1. **Introduction:**

The research focuses on investigating the potential benefits of employing agrivoltaic systems to enhance the profitability and economic viability of high-value crops, with a specific emphasis on tomatoes and lettuce. Agrivoltaic (AV) systems, which integrate agricultural production with photovoltaic (PV) solar energy generation, offer advantages that are in line with the goals of the Green New Deal (GND) These systems optimize the utilization of land, water, and PV panels, resulting in improved land-use efficiency, water use efficiency, and PV panel efficiency (Amaducci et al., 2018). However, the impact of agrivoltaic on profitability is still a significant area of research because Costs and Investment of Agrivoltaic systems require upfront investment in solar panels, support structures, and associated infrastructure (Trommsdorff et al., 2021). The cost of establishing and maintaining the system must be balanced with the potential benefits to determine the profitability. Therefore, this research can help identify cost-effective design and maintenance strategies (Jain et al., 2021)

This study investigates the potential benefits of employing agrivoltaic for tomatoes and lettuce production in two diverse regions, namely Arizona and Alabama. Hence, the primary research focus aim at delving into the methods that can enhance the profitability and economic viability of high-value crops, specifically tomatoes and lettuce within agrivoltaic systems. The focus is to understand the interaction between the PV panels and the growth of these crops to identify optimal strategies that can maximize profit while also ensuring efficient solar energy generation. It is paramount that by analyzing different configurations and their impact on crop growth and solar energy generation, the research aims to identify the most effective layout for achieving optimal outcomes. Factors such as shading, temperature, and humidity can significantly influence crop growth and productivity (Barron-Gafford et al., 2019). The most important purpose of this research is to identify the economic viability of agrivoltaic systems for high-value crop production as a key aspect of this study. By quantifying the economic impact of agrivoltaic, the study aims to provide valuable insights for farmers and investors on the financial feasibility of adopting this integrated approach. Consequently, this research holds significant importance due to several reasons. Firstly, high-value crops such as tomatoes and lettuce play a crucial role in agricultural economies, contributing to food security and generating substantial revenue. Enhancing their profitability within agrivoltaic systems can have a positive impact on the overall agricultural sector (Agostini et al., 2021). Secondly, with the increasing demand for renewable energy and limited land availability, agrivoltaic provides a potential solution by allowing the dual use of land for both food production and clean energy generation. This study aims to shed light on the viability and benefits of this integrated approach (Trommsdorff et al., 2021). Furthermore, Prior research has explored the application of agrivoltaic systems in various crop types and regions, highlighting the potential for increased productivity, water savings, and improved microclimatic conditions (Jain et al., 2021). However, limited studies have specifically focused on high-value crops like tomatoes and lettuce, and their suitability within agrivoltaic systems in the specific regions of Arizona and Alabama. By building upon existing knowledge, this study aims to fill this research gap and provide valuable insights for farmers, policymakers, and investors interested in adopting agrivoltaic for high-value crop cultivation and this research work in turn will contribute to the existing body of knowledge by conducting a comprehensive case study on the productivity and economic viability of tomatoes and strawberries within agrivoltaic systems in Arizona and Alabama. By analyzing factors such as crop growth, yield, quality, and economic returns, I aim to provide practical recommendations for optimizing the coexistence of PV systems and high-value crop production. The findings of this research can serve as a foundation for future research and inform decision-making processes related to sustainable agriculture and renewable energy integration.

In summary, this research aims to enhance the profitability and economic viability of high-value crops, specifically tomatoes and lettuce, within agrivoltaic systems in Arizona and Alabama. By investigating the interactions between PV systems and crop cultivation, this study seeks to contribute to the growing body of knowledge on sustainable agriculture and renewable energy integration, ultimately benefiting farmers, policymakers, and the agricultural sector.

1. **Literature review**

In agrivoltaic systems setups are done to accommodate, grow crops and generate solar energy on the same piece of land. By doing this, we aim to make the best use of the land and produce both food and energy efficiently. This review is exploring how profitable it is to grow high-value crops like tomatoes and lettuces using this system in two states, Arizona, and Alabama, with differing climates. To be more specific, I am looking at how the weather conditions in these states impact the growth of crops and generation of solar power, how much energy can be produced, how efficiently water is used, and whether this whole setup is economically viable or feasible. So, this investigation is trying to find out if combining agriculture with solar power generation can be a win-win in these areas, especially focusing on growing tomatoes and lettuce.

**2.1 Agrivoltaic (AV) system**

APV enables the concurrent collection of both agricultural products and solar electricity within the same farming area through the optimization of both production systems(Dupraz et al., 2011). APV is described as the utilization of a single land area for both generating solar electricity and conducting agricultural production, including aquaculture, APV is alternatively defined as an emerging strategy that combines energy and food harvesting on the same land(Amaducci et al., 2018). This approach aims to enhance land productivity, leading to increased crop yields and improved socio-economic well-being for farmers (Neupane Bhandari et al., 2021). In relation to productivity, APV offers various advantages, such as shielding crops from radiation stress, decreasing water requirements by minimizing evaporation, achieving higher crop yields for shade-tolerant plants, and more (Dupraz et al., 2011). These benefits can significantly contribute to bolstering economic progress and food security, particularly in rural regions (Neupane Bhandari et al., 2021). APV presents a promising avenue for simultaneous food production, water conservation, and renewable energy generation in the same location (Agostini et al., 2021). Additionally, it extends electricity access to areas that previously lacked it. The implementation of APV also results in the creation of fresh employment opportunities within the agricultural and energy sectors, leading to improved socio-economic conditions, particularly for farmers. The electricity generation from solar sources aids in reducing CO2 emissions, aligning with national targets for addressing climate change. Furthermore, the APV infrastructure can be strategically employed to harvest and manage water for crop irrigation and other uses. Notably, photovoltaic arrays can serve as channels for irrigation runoff, directly delivering water to the crops (Neupane Bhandari et al., 2021). Incorporating vegetation around and underneath solar panels proves effective in reducing panel dust and soiling (Barron-Gafford et al., 2019). While APV offers considerable benefits, it also presents certain challenges. A more comprehensive grasp of technical, economic, and agricultural facets is necessary, and research into factors influencing societal acceptance of these novel applications is vital. Implementing APV systems poses difficulties as they intricately intersect with agriculture, the local economy, and on-site stakeholders (Dupraz et al., 2011). These systems are more expensive than ground-mounted PV setups and at the policy level, several countries have yet to address issues like the sale of PV electricity to local consumers, grid integration, and related matters, which have been addressed for PV-only solar power systems (Trommsdorff et al., 2021).  
(Dinesh & Pearce, 2016) conducted an experiment where lettuce crops were grown under solar AV arrays on stilts, analyzing how shading affected lettuce yields. The results showed that lettuce adapted well to shading from the PV arrays, with no significant impact on yield. This allowed the same land to be used for both electricity and food production successfully. Using the Land Equivalent Ratio (LER) methodology, the experiment demonstrated that the agrivoltaic system, combining lettuce and electricity generation, outperformed monocrop systems in terms of yield. In essence, the study highlighted the efficiency of agrivoltaic systems compared to traditional monoculture farming.

* 1. **Climate Conditions of Arizona and Alabama:**

2.2.1. Arizona: Arid Climate:

Arizona is a hot and dry place, with very little rain, usually less than 10 inches every year (Colby & Jacobs, 2007). This kind of weather makes it challenging to grow plants because there’s barely enough water available (Elias et al., 2019). Hence, cultivating and making use of land in Arizona to grow crops and produce solar energy at the same time—is called agrivoltaic system—Farmers and solar investors really need to be smart about how water is used . This is because, without proper water management, it can be hard to keep the plants alive and get energy from the solar panels in such a dry place (Toledo and Scognamiglio, (2021). So, saving and efficiently using every drop of water is critical here.

2.2.2. Alabama: Humid subtropical climate

Alabama has a very different climate compared to Arizona—it’s usually warm, and it rains a lot, with about 56 inches of rain each year (Garreaud et al., 2009). This means there is plenty of water for plants to grow. Because of this, when setting up agrivoltaic systems in Alabama—where crops are grown, and energy are produced on the same land—the focus could be on managing the amount of light the crops receive. This is because there's already enough water, so the goal is to find the best light conditions to help the crops grow well while also efficiently producing solar energy (Albatayneh et al., 2023). The ample water allows for the possibility to explore growing different kinds of high-value crops and finding the best conditions for both farming and energy production.

**2.2. High-Value Crops: Tomatoes and Lettuces**

Tomato and lettuce are acknowledged as high value crops due to their substantial market demand and the profitability they offer to producers. Tomatoes, thriving in abundant sunlight and requiring moderate water, benefit from well-managed water resources and optimum sunlight to facilitate better growth and yield (Al-Agele et al., 2021). Conversely, lettuces prefer cooler temperatures and consistent moisture, flourishing where water is abundant and temperatures are moderate, preventing bolting and maintaining quality(Chowdhury & Mandal, 2021). Given their contrasting growth requirements, optimizing agrivoltaic systems—where agriculture and solar power coexist—requires a nuanced understanding and management of sunlight, temperature, and water to cater to the specific needs of each crop (Gorjian et al., 2022).

**2.3. Optimization Strategies in Arizona and Alabama**

In Arizona, where the climate is predominantly arid, the optimization strategies for agrivoltaic systems primarily revolve around enhancing water-use efficiency due to the scarcity of water. Studies by (Colby & Jacobs, 2007) suggest that such systems can aid in lowering high evapotranspiration rates and conserving water. Furthermore, research conducted by (Barron-Gafford et al., 2019) indicates that implementing agrivoltaic systems in such dry climates can significantly ameliorate the microclimate for the growth of vegetable crops, lead to increased yield, and decrease water requirements. Conversely, in Alabama, which is characterized by its substantial rainfall, the optimization strategies are more centered on manipulating and optimizing light conditions to promote crop growth and yield, given the ample availability of water. According to (Goetzerger and Zastrow (1982), the use of colored solar panels to modify light quality can be beneficial in enhancing crop growth and productivity. Additionally, findings by (Dinesh and Pearce,(2016) support the notion that optimizing light exposure and minimizing excessive sunlight can boost the yields, especially of crops that prefer shade, like lettuces**.**

**3.1 Methodology**

This chapter explains the methods to figure out the best ways to make more profit from growing valuable crops like tomatoes and lettuces while also generating solar energy on the same land, in both Arizona and Alabama. The idea is to design a model that lets solar panels and crops help each other grow and considering the different weather conditions in each state. Arizona is usually very hot and dry, while Alabama is warmer and gets more rain.

Here, I am going to walk through how important information was collected, build a model to help understand our profits better, and how I make sense of all the information gathered. Essentially creating a step-by-step guide to help understand how to efficiently use land for both farming and energy production in different weather conditions is of paramount importance.

**3.2 Study Area:**

The study focuses on Arizona and Alabama, which have contrasting weather conditions. Arizona is typically very hot and dry, receiving little rainfall, characteristic of an arid climate. This necessitates strategies to manage water scarcity and high temperatures, especially when cultivating crops and installing solar panel (Barron-Gafford et al., 2019). Conversely, Alabama experiences a humid subtropical climate with warmer temperatures and abundant rainfall, requiring efficient utilization of sunlight for crop cultivation and solar energy production amidst ample rainfall (Toledo and Scognamiglio, (2021). The distinct climatic conditions of each state pose unique challenges and considerations in optimizing the growth of crops and the generation of solar energy.

**3.3 Data Collection:**

Data collection is a pivotal step in the study. It involves gathering detailed and varied information, both numerical and descriptive, related to several aspects that can impact the integration of agriculture and photovoltaic systems in Arizona and Alabama.

**Agricultural Yields**: Data on the yields of tomatoes and lettuces in different conditions is sourced to understand their growth patterns.

**Energy Yields:** Information on solar energy yields is gathered to analyze the energy output of agrivoltaic systems.

**Market Prices:** Current market prices of tomatoes, lettuces, and solar energy are collated to evaluate profitability.

**Cost Structures:** Data related to the costs involved in setting up agrivoltaic systems, including installation, maintenance, and operational costs, are compiled.

**3.4 Economic Model Development:**

The collected data serve as inputs to the economic model developed. The model seeks to maximize profitability through optimizing:

**Objective of the Model:**

The core aim of this model is to ascertain the optimal conditions and configurations that maximize profitability. This involves fine-tuning the following parameters:

*Yc*​: Yield of high-value crops (tons).

*Ys*​: Energy produced by solar panels (kWh).

*Pc*​: Price per ton of high-value crops ($/ton).

*Ps*​: Price per kWh of solar energy ($/kWh).

*Lc*​: Land allocated to crops (acres).

*Ls*​: Land allocated to solar panels (acres).

**Objective Function:**

Maximize Z= (Yc×Pc+Ys×Ps) – (Lc×Cc+Ls×Cs)

Where *Z* is the total profit, and *Lc*​& *Cs & Ls*​ are the total costs of growing crops and maintaining solar panels, respectively.

**Constraints:**

Land Allocation: *L*=*Lc*​+*Ls*​

Represents the total available land, which is the sum of the land allocated to crops and solar panels.

**Yield Functions:**

Yield functions based on the land allocation.

Yc= f(Lc)

Ys=f(Ls)

Represents the relationship between land allocation and the yields of crops and solar panels.

**Return on Investment (ROI):**

ROI is a metric that evaluates the profitability of an investment relative to its cost. It's expressed as a percentage and provides an indication of the returns earned on each dollar invested.

Total Revenue = Revenue from crops + Revenue from solar energy

(Yc×Pc) + (Ys×Ps)

Total cost = cost of setting up and maintaining crops + cost of setting up and maintaining solar panels. (LC×Cc) + (Ls×Cs)

ROI = net profit ÷ total investment \* 100%

**Break-even point:** APV facilitates the simultaneous harvest of agricultural goods and solar energy on the same tract of land by fine-tuning both production methods (Dupraz et al., 2011). It involves the dual use of land to produce both solar power and agricultural goods, encompassing fields like aquaculture. Another perspective on APV sees it as a novel approach intertwining energy production and food cultivation within a shared space (Amaducci et al., 2018).

In the context of agrivoltaic system I am looking at two main things: farming and solar power. Each has its own point where the money coming in matches the money spent. But to get the full picture, combining both and to see when their total earnings cover all the costs together.

**Fixed Costs** = Initial setup costs for crops + Initial setup costs for solar panels

**Variable cost (crops)** =

Where:

Cc= represents the total cost associated with the crops.

Yc= represents the yield or volume or crops produced

**Variable Cost (solar) =**

Where:

Cs represents the total cost associated with the solar panels.

Ys represents the energy produced by solar panels.

**Levelized cost of electricity (LCOE):** now, building a mathematical model for the LCOE while integrating the profitability of high-value crops (tomatoes and lettuces) in agrivoltaic systems in Arizona and Alabama, combining the concept:

Where:

*I*0​ = Initial investment cost for the agrivoltaic system.

*At*​ = Annual operating costs, which includes maintenance of solar panels and agricultural

*Mt*,*el*​ = Electricity generated in year *t*.

*r =* Discount rate.

*t* = Year.

*Ct*,*T*​ = Cost associated with producing tomatoes in year *t*.

*Ct*,*L*​ = Cost associated with producing lettuces in year *t*.

*Yt*,*T*​ = Revenue from selling tomatoes in year *t*.

*Yt*,*L*​ = Revenue from selling lettuces in year *t*.

**Explanation of the mathematical model:**

The numerator is the sum of the initial investment and the discounted net annual costs (operating costs + crop production costs - revenues from crop sales).

The denominator is the sum of the discounted electricity generation over the lifespan of the project.

**Region-Specific Adjustments**:

For Arizona (*A*) and Alabama (*B*), you'll have different values for some variables. For instance:

* *Mt*,*el*,*A*​ and *Mt*,*el*,*B*​: Electricity generated in Arizona and Alabama respectively.
* *Yt*,*T*,*A*​ and *Yt*,*T*,*B*​: Revenue from selling tomatoes in Arizona and Alabama respectively.
* *Yt*,*L*,*A*​ and *Yt*,*L*,*B*​: Revenue from selling lettuces in Arizona and Alabama respectively.

**Framework for AV profitability:**

Mathematical Model:

Objective Function: Maximize the combined profitability from both crop cultivation and the photovoltaic system:

Max *E*[*TC*​]+*E*[*TPV*​]

Using the given equations:

*E*[*TC*​] = *PY*​*C*×Yield−(*YV*​*C*×Yield+*FC*​)

*E*[*TPV*​] = (*PS*​+*REC*−*LCOEPV*​)×*kWhPV*​

Where:

Yield = total yield of the crop (in unit) for the given period.

*E*[*TC*​] = Expected profitability from crop cultivation (e.g., tomatoes and lettuces).

*PY*​*C* = Average selling price per unit of the crop yield.

*YV*​*C* = Variable cost per unit of crop yield.

*FC*​ = Fixed costs associated with crop cultivation (e.g., land rent, water system setup).

*E*[*TPV*​] = Expected profitability from photovoltaic (solar) system.

*PS*​ = Selling price of electricity per kWh.

*REC* = Revenue or incentives from renewable energy certificates.

*LCOEPV*​ = Levelized Cost of Electricity for the photovoltaic system.

*kWhPV*​ = Total electricity generated by the solar panels in a given period.

**Region-Specific Adjustments**:

I will have to adjust variables like *PY*​*C*, *YV*​*C*, *FC*​, *PS*​, *REC*, *LCOEPV*​, and *kWhPV*​ based on the data specific to Arizona (denoted by subscript *A*) and Alabama (denoted by subscript *B*).

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