0.575	0.9	517.5 m^3	B=0.5+0.65 /2
5	RCC belt of 0.1m 1:2:4	1	1000	0.65	0.1	65 m^3	B=05+0.8/2
6	Reinforcement for RCC 80 kg/m^3					5200 kg	65 x 80
7	PCC 1:2:4 of 7.5 cm thickness at top	1	1000	0.5	0.075	37.5 m^3	

Abstract of estimated cost

Sl. No.	**Description of items of work**	**Quantity**	**Unit**	**Rate**	**Per unit**	**Amount**
1	Site clearance	1000	m^2	7	m^2	7000
2	Earthwork excavation of sides	1600	m^3	234.5	m^3	375200
3	DR masonry	1722.5	m^3	3440	m^3	5925400
4	RCC belt of 0.1m 1:2:4	65	m^3	34	m^3	2210
5	Reinforcement for RCC 80 kg/m^3	52	q	97.17	q	5052.84
			GRAND TOTAL			Rs. 63,14,862.84

APPENDIX V

FEASIBLE AREAS FOR AGRIVOLTAIC SYSTEM IN KCAET

Site	**Area (m^2)**	**Area (acre)**
PH 1	225	0.055
PH 2	194	0.047
PH 3	100	0.024
PH 4	87	0.021
PH5	776.5	0.191
RS 1	60	0.014
RS 2	133	0.032
RS3	96	0.023
Plot 1 (MH)	263	0.064
Plot 2	1140	0.28
Plot 3	486	0.12
Plot 4	691	0.17
Plot 5	4467	1.1
Plot 6	1236	0.31
Plot 7	1233	0.3
Pond 1	983	0.24
Pond 2	835	0.21
Total Area	**13005.5**	**3.201**

Total polyhouse (PH) area= 1382.5 m^2 = 0.338 acre

Total rain shelter (RS) area= 289 m^2 = 0.069 acre

Total field area= 9516 m^2 = 2.344 acre

Total pond area= 1818 m^2 = 0.45 acre

Excluding the area used for cultivating paddy total feasible area available for agrivoltaics is 3.201 acres. The reason for excluding paddy area is that it may be difficult for large machinery to work in between the structures that are built for agrivoltaics.

Feasible Crops in KCAET

Sl.No.	Crop	Shade tolerance	Temperature (°C)
1.	Turmeric	Shade tolerant	20-35
2.	Ginger	Partial Shade/ Morning sun	20
3.	Beans	Shade tolerant	19-30
4.	Spinach	Partial Shade	24
5.	Pumpkin	Full sun	19
6.	Cucumber	Partial Shade	21-26
7.	Okra	Full sun	24-35
8.	Bitter gourd	Partial Shade	24-27
9.	Fodder	Shade tolerant	15-38

PLANNING AND ESTIMATION OF A PILOT PROJECT ON AGRIVOLTAIC SYSTEM FOR RARS PATTAMBI

by

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ABSTRACT

Submitted in partial fulfilment of the requirements for the degree of

BACHELOR OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY TAVANUR- 679573,

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ABSTRACT

Increase in world population, and rising living standards and industrialisation are driving global energy demand further upwards. To meet sustainable development goals and energy demand, the energy sector must be transformed by deploying low-emission energy sources and increasing the share of renewable energy. Agrivoltaics involves the integration of solar photovoltaic (PV) systems with agricultural activities, aiming to enhance land-use efficiency by generating renewable energy while simultaneously improving agricultural productivity.

This project report explores the implementation and potential benefits of Agrivoltaics (APV) within Kerala Agricultural University. The objectives of this project include identifying suitable sites within research stations of KAU for the deployment of agrivoltaic systems, designing an APV system for the Regional Agricultural Research Station (RARS) at Pattambi and estimating the number of solar panels required to meet the energy needs of the site. KAU's extensive network of farms, ponds, buildings, and unused lands provide ample opportunities for the successful incorporation of agrivoltaics. By harnessing solar energy, KAU can achieve significant environmental benefits, including water conservation, enhanced crop yields, and climate resilience, while also contributing to the university's energy needs and supporting its commitment to sustainable development.

A 125 kW agrivoltaic system has been designed for installation at RARS Pattambi, with an estimated cost of Rs. 91,87,500. Mono PERC solar panels, each rated at 555 Wp, were selected for the agrivoltaic installation along a 1 km canal bank, the only available land for this purpose at RARS Pattambi. The proposed system will consist of 250 panels, each measuring 2384 x 1096 x 35 mm. This design aims to balance energy production with agricultural productivity, demonstrating significant environmental benefits such as reduced carbon emissions and improved climate resilience.