

ANALYSING AND FABRICATION OF AGRIVOLTAICS TO ADDRESS WATER LAND- ENERGY NEXUS

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Engineering degree in
Mechanical Engineering

By

Korlepara. Aditya Naga Lakshmi Venkat (Reg. No. 40150022)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A++” by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of Korlepara. Aditya Naga Lakshmi Venkat (Reg. No. 40150022) who carried out the project entitled "ANALYSING AND FABRICATION OF AGRIVOLATICS TO ADDRESS WATER LAND- ENERGY NEXUS" under our supervision from December 2023 to April 2024.

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ABSTRACT

The energy supply chain has benefited from fossil fuels, but climate change threatens to shift to unconventional sources. The United Nation's Sustainable Development Goals (UN SDG) aim to reduce carbon dioxide emissions and increase energy independence. Land is crucial for agriculture and environmental functions, and the rise of photovoltaics is causing conflicts between food production and power generation. Solar photovoltaic systems are essential for decarbonization, but land and space requirements, efficiency, and solar resources remain challenges. Agrivoltaics, a symbiotic relationship, benefits both solar panels and crops by enhancing performance. Agri-Voltaic Systems (AVS) are promising non-depletable renewable energy source that combines solar Photo Voltic (PV) with agricultural products. These systems allow of farming activities while generating additional revenue from property. Governments in countries like China, Japan, France, the United States, South Korea, and Japan have implemented agrivoltaics. The integration of solar energy generation, agricultural output, and electrical energy in one production area can balance the world's energy needs. The combination of solar farming with agriculture can be a Climate-Smart Agriculture (CSA) alternative for Indian farmers, promoting energy security and farmer upliftment. We have created three agrivoltaic designs: a horizontal solar panel, a vertical solar panel (bifacial), and a tilted solar panel. The designs are created in two sections using the Solidworks software. Part design and assembly design are two different things. Then we have Fabricated the three types of design in a small pot made by Acrylic sheets and then compared the power outcome in all three designs and growing the plants with and without solar panels.

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LIST OF ABBERVATIONS

UN SDG	The United Nation's Sustainable Development Goals
PV	Photo Voltaic
AVS	Agri-Voltaic System
CSA	Climate-Smart Agriculture
GDP	Gross Domestic Product
KUSUM	Kisan Urja Suraksha Evam Utthan Manaabhiyan
GHG	Green-House Gas
GIS	Geographic Information Systems
GRA	Grey Relational Analysis
TPV	Translucent Photo-Voltaic
PAR	Photosynthetically Active Radiation
SWOT	Strengths, Weaknesses, Opportunities, and Threats
LPF	Light Productivity Factor
SDG's	Sustainable Development Goals

TOWS	Threats, Opportunities, Weaknesses, Strengths
CLCA	Consequential Life-Cycle Assessment
LER	Land Equivalent Ratio

Chapter-1

INTRODUCTION

1.1 INTRODUCTION

The energy supply chain has traditionally relied heavily on fossil fuels, which have been instrumental in meeting global energy demand. However, the escalating threats posed by climate change have spurred a shift towards unconventional energy sources over the past two decades.

Unconventional energy sources, such as solar, wind, geothermal, and biomass, offer several advantages over fossil fuels, including lower greenhouse gas emissions, reduced air pollution, and enhanced energy security. This transition has been driven by technological advancements, policy support, and a growing recognition of the environmental and social impacts of fossil fuel use. [1].

Reducing carbon dioxide emissions and lessening the effects of climate change require a global shift towards sustainable energy. Although there has been some success in supporting renewable energy sources, much more has to be done to meet the Sustainable Development Goals (SDG 7) of the United Nations, which call for universal access to modern, cheap, sustainable, and dependable energy. Transportation, business, communication, and agriculture are just a few of the industries that depend heavily on sustainable energy sources including solar, wind, hydropower, and bioenergy. Countries may lessen their dependency on fossil fuels—which are a significant source of greenhouse gas emissions—by switching to renewable energy sources.

In addition to promoting sustainable energy sources, the UN SDG 7 also emphasizes the importance of improving energy efficiency, expanding access to energy services, and promoting investment in clean energy technologies. These efforts are essential for achieving a sustainable energy future and addressing the challenges of climate change.

While progress has been made in promoting sustainable energy, more work is needed to accelerate the transition towards cleaner energy sources and achieve the goals outlined in UN SDG 7. By working together to promote sustainable energy

solutions, This can reduce carbon dioxide emissions, mitigate the effects of climate change, and ensure a sustainable future for all. [2].

Land is a crucial resource for economies that rely on agriculture and for essential environmental functions such as carbon dioxide (CO₂) absorption, biodiversity maintenance, and regulation of the water cycle. However, the rapid expansion of photovoltaic (PV) solar power is leading to potential conflicts between food production and energy generation.

The increasing deployment of solar PV installations, particularly large-scale solar farms, is placing pressure on available land resources. This is particularly problematic in regions where arable land is limited or where agriculture is a key economic activity. The competition for land between agriculture and solar energy development highlights the need for careful planning and sustainable land use practices.

One approach to mitigating conflicts between food production and solar energy generation is the concept of agrivoltaics. Agrivoltaics involves the dual use of land for both agriculture and solar energy production. By integrating solar panels into agricultural settings, farmers can continue to cultivate crops or raise livestock while also generating renewable energy.

Additionally, innovative solar PV installation designs, such as rooftop solar panels on buildings or solar canopies over parking lots, can help reduce the need for additional land for solar energy generation. These approaches can help minimize conflicts between food production and solar energy development while promoting sustainable land use practices and supporting the transition to clean energy. [3].

The following graphic 1.1 provides a statistical assessment on the depletion of natural resources. It shows how all natural resources are decreasing daily, with grey representing coal, orange representing gas, and blue representing oil.

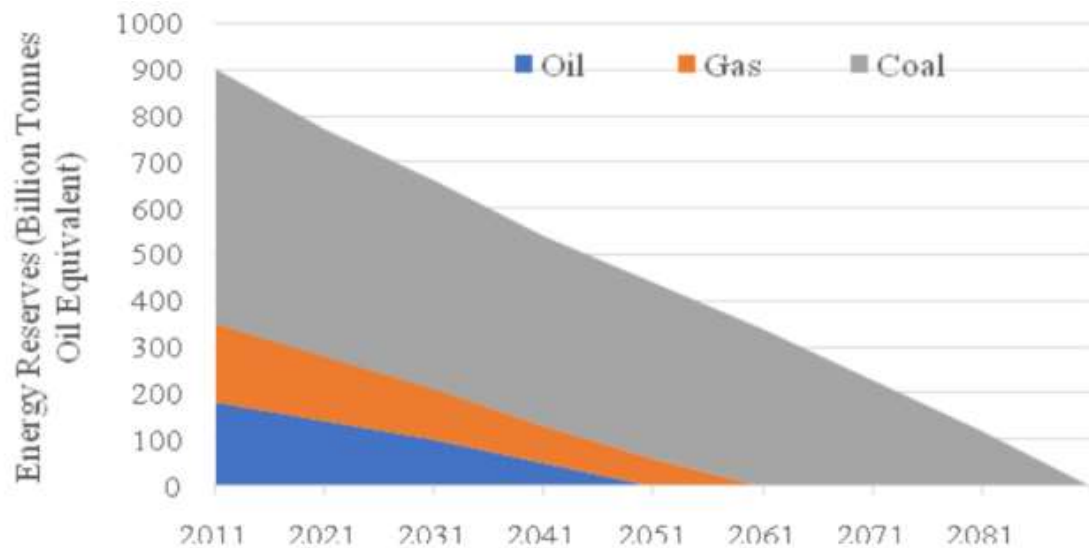


Fig:1.1: The statistical review on the depletion of natural resources

1.2 GLOBAL ENERGY SHIFT AND CLIMATE CHANGE

Fossil fuel phase-out refers to the gradual reduction and ultimate elimination of the use and production of fossil fuels. This transition is aimed at addressing several key issues, including reducing air pollution-related illnesses and fatalities, mitigating climate change, and enhancing energy independence.

By phasing out fossil fuels, countries can significantly reduce the emission of harmful pollutants such as sulfur dioxide, nitrogen oxides, and particulate matter, which are major contributors to respiratory illnesses and premature deaths. Additionally, reducing reliance on fossil fuels can help control greenhouse gas emissions, which are the primary drivers of climate change.

Furthermore, transitioning to renewable energy sources such as solar, wind, and hydropower can enhance energy security by reducing dependence on imported fossil fuels and diversifying the energy mix. This shift can also stimulate economic growth and create new job opportunities in the renewable energy sector.

Fossil fuel phase-out is a crucial component of the broader transition to a sustainable energy system based on renewable sources. It requires coordinated

efforts from governments, businesses, and individuals to accelerate the adoption of clean energy technologies and achieve a low-carbon future. [3].

While many countries are taking steps to phase out coal-fired power plants, the transition from coal to other energy sources is not happening quickly enough to meet climate targets. Despite efforts to accelerate the shift to cleaner energy sources, such as renewables and natural gas, coal continues to play a significant role in global energy production.

One of the challenges in phasing out fossil fuels is the transportation sector, particularly the sale of gasoline- and diesel-powered vehicles. Many countries have set deadlines for banning the sale of such vehicles in favor of electric or alternative fuel vehicles. However, there is still no global agreement on when to completely stop burning fossil fuels.

The transition away from fossil fuels requires a coordinated effort among governments, industries, and individuals. This includes investing in renewable energy infrastructure, improving energy efficiency, and promoting sustainable transportation options. Additionally, policies and incentives that encourage the adoption of clean energy technologies are crucial for accelerating the transition and meeting climate targets.

While progress is being made in reducing reliance on coal and fossil fuels, more ambitious and coordinated actions are needed to achieve the rapid and comprehensive transition to a low-carbon energy future. [4].

The expansion of power generation, particularly from renewable sources like solar photovoltaic (PV) installations, has led to increased competition for resources, especially in the agricultural sector. Currently, agriculture utilizes approximately 12% of the world's land area (equivalent to 1.6 billion hectares) for crop cultivation. This land is crucial for food production and is already under pressure due to factors such as population growth and urbanization.

One of the challenges posed by the expansion of solar PV installations is the competition for land, particularly in areas where agricultural activities are prevalent. This competition is further exacerbated by the fact that PV installations perform optimally in locations with prolonged daylight and minimal cloud cover, characteristics that are often found in regions suitable for agriculture.

This competition for land between agriculture and solar PV installations highlights the importance of strategic planning and land use policies. It is essential to balance the need for clean energy generation with the need for food production and other land-based activities. Solutions such as agrivoltaics, which involve combining solar PV installations with agricultural practices, can help maximize land use efficiency and mitigate conflicts between these sectors.

Addressing the competition for resources between power expansion and agriculture requires a comprehensive approach that considers the environmental, social, and economic impacts of both sectors. Collaboration between stakeholders, innovative land use strategies, and sustainable development practices are key to finding a balance that ensures both energy security and food security for future generations. [5].

1.3 SUSTAINABLE DEVELOPMENT GOALS AND ENERGY

Clean and affordable energy is a fundamental pillar in the global effort to achieve long-term sustainability goals. Renewable energy technologies such as fuel cells, solar panels, and wind turbines are playing an increasingly significant role in this transition, offering environmentally friendly alternatives to traditional fossil fuels. Among these technologies, solar photovoltaic (PV) systems are particularly noteworthy due to their cost-effectiveness, adaptability to diverse environments, long lifespan, and high efficiency in converting sunlight into electricity.

Solar farms, which are large-scale installations of solar panels, are key drivers of the widespread adoption of solar PV systems. These solar farms are meticulously designed to cover expansive areas efficiently, maximizing energy production. However, the expansion of solar farms is not without its challenges, particularly

concerning land and space requirements. In densely populated areas, finding suitable land or rooftop space for solar farms can be a daunting task. Moreover, concerns related to land use conflicts, such as competing with agriculture for land or impacting natural ecosystems, need to be carefully addressed through sustainable land management practices.

While solar panel technologies have made remarkable advancements in recent years, there is a continuous need for research and development to further enhance their efficiency and performance. Improving the efficiency of converting sunlight into electricity is paramount for maximizing energy output and reducing overall installation costs. Innovations in solar panel technology, such as the development of more efficient materials and manufacturing processes, are key areas of focus for researchers and industry stakeholders alike.

Solar PV systems are indispensable components of the transition to clean energy. Ongoing advancements in technology, coupled with sustainable deployment strategies, are essential for unlocking the full potential of solar energy and realizing a sustainable future powered by clean and renewable sources. [2].

1.4 FOSSIL FUEL PHASE -OUT AND RENEWABLE ENERGY

Agrivoltaics, a concept that combines solar photovoltaic (PV) technology with agricultural practices, represents a symbiotic relationship where both solar panels and crops benefit from each other's presence, leading to enhanced performance. One of the key advantages of agrivoltaics is the ability to generate electricity that can be used to power the farm's electric tractors, equipment, and precision agriculture technologies. This integration not only reduces the farm's reliance on fossil fuels but also contributes to lower operational costs and carbon emissions.

Furthermore, the shade that the solar panels generate can aid in lowering soil water evaporation, improving agricultural water usage efficiency. This is especially helpful in areas where conserving water is a top concern or when there is a shortage of it. Agrivoltaics is a sustainable farming solution that combines solar energy generation with agricultural methods to handle the concerns of energy and water. [5].

Agrivoltaics, or the practice of combining solar photovoltaic (PV) systems with agriculture, exhibits diverse implementations and regulatory frameworks across different countries. The term "agrivoltaics" is commonly used to describe specialized dual-use technology that was initially developed and widely adopted in Europe and Asia. This technology often involves the installation of solar arrays on mounts or cables, raising them approximately five meters above the ground. Another common approach is to install solar panels on greenhouse roofs. These configurations are carefully designed to allow farm equipment access to the land, ensuring that agricultural activities can continue without interference from the solar infrastructure. The adoption of agrivoltaic systems has particularly gained traction in urban and suburban areas. By integrating solar infrastructure with agricultural practices, these systems support local farming operations. Farmers can maximize their land use efficiency, enabling them to produce more food while minimizing the environmental impact of their operations. This integrated approach not only promotes sustainable agriculture but also contributes to renewable energy generation, aligning with global efforts to combat climate change and enhance food security.

In addition to supporting local farming operations, agrivoltaics also offers other potential benefits. By providing shade to crops, solar panels can help regulate temperature and reduce water evaporation from the soil. This can lead to more efficient water use in agriculture, which is especially important in regions facing water scarcity or where water conservation is a priority. [6].

1.5 CHALLENGES IN TRANSITIONING TO RENEWABLE ENERGY

Agrivoltaic systems (AVS), which involve combining solar photovoltaic (PV) technology with agricultural practices, have an intriguing history. Although the concept was first proposed in 1982, it didn't gain widespread attention or discussion until the early 2000s. The inspiration for AVS comes from intercropping techniques used in traditional farming, where different crops are grown together in the same field to increase land productivity and overall revenue.

The idea behind AVS is to utilize the same area of land for both agricultural production and solar energy generation. This dual-use approach optimizes land resources and provides multiple benefits. By integrating solar panels into agricultural settings, farmers can generate clean energy while continuing to cultivate crops or raise livestock. The solar panels provide shade, which can benefit certain crops, reduce water evaporation from the soil, and create a more favourable microclimate for plants.

AVS technology is gaining popularity due to its flexibility and scalability. It can be implemented on small farms as well as large-scale agricultural operations. The growing interest in AVS is evident from the increasing number of industrial and research facilities dedicated to studying and implementing this technology around the world.

One of the key advantages of AVS is its ability to generate both agricultural products and electrical energy simultaneously. This dual production approach can significantly increase the overall revenue from a given area of land. Additionally, AVS helps to reduce the environmental impact of traditional farming practices by promoting renewable energy generation and sustainable land use.

Overall, the development and adoption of AVS technology represent a significant step towards achieving a more sustainable and efficient agricultural system. As technology advances and more research is conducted, AVS has the potential to play a crucial role in meeting the world's growing food and energy needs. [7].

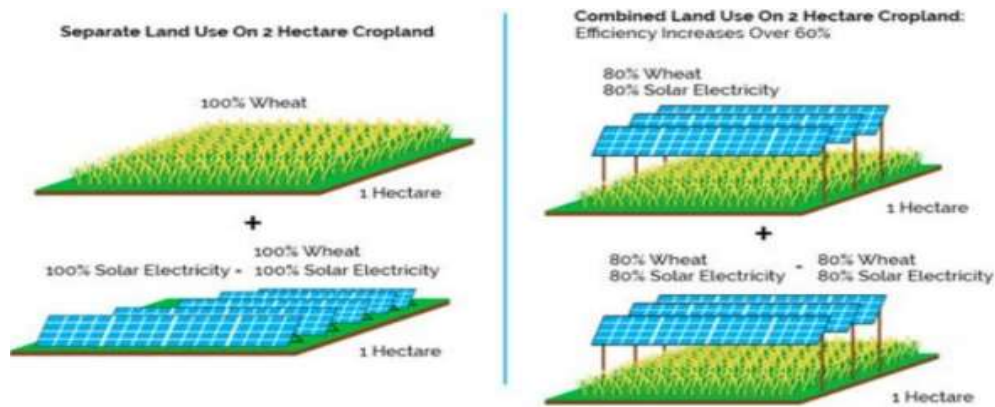


Fig: 1.2: Comparison of efficiency of traditional farming using Agrivoltaics

The effectiveness of traditional farming and agrivoltaics is compared in figure 1.2 above. As you can see, in the conventional method, the land is only utilized for 100% sun farming or 100% agriculture. However, when combine the two land uses, It can obtain about 80% of the goods from agriculture and even 80% of the electricity from solar power.

1.6 AGRIVOLTAICS: COMBINING SOLAR POWER AND AGRICULTURE

Solar photovoltaic technology utilizes solar modules to directly convert sunlight into electricity, offering a promising and sustainable renewable energy source. The efficiency of this process is influenced by the intensity of sunlight and the surface temperature of the solar cell. While the panels themselves may block some solar radiation due to their opacity, this setup establishes a mutually beneficial relationship between energy production and insulation.

Integrating solar energy generation with agriculture, known as Agri-Voltaics (AV), could potentially balance the world's energy needs if even a small percentage, such as less than 1%, of agricultural land were converted to AV systems. This dual-use approach not only generates renewable energy but also maintains agricultural productivity by providing shade and reducing water evaporation from the soil.

However, combining these operations in the same region might reduce the efficiency of solar energy generation, agricultural output, or both. Factors such as

shading from the solar panels, changes in microclimate, and competition for land use could impact productivity. Despite these challenges, the overall revenue from such integrated systems could still increase due to the additional income from electricity generation.

Research and development efforts are ongoing to optimize the design and operation of Agri-Voltaic systems to maximize the benefits of both energy generation and agriculture. By addressing these challenges, AV systems have the potential to play a significant role in sustainable energy production while supporting agricultural practices. [8].

Chapter-2

LITERATURE SURVEY

Seven Agir, Pinar Derin-Gure, Bilge Senturk (2023) Technology called agrivoltaics, which aims to integrate agriculture with renewable energy production, offers a lot of promise to resolve problems over land usage. For stakeholder engagement and social acceptance, it is essential to comprehend how farmers view the advantages and disadvantages of using agrivoltaics. However, the United States and Europe have been the main focus of study on the societal adoption of agrivoltaic systems. These studies have demonstrated that early identification of the elements influencing stakeholders' views and the legal environment is crucial for the practical and ethical adoption of the technology. In this study, the first to examine Turkish farmers' opinions on agrivoltaics, The employ extensive semi-structured interviews to explore how early adopters evaluate the potential and difficulties associated with the technology. [1]

A. Agostini, M. Colauzzi, S. Amaducci (2020) Agrivoltaic systems are photovoltaic (PV) technologies in which PV panels are positioned at a height that allows for regular farming practises to be carried out below. Agrivoltaic systems improve water usage efficiency and lessen water stress, which helps crop yield while also preserving agricultural land. Due to these advantages, interest in agrivoltaic systems is growing, but the lack of a comprehensive environmental and economic study constrains their adoption. By simulating the environmental and financial outcomes of a cutting-edge agrivoltaic system constructed on tensile structures (Agrivoltaic) in the Po Valley, this work seeks to close this gap. [2]

M. Sojib Ahmed, M. Rezwan Khan, Anisul Haque (2022) Sustainable food and energy production from common lands are promised by agrivoltaics (AV). While there is a wealth of literature on AVs for leafy crops, few publications are comparable on AVs for important crops (such as rice, maize, wheat, etc.). In this article, The propose an end-to-end modelling methodology to analyze location-specific AVs over paddy rice and consider the local ambient circumstances to determine the geographically distributed rice production using panel arrays, the

panel yield, and the AV system's financial elements (costs, income, and profit). Due to the several orders of magnitude more investment that can be made in solar panels than paddy rice, solar energy provides a far higher absolute profit than rice farming on a given plot of land. Policy-level restrictions are necessary to establish a permitted reduction in rice for more incredible energy. [3]

Mohammad Abdullah Al Mamun, Paul Dargusch, and Ali (2022) Increasing the production of large-scale photovoltaic (PV) energy is crucial for worldwide efforts to reduce climate change. Such PV development is hampered by its substantial area needs, which are exacerbated by increased land rivalry brought on by population expansion and rising food consumption. Agricultural photovoltaic systems Crop cultivation and PV power generation present a viable remedy for the issue of the land economy. In this paper and offer the findings of a systematic review of agrivoltaic research and pertinent analysis, debate, and recommendations for further study. 98 studies in all were evaluated. 48 of them dealt with particular applications, while 50 were focused on the volume of PV generation. Of the 50 questions, 14 focused on small-scale (less than 100 kW) PV systems. [4]

Aidana Chalgynbayeva , Zoltán Gabnai (2023) An agrivoltaic system emphasizes the dual use of land by combining agricultural food production and energy generation in one location. This article presents a bibliometric analysis of agrivoltaic topics based on publications indexed in SCOPUS, in which economic evaluations of agrivoltaics, agrivoltaic systems for crops and livestock animals, photovoltaic greenhouses, and agrivoltaics with open fields are discussed, or in which its ideas are used to analyze specific locations. The SCOPUS database was used to do a bibliometric study. R Studio and Bibliophagy were two bibliometric tools used to analyze the data for this study. [5]

F.J. Casares de la Torre, Marta Varo (2022) The rise in the global population is driving up the price of food and energy. As a result, there is a land use conflict since agricultural land cannot be used for major renewable energy plants. Agrivoltaics, a remedy, combines land use for solar and agricultural purposes. This study examines the conversion of horizontal NeS photovoltaic arrays into

agrivoltaic installations by growing tree crops in hedgerows between collector rows. In particular, research is done on how the crop affects the solar panels' shade. It has been demonstrated that there is a region between the collectors where the crop won't shade the solar panels. [6]

Nimay Chandra Giri, Ramesh Chandra Mohanty (2022) To build sustainable energy sources and the economy of a developing nation like India, access to solar photovoltaic electricity is essential. To treble farmer income by 2022, the nation has set a goal of 100 GW of solar photovoltaic energy generation, of which 50 GW have already been reached. As the economy changes, the need for food and energy has increased by approximately 40% and 25%. The rivalry over land use concerns will increase as a result of this transformation. According to this viewpoint, a dual land use method, or "agrivoltaic system," is necessary to ensure land tenure as well as to improve energy and food security, socioeconomic viability, and national livelihoods. [7]

Shiva Gorjian, Erion Bousi and All (2022) Global food demand is increasing due to the growing world population. Areas will also be used to produce renewable power to combat climate change and global warming. "Agrivoltaic technology"—the synthesis of crop production and solar photovoltaics—benefits both parties and offers a sufficient, resource-efficient solution to the ongoing competition issue for arable lands. From a starting capacity of 5 MW in 2012, agrivoltaic systems have grown tremendously in recent years, reaching a global installed capacity of 2.8 GW in 2020. [8]

Uzair Jamil, Abigail Bonnington and Joshua M. Pearce (2023) By raising the nonemitting portion of power generation to 90% by 2030, Canada has pledged to reduce greenhouse gas (GHG) emissions. As the price of solar energy has fallen, agrivoltaics—the joint development of solar photovoltaic (PV) systems and agriculture—offers an economical route to achieving these objectives. This study uses numerical simulations and geographic information system analyses of agricultural regions to quantify the potential for agrivoltaics in each province of Canada. By utilizing vertical system topologies and bifacial PV for single-axis tracking, the systems modeled would allow conventional field crop farming to continue (and maybe boost production). [9]

Uzair Jamil and Joshua M. Pearce (2023) Canada are one of the top exporters of agricultural products, and Saskatchewan is home to around half of the country's agriculture. A recent agrivoltaics study reveals increased biomass for a variety of crops. This research examines the possible financial impacts of increased agricultural and livestock production using agrivoltaics in Saskatchewan. The legislation that could affect Saskatchewan's adoption of agrivoltaics is then examined. Experimental outcomes from wheat production using agrivoltaics are examined for various adoption scenarios. The effects of utilising sheep to gather pasture grass regions in the province for agrivoltaics are also looked at. [10]

David Jung, Gabriel H. Gareis, Andreas Staiger, Alois Salmon (2022) The economic feasibility of agrivoltaic systems may be affected by soiling losses, particularly because agricultural operations generate dust that settles right on top of and next to the PV panels and evaluated the current-voltage curve and tracked the performance ratio of an agrivoltaic pilot plant in central Chile for six months in the summer and fall to examine the effects of soiling. Our research demonstrates how soiling substantially influences energy production and, consequently, the financial feasibility of an agrivoltaic system. When there is no precipitation or cleaning throughout the summer, the PR can fall to as low as 40%, and average daily soiling losses can reach 0.35% per day. This suggests that a study should look at how farming activities and soiling are related, as well as the best cleaning techniques and technology for agrivoltaic systems. [11]

Odysseas Alexandros Katsikogiannis, Hesam Ziar, Olindo Isabella (2022) Agrophotovoltaic (APV) systems, which provide concurrent production on the same piece of land, were investigated as a way to guarantee future renewable energy and food supplies. The deployment of APV is restricted to regions with significant solar insolation since typical photovoltaic (PV) array topologies result in unsuitable circumstances for crop development. Compatibility with diverse climates and crop types may be accomplished by optimising the APV array's design. In order to build a multi-scale modelling technique and choose the best topology for a medium- to large-scale fixed bifacial APV array, these goals were the focus of this research. Under the Boston, Massachusetts, climate, three

primary topologies—S-N facing, E-W wings, and E-W vertical—were examined. [12]

Alexander V. Klovov, Egor Yu. Loktionov and All (2023) Agrivoltaics (Agri-PV, AV), which combines the use of land for the production of agricultural goods and electricity, has lately experienced a sharp rise in popularity due to its ability to boost revenue per unit of land area dramatically. A comprehensive definition of an AV system includes energy converters that may use solar energy as well as energy from any other local renewable source, such as bioenergy. Current methods of AV can lead to a nearly doubling of revenue per unit area and reflect the advancement of agroecology and integrated PV power delivery to the grid. Large-scale unmanned precision agriculture and smart farming might revolutionize agriculture with the help of AV. Still, these advancements won't be achievable without on-site power supply, a reduction in chemical fertilisers and pesticides, and on-site produce processing. [13]

Chung-Feng Jeffrey Kuo , Te-Li Su and All (2023) The study's symbiotic photovoltaic (PV) electro farming system was created for PV installation on agricultural land. The study examines the impact of various PV system design parameters on agricultural farmland as impacted by yearly sun hours. The PV panel's solar hours should be increased for optimal power production. In order to maximise the two quality attributes of the symbiotic electro farming PV system with the optimal design parameter combination, this work integrates the Taguchi technique with Grey Relational Analysis (GRA). PV power generation and sun hours on farmland were the multi-quality parameters chosen. Location, upright column height, module tilt angle, and PV panel width are among the control elements. [14]

Manoch Kumpanalaisatit, Worajit Setthapun(2022) Globally, the rate of solar energy production is rising at the same time as the net electricity demand is rising significantly, which is causing rivalry for agricultural lands and forest invasion. Potential remedies for this issue include agrivoltaic systems combining photovoltaic (PV) systems with agricultural production. There are now two different types of agrivoltaic systems: Systems incorporating agricultural

operations on accessible land in PV facilities. Systems specifically created and installed for the co-production of crops and PV electricity. [15]

Sangik Lee, Jong-hyuk Lee and All (2023) Through integrating photovoltaics and agriculture, an agrivoltaic system (AVS) presents a promising approach for addressing the worldwide demand for renewable energy and sustainability. AVSs increase the efficiency of land utilization, according to several empirical studies that have actually planted facilities and grown genuine crops. But because there aren't many defined models and design standards, actual end-users and farmsteads don't often embrace AVSs. In the present study and carried out a thorough AVS design, taking into account structural safety and agronomic factors and an analysis of design requirements to support the use of AVSs. Various design variants were considered to represent site circumstances and user preferences based on the solar module arrangement and altering installation requirements. [16]

Rittick Maity, Kumarasamy Sudhakar, and All (2023) The strengths, weaknesses, opportunities, and threats (SWOT) that might be present when putting in place an agrivoltaic system are thoroughly examined in the study "SWOT and TOWS Matrix Analysis of Agrivoltaic Systems." In order to identify and assess the internal and external aspects that could influence the deployment and success of the agrivoltaic system, this study uses a SWOT analysis methodology. In order to create strategic recommendations based on the recognized SWOT variables, a TOWS matrix analysis is also carried out. The analysis's findings demonstrate the agrivoltaic system's many advantages, including its ability to provide sustainable energy, boost agricultural yields, and help farmers financially. [17]

M. Varo Martínez, L.M. Fernández de Ahumada and All (2022) The population's demands for food and energy are rising as the world's population is expanding continuously. It is essential to move towards a more effective and sustainable agriculture system given these circumstances and the detrimental effects of climate change. This is how agrivoltaics proposes to coexist on the same plot of land with photovoltaic energy generation. The behaviour of the agrivoltaic facilities has been examined in a number of studies from a theoretical

perspective. But in order to verify this new system's efficacy, test plants must be used. This study describes an experimental agrivoltaic plant built in Cordoba, Spain. [18]

Caitlin G. McLennan, Jon Witten, JD and Kate Davies, PhD (2023) Governments are moving quickly to undertake a clean energy transition using new and creative technology as the climate heats up, primarily due to the fossil fuel sector. It is the responsibility of policymakers to be aware of the inherent trade-offs of any technology and to carefully and fairly disseminate it to the general population. Agrivoltaics, or agrivoltaic solar, offers innovative solutions for a number of issues related to anthropogenically-caused climate change, including preserving farmland and generating sustainable energy while fostering cross-sector cooperation. However optimistic, several stakeholders express conflicting views when agrivoltaics are applied to typically rural areas. In order to comprehend and explore the technology's geographically unique advantages and disadvantages, this thesis uses geographic information systems (GIS), political study of land-use and regulatory frameworks, and content analysis of news media and public hearing materials. [19]

Kamran Ali Khan Niazia, Marta Victoria (2022) Agrivoltaics (APV) is the dual use of land that combines photovoltaic (PV) systems with agricultural crop production. This study examined three alternative APV configurations: single-axis horizontal tracking, vertically mounted bifacial, and static with optimum tilt. For various PV capacity densities, a model is created to determine the shadowing losses on the PV panels and the decreased solar irradiation reaching the region underneath them. Using a site in Denmark as a case study, The first examine the trade-offs, and then expand the analysis to the rest of Europe and find that a capacity density of around 30 W/m² is adequate for APV systems and that vertical and single-axis tracking creates more uniform ground irradiance. [20]

Surendra Poonia, N.K. Jat, Priyabrata Santra, and All (2021): Solar PV generation from ground-based systems is rising, creating rivalry for land between agricultural and PV power. The agri-voltaic system (AVS) is the answer to this problem. The AVS systems permit agricultural activities while allowing for

PV generation, generating additional revenue from the property. Therefore, laws for installing AVS on agricultural land have already been implemented by the governments of various nations, including China, Japan, France, the United States, South Korea, and Japan. Following this pattern, the KUSUM (Kisan Urja Suraksha evam Utthan Mahaabhiyan) national-level programme, which aims to promote energy security and farmer upliftment, has also announced a strategy to install AVS in farmers' fields in India. [21]

José S. Pulido-Mancebo, Rafael López-Luque and All (2022) One of society's biggest problems is how to meet the rising need for food and energy effectively and sustainably. Agrivoltaics is now being proposed as a potential, effective answer. To achieve this, agrivoltaics suggests utilising photovoltaic technology to coexist with agricultural and renewable energy production on the same piece of land. The connection between the two systems, agricultural and solar, significantly impacts how well this new production model performs. The impacts of photovoltaic panel shadows on cropland are thus among the most crucial factors to take into account. Therefore, an in-depth understanding of the spatial distribution of solar radiation within the area of land between collectors and crops is necessary for future investigations of crop behaviour in agrivoltaic settings. [22]

Meagan Reasoner and Aritra Ghosh (2022) Research into the fusion of photovoltaics (PV) with agriculture has expanded into a new industry called agrivoltaics (AV) as more countries work towards net-zero emission objectives by 2050. Researchers have been able to create strategies for improving the agrivoltaic system thanks to measurements of the land equivalent ratio (LER). Studies on novel engineering techniques for photovoltaic tracking and next-generation PV cells were examined to identify the variables that affect optimization. This analysis also took into account AV farm designs and how various spacing, height, and density affect the shading beneath the panels. The photosynthetically active radiation (PAR) fluctuates when panels block the light from reaching the plants, which affects plant development. [23]

Muhammad Hussnain Riaz, Hassan Imran and All (2021) Agrivoltaics (AV) is a cutting-edge strategy in which agricultural output and solar photovoltaic (PV)

energy generation are combined to enable food-energy-water synergies and the preservation of landscape ecology. Due to the unique co-optimization issues brought on by this dual-use need (such as shading, soiling, and spacing), module technology and farm architecture options significantly differ from those of conventional solar farms. The contrast how well vertical East/West (E/W)-faced bifacial farms perform with the usual, ideally titled North/South (N/S)-faced monofacial farms. Surprisingly, suppose the PV array density is lowered to half or lower than normal ground-mounted PV farms. In that case, the vertical farm provides roughly the same amount of energy production and photosynthetically active radiation (PAR) as the traditional farms. [24]

Muhammad Hussnain Riaz, Hassan Imran (2022) Agrivoltaics (AV) is a new technology with built-in resilience against climatic vulnerabilities and synergistic advantages for the food, energy, and water demands of the expanding global population. An AV system must balance the sunlight distribution between solar panels and crops according to the necessary limitations to maintain the intended food-energy outputs. The lack of a standardized crop-specific indicator (to quantify the effectiveness of irradiance sharing) has made it challenging to optimize or analyze the performance of AV systems given the growing diversity of monofacial and bifacial farms. The offer a new metric called the light productivity factor (LPF), which assesses the efficiency of irradiance sharing for a certain crop variety and PV array configuration. [25]

Aminata Sarr, Y. M. Soro (2023) Agrivoltaic systems, which combine photovoltaic energy production with agricultural production in the same area, have come to be seen as a potential solution to the problems associated with the loss of cultivated land caused by the use of solar panels in agricultural production systems. To fulfil the rising demand for farm products and energy brought on by the fast population increase, they also make it possible to optimize land usage and reduce disputes over access to land. [26]

Anne-Kathrin Schneider, Felix Klabunde and All (2023) Worldwide efforts are being made to accomplish the Sustainable Development Goals. From an ecological and social perspective, sustainable agriculture is also a goal for science and society, even if energy production and consumption should be

focused on renewable sources. Agribusiness interests, from food production to energy generation, are concentrating on agricultural land in particular as a result of the growth of renewable energies. In this cross-disciplinary study, Present the potential and constraints of collaborative synergy at the intersection of food production, energy generation, energy consumption, biodiversity conservation, and social acceptance of renewable energies in a hypothetical scenario. [27]

Julieta Schallenberg-Rodriguez, José-Julio Rodrigo-Bello, B. Del Río Gamero (2023) In regions where the available land is of particular interest to deploy agrivoltaic systems. Using greenhouses to produce food and energy simultaneously increases farmers' income, converting farming into a more attractive sector. The farming sector could benefit from agrivoltaic, since farmers could profit from a double incoming source: vegetables and energy. This research aims to establish how relevant agrivoltaic can be in terms of energy production at the regional scale. [28]

Aditya Shukla, Mukesh Kumar, and Akanksha Shukla (2022) Land conflict between agricultural and solar PV generation have resulted from the tendency towards increasing solar PV generation from ground-based installations. The Agri-voltaic system (AVS) is the answer to this problem. However, many of them have issues since they rely so much on inadequate agricultural methods. Sometimes the challenges are so great that people commit suicide. Additionally, the government must increase its GDP and energy supply to keep up due to India's dense population and ongoing population expansion. The combination of solar farming with agriculture, or Agrivoltaics, is examined in this article as a Climate-Smart Agriculture (CSA) alternative for Indian farmers. Similar to that, the report discusses prospects and limitations for India's Agrivoltaic industry. [29]

I. Sirnik, J. Sluijsmans (2023) Emissions reduction for greenhouse gases is a global challenge. One of the options to minimise these emissions is the development of new agrivoltaic systems that integrate solar energy generation with agriculture. While landscape experience in solar energy generation and circularity are important topics in agriculture, agrivoltaics has paid little attention to these challenges. This study looks at circularity and the landscape

experience in built agrivoltaic projects described in academic literature and newly built agrivoltaic projects in the Netherlands. It helps to enable agriculture transitions and boost public acceptability when people understand circularity and landscape experience in agrivoltaics. [30]

Eric J. Stallknecht, Christopher K. Herrera and All (2023) Photovoltaics may cover agricultural fields and greenhouses to build multifunctional farming systems that produce both traditional crops and renewable electrical energy for profit. In this study, utilising translucent photovoltaic (TPV) absorbers and assess the effects of wavelength-selective cut-offs of visible and near-infrared (biologically active) light on the development of three different, representative, and commercially significant crops: petunia, basil, and tomato. Notwithstanding variations in TPV harvester absorption spectra, the most important predictor of crop output and quality is photon transmission of photosynthetically active radiation (PAR; 400–700 nm). [31]

Moritz Wagner, Jan Lask (2023) While the supply of land for agricultural purposes is dwindling, demand for food and renewable energy is rising sharply. A possible solution that has the potential to meet this need without causing land-use conflicts is agrivoltaic systems (AVS), which combine solar energy generation and agricultural output on the same site. The current study carried out a consequential life-cycle assessment (CLCA) to evaluate the environmental effects of switching from single-use agriculture to AVS in Germany. [32]

Brecht Willockx, Cas Lavaert, Jan Cappelle (2022) Agrivoltaic systems, which combine agriculture and photovoltaics (PV), are becoming more popular. Numerous small-scale installations demonstrate the potential advantages for the energy and agriculture industries. Due to this multifunctional technology, many stakeholders (farmers, PV installers, and policymakers) must navigate a difficult design process. The first user-friendly "quick-scan" webtool with many crop and energy level performance indicators is proposed in this study. The webtool offers insights into the link between key cost-determining design factors and performance indicators, significantly shortening the design period. It has been determined that crop impact data remains the key piece. [33]

Mohammad Effendy Ya'acob, Noor Fadzlinda Othman and Nur Aisha Nazri (2022) The most significant issue in the global agriculture industry is Recent developments in Malaysia have revolved around the country's limited agricultural land, particularly in areas that are urban or suburban. There are existing infrastructures in place. Increasing demand and quicker returns have led to the conversion of most agricultural land to industrial land. By integrating into the existing solar photovoltaic (PV) farm infrastructure, agrivoltaic systems significantly contribute as a practical solution to reducing and creating agricultural space for agricultural operations. A solar PV array's underside is shadowed by its PV modules, which have an opaque surface and only allow sunlight to pass via holes between them and reflect light from the ground. [34]

Leroy J. Walston, Tristan Barley and All (2022) Decarbonization targets must address global climate change and rising energy demands, requiring substantial ongoing solar energy expenditures. The demand for land resources for energy production and other land uses (such as agriculture and biodiversity preservation) has grown due to the worldwide spread of utility-scale solar projects. In order to address this growing problem, greater emphasis has been placed on solar development strategies that maximise the advantages of solar energy generation and multiple ecosystem services, such as the creation of agrivoltaic systems that co-locate solar energy production with different types of conservation and agricultural land uses. This study aims to synthesise the possible ecosystem services of agrivoltaics comprehensively and discuss how these development methods may contribute to many of the Sustainable Development Goals (SDGs) of the United Nations. [35]

Daisuke Yajima, Teruya Toyoda (2023) Global issues that demand immediate action include escalating food production brought on by population increases and climate change. In general, the deployment of renewable energy to combat climate change and the need for enough land to boost food production are incompatible. However, an agrivoltaic system uses a shared area of land to grow crops and produce renewable power, increasing the land yield. Additionally, this strategy supports regional production, which lowers logistics-related CO₂ emissions. Even in more recent experiments, photovoltaic arrays

were constructed by computing the irradiance in W/m². A proper lighting plan for productive agriculture must be devised for the fields. [36]

Sebastian Zainali a, Silvia Ma Lu and Ali (2023) Agrivoltaic systems are gaining popularity as a key technology for achieving several sustainable development objectives, including zero hunger, clean and inexpensive electricity, clean water and sanitation, and climate action. However, selecting the best agrivoltaic system necessitates having a thorough grasp of how shade affects crops because a poor decision might result in considerable agricultural output losses. In order to examine the shadowing conditions on the ground used for crop production, fixed vertical, one-axis tracking, and two-axis tracking photovoltaic arrays for agrivoltaic applications were created. Comparing the models' accuracy to that of commercial programmes like PVSyst and SketchUp, they were very accurate. [37]

CHAPTER -3

AIM AND SCOPE

3.1 AIM OF THE PROJECT

Our primary aim of this project is to fabrication of Agrivoltaics to address water land – energy nexus for famers and solar companies to reduce land wastage.

3.2 OBJECTIVE

- To conduct a comprehensive analysis and critical evaluation of agrivoltaic system.
- To solve the land wastage happening by using solar farms.
- To design and fabricate the different types of agrivoltaics models.
- To optimize agrivoltaics plant for efficient power generation.
- To decide the best agrivoltaic system among all the designs.

3.3 SCOPE OF THE PROJECT

- Review of various articles to identify the different types of designs using Google scholar.
- Utilising the solidworks software, the following designs were created.
 - Horizontal Agrivoltaics
 - Vertical Agrivoltaics
 - Tilted Agrivoltaics
- Designing the common components and putting together the panels for the necessary designs
- Analysing the best design and suggesting the farmers to hoe to use the land

CHAPTER-4

MATERIAL & METHODOLOGY

4.1 METHODOLOGY FOR AGRIVOLTAICS

This chapter will discuss the agrivoltaic system design approach. I've created three agrivoltaic designs. Which are

- 1) Horizontal solar panel.
- 2) Vertical Solar Panel (Bi-Facial)
- 3) Tilted Solar Panel

For all three designs, the common parts are rods, a back-sheet, tempered glass, solar cells, and a steel frame. For the different designs, the orientation of the parts, I have chosen the dimensions of the solar panel from one of the panels that is in the energy lab, and the dimensions that I have recorded are:

4.2 MATERIALS USED

For fabrication of Agrivoltaics 16 steel rods were utilized, each measuring 6mm in diameter and 14 inches in length. Additionally, incorporated 48 solar panels, acrylic sheets, and an acrylic sheet cutter for construction purposes. The experiment also required red soil mixed with manure as a growth medium for the plants. For the plant samples and used mung bean and fenugreek seeds. Wires were used for electrical connections, and a digital multi-meter (DMM) was employed for measuring electrical parameters.

4.3 FLOW CHART

The below figure shows the project methodology flow chart.

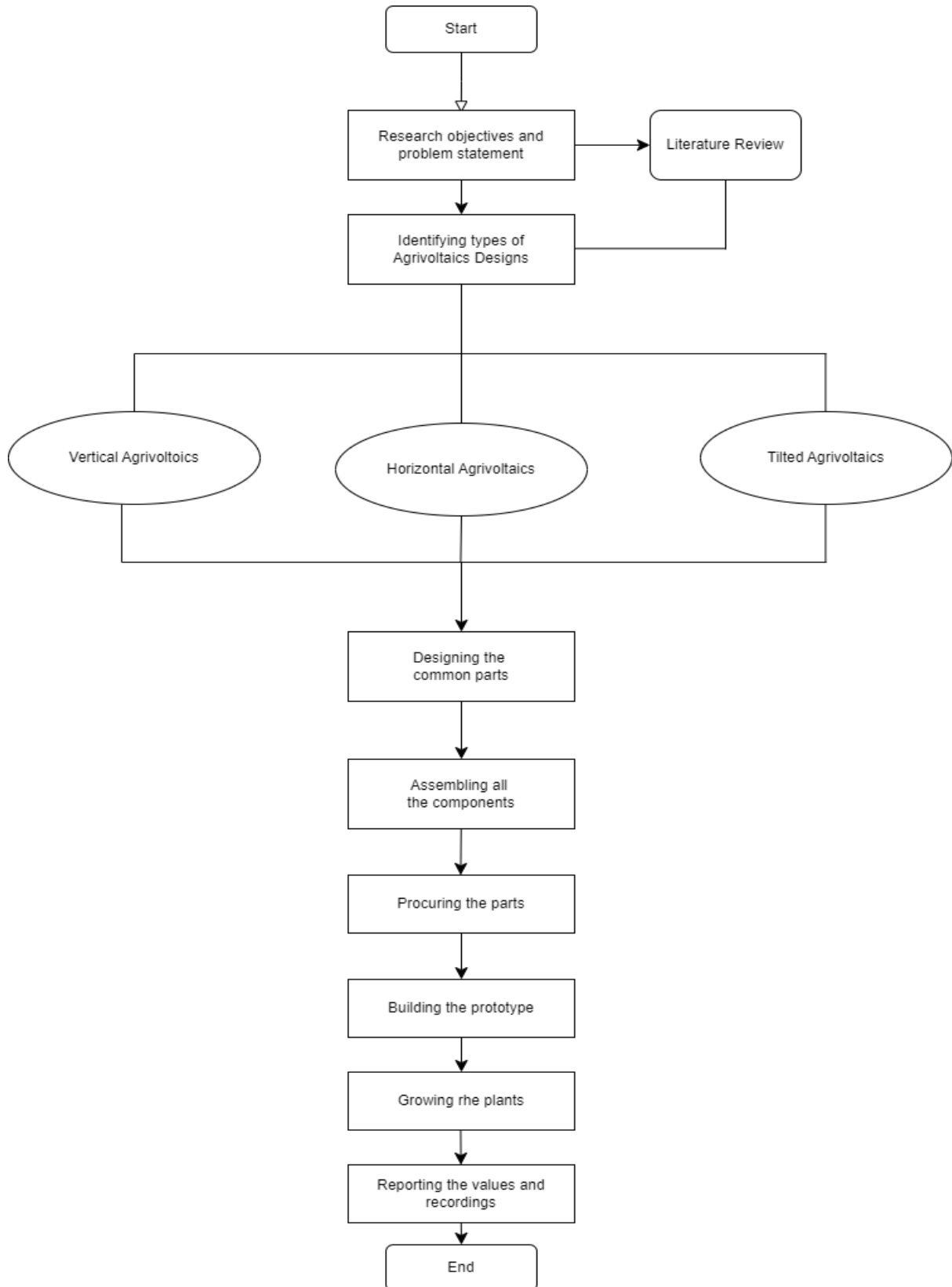


Fig:4.1: Flow Chart

4.4 SOLIDWORKS DESIGN

4.4.1) Rod

Step 1- In the Solidworks software, create a new part design.

Step 2- Now select Front Plane, and then select the circle option in the tool bar.

Step 3- Draw two circles with the same centre point, and the diameters of circles should be 60mm and 40mm, respectively.

Step 4- Now, quit the sketch and select the extrude base option to extrude the middle section of two circles for 355.6mm.

Step 5- Apply the Steel substance for the rod now.

Step 6- Save the Sketch.



Fig:4.2: Rod

4.4.2) Rod (For Tilted)

Step 1- In the Solidworks software, create a new part design.

Step 2- Now select Front Plane, and then select the circle option in the tool bar.

Step 3- Draw two circles with the same centre point, and the diameters of circles should be 60mm and 40mm, respectively.

Step 4- Now, quit the sketch and select the extrude base option to extrude the middle section of two circles for 304.8mm.

Step 5- Apply the Aluminium substance for the rod now.

Step 6- Save the Sketch



Fig:4.3: Rod (Tilted)

4.4.3) Solar Cells

Step 1- In the Solidworks software, create a new part design.

Step 2- Now select Front Plane, and then select the rectangle option in the tool bar.

Step 3- Now draw a rectangle with 1990 mm of length and 991 mm of breadth.

Step 4- Now, quit the sketch and select the extrude base option to extrude the rectangle for 7.00mm

Step 5- Now draw a rectangle with 152 mm of length and 20 mm of breadth, On the cuboid which is created before.

Step 6- Now, quit the sketch and select the extrude base option to extrude the rectangle for 0.50mm

Step 7- Use the local pattern and the initial pattern for up to five sections right now.

Step 8- Now, cut the ends of those sections using a 5mm fillet.

Step 9- Once more, utilise a local pattern and duplicate it up to 60 times. 5 times on one side and 12 times on the other.

Step 10- Apply the silicon substance for the solar cells now.

Step 11- Save the Sketch.



Fig:4.4: Solar cells

4.5 HORIZONTAL AGRIVOLTAICS

Firstly, Enter the assembly area of Solidworks and insert the frame into which the horizontal solar panel will be placed. Next, must insert all other elements, and the rod must be imported four times. Now need to mate all the components. Then will first align all of the rods in the frame's four corners. The glass will then be attached to the frame, where this portion should be, and to the other side of the rods. The solar cells should next be attached to the back of the glass, and then the back sheet should be attached to the solar cells. The frame should be horizontal in the first place, and even the other elements should be.



Fig:4.5: Horizontal Solar Panel

The design incorporates the use of solar panels and agricultural production simultaneously. This innovative design brings forth the possibility of enhancing the land's productivity while harnessing the sun's energy. The combination of agriculture and solar power allows farmers to cultivate crops while producing renewable energy. Ultimately, this approach aims to contribute towards sustainable living and a greener environment.

4.6 VERTICAL (BI-FACIAL) AGRIVOLTAICS

First, Enter the assembly area of Solidworks and insert the frame into which the horizontal solar panel will be placed. Next, Insert all other elements, and the rod must be imported two times and now need to mate all the components. Then align all of the rods in the frame's base two corners. The glass will be similarly affixed to the frame as before. The solar cells should next be attached to the back of the glass, and then the back sheet should be attached to the solar cells. The solar cell has to be mated on the other side from when it was done previously. The frame should be vertical in the first place, and even the other elements should be.

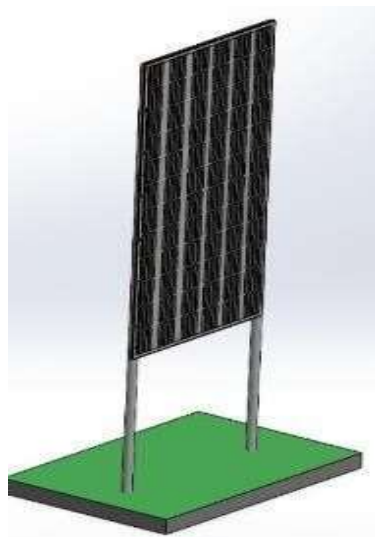


Fig:4.6: Vertical Solar Panel

And can create a vertical Agrivoltaics system. This design involves stacking layers of vegetation and solar panels to maximize land use efficiency and energy production. By combining agriculture with photovoltaic technology, simultaneously produce food and renewable energy. This system can save land

space, reduce water consumption, and lower carbon emissions. Implementing such a system can promote sustainable agriculture and energy production.

4.7 TILTED AGRIVOLTAICS

First, Enter the assembly area of Solidworks and insert the frame into which the horizontal solar panel will be placed. Next, Insert all of the other elements, and the rod must be imported twice, and another rod has more length another two times. Now need to mate all the components. Then align all of the rods in the frame's two corners and the other rod to the other two corners. The glass will then be attached to the frame, where this portion should be, and to the other side of the rods. The solar cells should next be attached to the back of the glass, and then the back sheet should be attached to the solar cells. The frame should be tilted 25 degrees first, and even the other elements should be. Then choose 25 degrees tilt since, as per the Indian location.

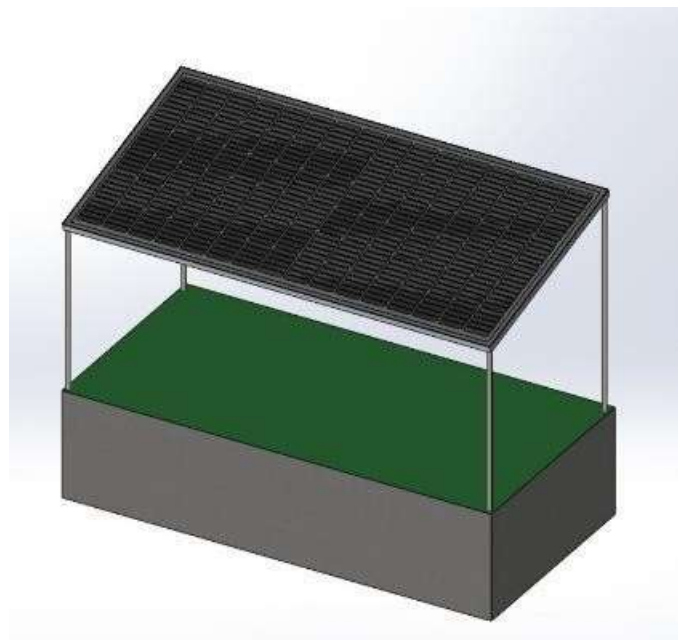


Fig:4.7: Tilted Solar Panel

This can be done with the help of Tilted Agrivoltalics design, a concept created to make agriculture more efficient. With this design, the panels can be tilted to get maximum sunlight, ensuring that crops grown under them receive the most

suitable environment for growth. By adopting this design, farmers can not only produce healthy crops but also ensure that they sustainably use resources.

Chapter-5

RESULTS AND DISCUSSION

Firstly, The types of plants and animal husbandry which can be adapted in Agrivoltaics is been listed and then tabulated them in table 5.1 and table 5.2.

Table 5.1: List of plants

S. No	Plants Can be Grown
1	Mung Bean
2	Fenugreek
3	Coriander
4	Blue Berries Farm
5	Cereals (Wheat 2 Barley)
6	Cucumber
7	Peach
8	Plum
9	Apricot
10	Mirabelle
12	Mint
13	Spinach
14	Parsley
15	Celery
16	Mirchi
17	Tomato
18	Green Peas
19	Animal Grazing
20	Bean
21	Corn
22	Asian pigeonwings
23	False daisy
24	Amaranthus campestris

Table 5.2: Table of Animal Husbandry

S. No	Animal Husbandry
1	Honey Bees
2	Butter Flies
3	Sheep Farming
4	Cattle Farming

The arrangement has been installed in small pots made of acrylic sheets of

Length - 16 Inches

Width – 12 Inches

Height – 6 Inches



Fig:5.1: Acrylic sheets boxes

The pots shown in Figure 5.1 above are produced from acrylic sheets that have been cut into three sections measuring 16 inches long by 12 inches wide, six sections measuring 16 inches long by 6 inches wide, and six sections measuring 12 inches long by 6 inches wide using an acrylic cutter. and been adhered to like an open package.

After that, the pots are filled with organic sand, a mixture of pesticides, and red dirt that speeds up plant growth and gives the seedlings the nutrients they need. This carefully formulated blend serves as an ideal medium for the fenugreek and mung bean seeds, ensuring optimal conditions for germination and early growth. Unlike traditional methods, which may rely on artificial lighting, solar panels are not installed

in this setup. Instead, these plants are chosen for their adaptability to low light levels, thriving even with minimal exposure to sunlight. Additionally, both fenugreek and mung beans have short growth cycles, allowing for quick progress tracking and efficient use of resources. This selection of plants and growing medium reflects a thoughtful approach to sustainable agriculture, maximizing yield potential while minimizing environmental impact. And the below figure 5.2 represents the pots which are filled with soil.



Fig:5.2: Pots with soil

Following a period of fifteen days during which the plants were observed daily, notable differences in growth were observed between the mung bean and fenugreek plants. The mung bean plants thrived, developing into large, robust plants within this timeframe. In contrast, the fenugreek plant's growth was markedly slower, with the first sampling taken nearly eight days after planting. This discrepancy in growth rates could be attributed to various factors, including differences in the plants' genetic makeup, environmental conditions, or nutrient requirements. Further analysis is needed to understand the specific factors influencing the growth of these plants and to optimize their growth in future experiments. After fifteen days of monitoring, the plants' development is seen in figure 5.3.



Fig:5.3: Plants after 15 days observation.

After the initial observation period, the plants were removed, and the soil was ploughed once again in preparation for the next set of plants. This time, however, only mung beans were used in all three pots. By standardizing the seed type across all pots, I aimed to compare their growth under identical conditions. This approach eliminates any potential variables introduced by using different seeds and allows for a more direct comparison of the plants' growth patterns and development. The vertical solar panels that are stored in soil are seen in figure 5.4 below. Next, the

horizontal solar panel arrangement that is stored in the soil is seen in figure 5.5. Lastly, the 25° slanted angle solar panel that creates the Indian circumstances is shown in figure 5.6.



Fig:5.4: Vertical Solar Panels



Fig:5.5: Horizontal Solar Panels



Fig :5.6: 25° Tilted Solar Panels



Fig: 5.7: All three solar Panels top view

Then checked the power outcome of the solar panels from morning 9:00 A.M to 5:00 P.M in regular intervals of 2 hours by Multimeter and been tabulated below in table no 5.3.

Table 5.3: Power outcome from three types of solar panels

	Vertical Solar Panels (In Volts)		Horizontal Solar Panels (In Volts)		25° Tilted Solar Panels (In Volts)	
	1 st set Panels	2 nd Set Panels	1 st set Panels	2 nd Set Panels	1 st set Panels	2 nd Set Panels
9:00 A.M	32.2	31.3	36.1	35.2	34.5	34.4
11:00 A.M	30.4	30.7	36.9	36	35.7	36.7
1:00 P.M	17.8	28.6	37.7	36.4	36.1	37.2
3:00 P.M	34	36.2	34.3	33.1	33.4	34.3
5:00 P.M	31.3	31.3	29.9	28.8	30.8	32.2

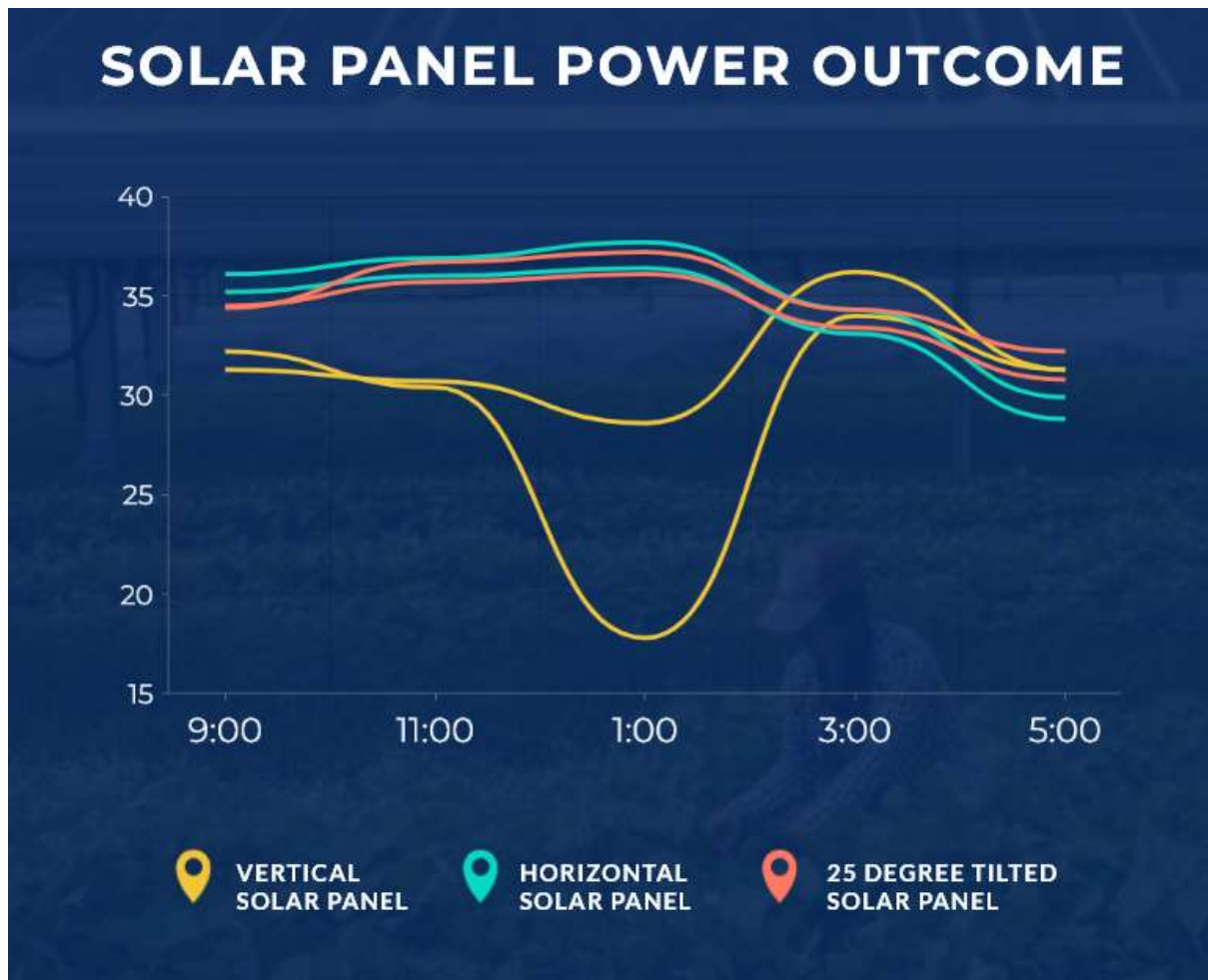


Fig: 5.8: Power Outcome graph

The power result graph is shown in figure 5.8 above, with the Volts represented on the y-axis and the time on the x-axis. Despite the bright weather and the immature state of the plants, there were probably some benefits and drawbacks to the solar panels.

Finally, after 15 days of observation the plants in tilted solar panels have grown rapidly but in remaining two pots the plants were growing slowly. The reasons may be because of lack of manure in soil since of repeated crop rapidly or since of the angle of the solar panel.

The fig 5.9 represents the pot of mung bean plants with Vertical Solar Panels and the growth of it is less. Whereas is fig 5.10 represents Horizontal Solar Panels and even in this the growth of plants is very less but okay compared to the before one. But fig 5.11 in the 25° Tilted Solar Panels the growth is too good and the plants grown rapidly.



Fig: 5.9: Vertical Solar Panel Pot

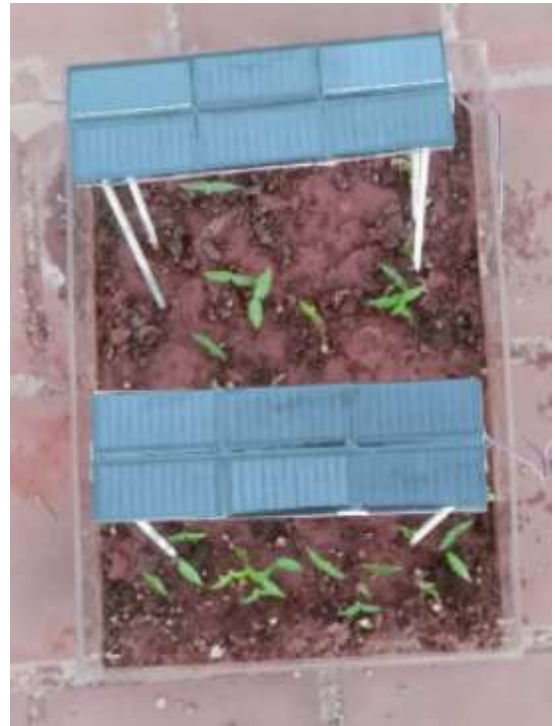


Fig: 5.10: Horizontal Solar Panel Pot



Fig: 5.11: 25° Tilted Solar Panel Pot

5.1 ADVANTAGES OF AGRIVOLTAICS:

High Voltage Output: The effective conversion of energy is shown by the high voltage output produced by the solar panels. **Sunlight Dependency:** The panels' performance showed a correlation with the amount of sunshine available, indicating that they are dependent on the sun to generate electricity. **Early development Monitoring:** You might evaluate the performance of the panels during the initial phases of plant development by monitoring the power result before to the plants reaching full maturity.

These are the common Advantages of the solar panels.

5.2 DISADVANTAGES OF AGRIVOLTAICS:

Weather Dependency: The performance of the panels may change according to the weather, with overcast days possibly resulting in a reduction in power production. **Initial Cost:** Although it isn't included in the graph specifically, installing solar panels usually has a larger upfront cost than using traditional energy sources. However, this cost can be covered over time by the money you save on energy bills.

While the common disadvantages of solar panels are well-known, it's important to note that individual solar panels can have their own unique pros and cons. These factors can vary based on the specific make, model, and design of each panel. Here's a detailed breakdown of the pros and cons of each solar panel used in the study in the table 5.4

Table 5.4: Pro's and Con's of different types of Agrivoltaics

	Horizontal Agrivoltaics	Vertical Agrivoltaics	Tilted Agrivoltaics
Pros	1) Improve crop yield and quality by providing shade, preventing stress, and maintaining consistent temperature.	1) Increase land use efficiency by enabling simultaneous crop and solar energy production on land using vertical structures like trellises.	1) Optimize solar energy capture by maximizing sun exposure, enabling farmers to generate electricity more

	2)Reduce greenhouse gas emissions, promote sustainable farming practices, and align with global climate change goals by generating clean, renewable energy.	2)Vertical agrivoltaics offer better light distribution, allowing uniform sunlight exposure, improving photosynthesis, growth, and overall crop performance compared to horizontal systems.	efficiently in diverse sun angles. 2)Provide farmers with diverse income streams, enabling renewable energy generation, grid participation, feeding tariffs, and economic sustainability through electricity sales, feed-in tariffs, and agricultural operations.
Cons	1) Reduce efficiency, affecting sunlight capture and resulting in lower electricity generation compared to standalone installations. 2)Durability and compatibility with agricultural practices for long-term sustainability and durability, avoiding damage from machinery and livestock, and ensuring crop rotation cycles.	1) Limited crop selection due to reduced sunlight, potentially impacting agricultural production diversity by affecting high light requirements and shading crops. 2) Require costly support structures, careful planning, and execution, resulting in increased installation and maintenance costs. Challenges include specialized equipment and expertise for solar panel maintenance.	1) May reduce land use efficiency by occupying additional space, limiting crop cultivation, and may not be suitable for limited land areas. 2) Affect crop management and harvesting, posing challenges in pruning, spraying, and harvesting, necessitating additional precautions and safety measures.

CHAPTER-6

CONCLUSION

This project represents a comprehensive effort to explore the potential of Agrivoltaics through a meticulous review of existing literature using Google Scholar. The objective was to identify and analyze various design options that could enhance the integration of solar panels with agricultural practices. Leveraging the capabilities of SolidWorks software, three distinct designs were conceptualized: Horizontal Agrivoltaics, Vertical Agrivoltaics, and Tilted Agrivoltaics.

Each design was meticulously evaluated to assess its advantages and challenges. Vertical solar panels, for instance, offer the advantage of higher panel density per unit of land, which can be particularly beneficial in space-constrained environments. However, they also present significant drawbacks. The shadow cast by the front panel can interfere with and reduce the performance of adjacent panels, leading to decreased overall efficiency. Moreover, areas prone to heavy winds may experience a greater risk of panel breakdown or damage when utilizing vertical panels, adding to maintenance costs and operational risks.

Horizontal solar panels, on the other hand, while avoiding some of the shadowing issues associated with vertical panels, are known to be less efficient. Their flat orientation limits their ability to capture sunlight optimally throughout the day, especially during morning and evening hours. This limitation results in reduced overall efficiency compared to other design alternatives.

After careful consideration and evaluation of these factors, tilted solar panels emerged as the most favourable option in terms of both cost and efficiency. By angling the panels, the issues of shadowing are minimized, and optimal performance can be achieved. Tilted panels allow for better alignment with the sun's path, maximizing solar energy capture throughout the day. This design also helps in self-cleaning, as rainwater can easily wash away dust and debris, maintaining optimal efficiency over time.

For the specific circumstances and climate conditions in India, a recommended tilt angle of 25 degrees is suggested for optimal performance of the solar panels. This angle takes into account the local weather conditions and maximizes the benefits of solar energy capture. Additionally, the use of tilted solar panels can help reduce the overall environmental impact of solar energy installations by optimizing land use and reducing the need for additional land development.

In conclusion, this project underscores the importance of selecting the most appropriate type of solar panel and installation approach based on specific circumstances and climate conditions. By carefully considering these factors, it is possible to achieve the best possible outcome and maximize the benefits of solar energy. The findings of this project provide valuable insights for future solar energy projects, offering guidance on how to effectively utilize available land and resources for sustainable energy production.

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