

Energy Assessment based Smart Sustainable Production in Wireless Environment Using Internet of Agricultural Things (IoAT)

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Abstract

The attainment of smart sustainable production of energy is the goal, which is being pursued globally. In the field of agricultural system, several challenges are present and as well, it is combined with the climatic crises. In general, the renewable energy resources is the origin of energy production and consumption so that using this energy source it is possible to improve the ecologically and social agriculture. Due to the expansion of renewable energy, the concept of Agrivoltaic System is created which convert the food production to energy generation process. Currently many of the research are developed to increase the crop yield and energy production. In this article, we concentrate on intelligent farming in agrivoltaic system with the help of Internet of Agricultural Things (IoAT). It focuses on newer preliminary methods like fluid dynamic system, improved photovoltaic (PV) module, land equivalent ratio analysis and shading ratio calculation. In IoAT, based system, crop field analysis, energy production model, sensor localization process, cost optimization and fault diagnosis processes are concentrated. So that the effective outcomes are attained in the cultivation of crops like melon, bean, millet, and cucumber. The parameters, which are calculated in the results analysis, are shading ratio and temperature, crops-based analysis, and energy-based analysis. With the help of IoAT system both, the crop yield and electricity production is increased.

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1. Introduction

The human race is now seriously threatened by climate change. The threats to humans and the planet will considerably increase if greenhouse gas concentrations in the atmosphere keep increasing. Many nations have vowed to keep global warming to 1.5oC over pre-industrial sectors. Worldwide population expansion also raises the need for food and energy, in addition to climate change. Agrivoltaics is one way to lessen the problems caused by climate change and food security and the structure of the Agrivoltaics are shown in figure 1 [1].

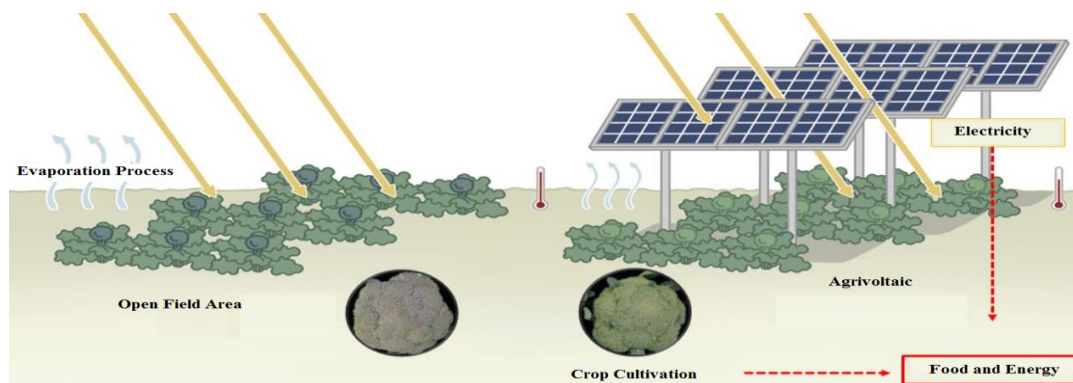


Figure 1. Agrivoltaic system

Using photovoltaics (PV) to produce energy while also doing agricultural activities on the same plot of land is referred to as "agrivoltaics." Agrivoltaics is seen as multipurpose, in contrast to monofunctional solar power plants (SPP), which are sometimes criticized for competing with food production for land usage. Agrivoltaics' installed capacity has increased significantly in recent years on a global scale, from 5 MW in 2012 to 2800 MW in 2020. In recent years, many agrivoltaic categories have appeared. The classification of agrivoltaics may be influenced with the usage of the ground beneath the PV arrays [2].

Localization of renewable energy have to be accomplished, as much as feasible, not including the utilization of huge land because the restricted area of developed/insular areas is one of their key restraints. Similar to this, a lack of available land creates problems for agriculture, and in remote areas and archipelagos, where it is most necessary owing to distance and food transit issues, food sovereignty is frequently low. These territorial restrictions are frequent in areas with dense populations, and they are often more severe for islands. Thus, it is necessary to assess the PV potential of greenhouses that can help to simultaneously tackle the issues of food and energy production [3].

PVs are the majority, which is frequently utilized in the industrial sectors, and it is being used to implement renewable energy systems to help battle climate variation and to attain carbon impartiality. However, because PV facilities need a lot of space, there is less cropland available [4]. Agrivoltaic systems, which employ solar energy for agricultural growth and electricity area, are quickly gaining attention as a solution to this problem. This is a cutting-edge smart-farm technology that integrates agricultural and energy production to increase sustainability and land use efficiency. Goetzberger and Zastrow originally developed it, and it has now diversified into a number of industries, including "agrivoltaics," "agrophotovoltaics," "PV agriculture," and "solar-sharing." As an effect of the PV modules utilized in Agrivoltaic systems, solar radiation, one of the key variables in agriculture, reduces, which has a negative impact on agricultural development. However, when the PV modules are positioned properly, it can aid agricultural development since insolation over the light saturation limit reduces the photosynthetic effectiveness of crops and as well its evaporates moisture. Additionally, by partially obstructing significant rains, a lot of snow, and chilly winds, these modules can help agriculture. Above all, more solar radiation may be used to generate energy, increasing agricultural income. Additionally, these methods often have lower water consumption rates and greenhouse gas emissions than rice fields [5].

Due to an expanding global population and economy, there is a parallel rise in the need for agricultural products to the rising energy demand. About 70% of all freshwater withdrawals worldwide are used for agriculture. Due to the tight ties between the sectors of water, food, and energy [6], the scarcity of freshwater have to be taken through supporting incorporated water resources organization to achieve the SDGs. Farmers and its systems have been successful in fulfilling the world's demand in terms of food, but they faced great hurdles in order to satisfy the need for food in the future, which is predicted to increase by 59% to 98% by the year 2050. Land must be exploited extensively in order to meet both agricultural and energy demands. However, because of the excessive use of land for energy conversion (i.e., land is used for cultivating energy crops), cities and network growth, climatic changes, and desertification, to name a few, we are also witnessing a global shortage of agricultural land in addition to water [7].

The production of solar energy in agricultural lands with restrictions, or the fact that this system gives farmers revenue from selling agricultural goods in addition to income from power generation with the help of same land, served as the primary driving force behind the creation of agrivoltaic systems[8]. The loss in agricultural revenue brought on by an unpredictable environment and market risk is offset in part by this new source of income [9]. The enhancement of biodiversity and carbon sequestration is indirectly impacted by environmental credit, according to [10]. In order to overcome these drawbacks in this paper Internet of Agricultural Things (IoAT) is developed and it is combined with the agrivoltaic systems mainly to provide energy assessment and that is leads to attain intelligent farming. The contributions of this study are:

- We propose an Internet of Agricultural Things (IoAT) to achieve intelligent farming using agrivoltaic systems. Here both the crop cultivation and electricity generation is performed an effective manner using certain materials and methods.
- The considered ideas in this article are Fluid Dynamics Model, improved PV Module and its other properties, Land equivalent ratio (LER) Calculation and Shading Ratio Calculation.
- In proposed IoAT method, initially its architecture is elaborated, then field structure and cropping model is detailed followed by that the energy production model, sensor localization, cost optimization and fault diagnosis are performed.
- Through a method the overall energy consumption is reduced at the time of crop cultivation and through IoAT, the final yield is increased.

The organization of the paper is listed here, in section 2 the baseline researches about agrivoltaic systems and PV modules are provided and its drawbacks are identified. In section 3 the required materials and methods which is involved in this article is discussed. In section 4 the proposed IoAT model is elaborated and it is combined with the agrivoltaic systems. In section 5 the performance analysis and results discussion is provided.

2. Related Work

In [11], the author Botero-Valencia et al., 2022 developed a flexible, independent, solar-powered temperature station using WiFi or 3G wireless connection. The parameters, which are considered in these measurements, are radiation, temperature, air pressure, precipitation and speed of the wind. The ability to operate this framework remotely is its main advantage. However, the construction of this structure is extremely costly and heavily dependent on location.

In [12], the author Eduardo et al., 2022 considered the agrivoltaics (APV) from greenhouse applications global potential. This framework has optimized the APV system, showing that the PV system is not responsible for the crop development by altering the Transparency Factor (TRF) to reduce 10% of the yearly Photo Synthetic Rate (PSN) of each species. This paradigm is still constrained to a small number of geographic regions or/and plant species, though.

In [13], the author Chong Seok Choiet al., 2021 investigated the possibility of a co-located solar PV growing from an economic and environmental perspective. The model village's annual energy needs may possibly be met three times over by the annual energy output, which would result in a considerable reduction in GHG emissions compared to grid supply or diesel electricity generation on a comparable size. Although, PV was extremely expensive and without any subsidies, the low positive Net Present Value of standalone PV land use also demonstrated.

In [14], the author Okakwu et al., 2022 analyzed how the total system head and as well the solar radiation affects the technological and financial structure of a PV-pump system for groundwater irrigation of agricultural produce. The results showed how adjusting the system head and solar radiation affected the results. It has been demonstrated that the system is still functional at higher sun radiation levels. The PV pumping system are mainly developed to underperform at higher system heads.

In [15], the author Anne-Kathrin Schneider et al., 2023 focused on carrying out gardening utilizing battery- or cable-powered equipment. The findings of this framework suggest that portable battery storage devices can spread out loads more evenly and demand less power for grid connections. However, it can be more difficult to install solar panels on farmland locations in heavily populated agricultural regions in terms of acceptability.

In [16], the author Oudes et al., 2022 designed and put to the experiment a kind of multifunctional solar power plant which can help with open, fact-based decision-making. The typology of this framework provides direction and elements for decision-making on the landscapes, which are used for the generation of solar energy. This study shows how changing the PV infrastructure for instance, the energy density allows energy production to coexist with different uses. However, installation comes at a significant cost.

In [17], the author Xueqian Fu et al., 2022 examined the important Agricultural Energy Internet technologies for the fields of agriculture and fisheries in a methodical manner. According to the study, the Internet of Things will be enhanced even further to enable agricultural energy systems to be automated and intelligent. The last finding of this paradigm is that further research is required to investigate the implications of agricultural electrification.

In [15], the author Friha et al., 2021 analysed the innovations in internet-based smart agriculture. In this article, several techniques are emerged. Some of the main ideas are Internet of Things based agricultural functionalities, drones based wireless communication, software defined networks and cloud based fog computing. However, there are still certain research areas that need further attention, including hardware boards, pricing for hardware and software, energy utilization, and privacy.

In [16], the author Huang et al., 2020 proposed a new Internet of Things for agriculture, or PAIoT, that combines PA with IoT technologies. This framework effectively handles the real production, considerably encouraging the advancement of intelligent farming. However, the container needs a lot of electricity, particularly in the plateau region, and the cost per unit of electricity is expensive.

In [17], the author Jayaraman et al., 2016 developed a novel approach namely SmartFarmNet, an internet based platform which can able to collect the environmental, soil, fertilization, and irrigation data, correlate such data, remove invalid data, assess crop performance, compute crop forecasts in an automatic manner, and create customized crop based recommendations for the farm. Vendor-specific solutions, however, offer either little to no connectivity with other IoT ecosystem devices.

In [18], the author Romain Carrausse et al., 2023 analysed the growth of agrivoltaism from its conception to its diffusion in various places. According to this study, agrivoltaism is the interactions among players in the power generation and agricultural sectors who are technologically and scientifically literate. However, their political backing in France does not support the governance dynamics that may bring these two regions together.

In [19], the author Pascaris et al. 2022 evaluated if increased public support for solar development results from the integration of energy and agricultural produce in an agrivoltaic system. This paradigm states that if agricultural products are included in the solar development in their community, 81.8% of respondents are more inclined to support it. This tactic's drawback is that it makes greenhouses warm up too much.

In [20], the author Odysseas Alexandros Katsikogiannis et al.'s 2022 goal is to create a multi-scale modeling approach with the aim of determining the topography for the conversion between the medium and the large scale fixed bifacial APV array. This framework observed a 33% drop in electrical AC yield while boosting land productivity by 50%, in comparison to traditional and separate production. However, plant yield is reduced because of the high irradiance, high temperature, and lack of shade provided by the APV during the daytime hours.

In [21], the author Max Trommsdorff et al., 2021 evaluated the APV system's technical viability while offering a study of design elements including row spacing and building orientation and their influence on the system's access to sunlight. With little water supplies and high solar radiation, the biggest technological potential for APV seems to be in arid and as well the semi-arid climatic zones. In certain areas, APV may lessen evapotranspiration, which would minimize the demand for irrigation, the effects of drought, and soil degradation.

In [22], the author Stefano Amaducchie et al., 2018 simulated a corn crop and created an agrivoltaic sun tracking system. In a simulation comparing the yield of maize grown in an agrovoltaic system to that grown in an open field, it was discovered that while the output under the system is somewhat lower when water is not a limiting resource, it is higher when drought stress is present. However, it would lead to increased losses in energy output.

In [23], the author Agostini et al., 2021 described how agrovoltaic systems are sustainable from an economic and environmental standpoint. This uses around 19% efficient commercial solar panels, with a 0.3% yearly productivity decline assumption. By lowering GHG emissions and boosting climate change resistance, agrovoltaic systems may potentially aid in the battle against global warming.

In [24], the author van de Ven et al., 2021 constructed a model for integrated evaluation that integrates the energy production and the land use, which also includes the climatic condition. The usage of solar energy was linked to land use using the Global Change Assessment Model (GCAM), which competed compared to non-commercial and commercial land uses. The methods of land management employed in solar land, however, have a significant role in the emission balance [25].

After considering the earlier researches it gets understood that reducing the energy consumption during the process of agrivoltaics are still in an open research area. In order to overcome this process in this research Internet of Agricultural Things (IoAT) is introduced which is the combination of agrivoltaic systems and Internet of Things (IoT) in agricultural field. The process of this proposed method is elaborated in the upcoming sections [26].

3. Materials and Methods

3.1 Fluid Dynamics Model

The fluid dynamic system is implemented in one of the computer-aided design (CAD) software solidworks, which includes Solidworks Flow Simulation. To solve the fluid region the idea of Navier-Stokes equations is used which deal with mass, momentum, and energy balancing parameters. Its mathematical expression is given in equation (1).

$$\frac{\delta \phi}{\delta t} + \sum_{j=1} v_j \frac{\delta \phi}{\delta x_j} = \sum_{j=1} \frac{\delta}{\delta x_j} \Gamma_{\phi} \frac{\delta \phi}{\delta x_j} + S_{\phi} \quad (1)$$

In equation (1), the term ϕ implies the variable interest for the parameters temperature, velocity vector or the mass fraction, v_j implies the velocity of j^{th} direction, Γ_{ϕ} implies the diffusion coefficient, S_{ϕ} implies the source and t implies the required time duration. Mainly here computational domain is considered to explain the laminar, turbulent, and transitional flows of homogenous fluids. It is very essential to measure the radiant heat transfer (discrete ordinate (DO)) for that purpose radiation model is introduced. Incident radiation is calculated using DO where each cell of the computational domain is involved in it. The mathematical expression, which is used to represent the radiation model, is given in equation (2).

$$\nabla I(\vec{r}, \vec{S}) \vec{S} + I(\vec{r}, \vec{S})(a_s + \sigma_s) = a_s I_{ref}^2 \frac{\sigma T^4}{\pi} + \frac{\sigma_s}{4\pi} \int_0^{4\pi} I_r(\vec{r}, \vec{S}') \phi(\vec{S}, \vec{S}') d\Omega' \quad (2)$$

In equation (2), the terms $r \rightarrow$ and $S \rightarrow$ implies the position and radiation vector, T implies the temperature, I_r implies the radiation intensity, a_s implies the spectral absorption, σ_s implies the scattering opacity, σ implies the Stefan-Boltzmann constant, and I_{ref} implies the refractive index. Finally, the terms ϕ and Ω implies the phase function and solid angle. In order to construct effective PV modules, 5 layers of it and two aluminum poles are needed. The PV module is assembled in figure 2.

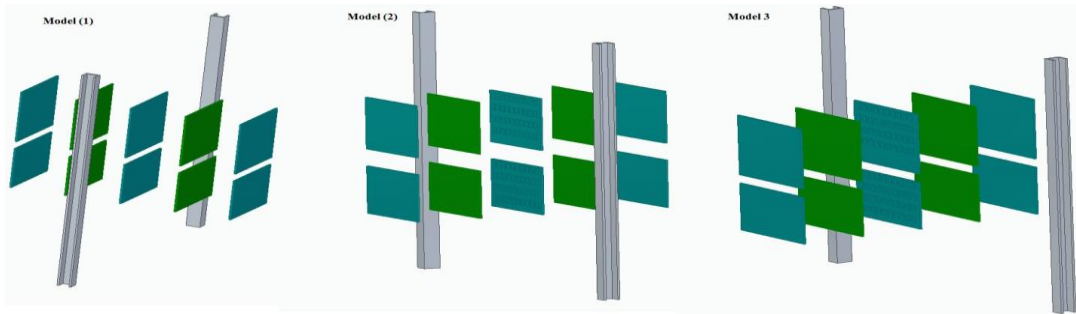


Figure 2. Assembly of pv module

The proposed model includes 5 layers were it consists of two glass layers, two EVA plastic layers, and one cell layer. For this research, 800 model assemblies are created and the dimensional properties and the soil characteristics are described in table 1 and 2. The other important properties of this model is that it consists of mounting structure height of 3m, and the domain height is 8m which also noted the other details like temperature, humidity, and velocity changes. The construction of defined cells are performed in Solidworks Flow Simulation were the defined cells are set to 1,000,000 in numbers. At each instant of time step, the transient model is used for the analysis. The system requirements which are used for this simulation are AMD Ryzen 9 5900 ×12-Core Processor 3.70 GHz with 64 GB of RAM and 2TB SSD.

Table 1: Dimensional properties

S.No	Part	Height	Width	Thickness
1	soil	50,000mm	20,000mm	350mm
2	EVA Plastic	1,000mm	2,500mm	2mm
3	Pillar	3,000mm	150mm	90mm
4	Glass	1,000mm	2,200mm	3mm
5	M-Si Cell Layer	1,000mm	2,500mm	1mm

Table 2: soil characteristics

S.No	Materials/Gas	Heat J/kg°C	Density Kg/m ³	Thermal Conduction W/m°C
1	Air	1,5006	1.5	0.035
2	EVA Plastic	2,000	950	0.35
3	Pillar	450	8,000	45
4	Glass	1,000	3,000	1.00
5	M-Si Cell	723.05	723.05	155

3.2 Improved PV Module

To construct the PV module in effective manner certain calculations are need to get concentrated they are estimated rating of pump, estimated rating of PV array, estimated rating of battery, estimated rating of solar control and estimated rating of battery storage . All these calculations are detailed below.

3.2.1 Estimated Rating of Pump:

Certain amount of power is required to pump the ground water to the head level and that analysis is mathematically expressed in equations (3) and (4).

$$P_{power} = \frac{\rho * g * h_{sys} * D_{rate}}{\eta_p} \quad (3)$$

In equation (3) the terms $\rho = 1000kg/m^3$, $g = 10m/m^2$, $\eta_p = 0.67$, and the D_{rate} implies the pump discharge rate and it is expressed in equation (4).

$$D_{rate} = \frac{C_{power}}{t} (m^3/hr) \quad (4)$$

To pump the ground water to the top level the pumping process is carried out six hours per day for our simulation analysis.

3.2.1 Estimated Rating of PV Array

Required PV array rating to constrain the pumping process is mathematically expressed in equations (5), (6), (7) and (8).

$$PV_{array} = \frac{1.25 * E_{pv}}{G_{in} * K_{loss} * SF_{pv}} \quad (5)$$

In equation (5), the terms E_{pv} implies the PV efficiency and it is assumed to 15% and SF_{pv} implies the safety factor of PV and it is assumed to be 1.25. Later on the safety factor is increased up to 25% mainly to compensate the losses due to the temperature, incomplete absorption of the radiant energy, dirt, aging, degradation, wiring and inverter. PV modules are aligned in both the series and the parallel module and both this modules are mathematically expressed in equation (6) and (7).

$$PV_{series} = \frac{V_{sv}}{V_{sa}} \quad (6)$$

$$PV_{parallel} = \frac{PV_{array}}{PV_{series} * P_{mod}} \quad (7)$$

In equation (6) the terms V_{sv} and V_{sa} implies the required design based system voltage. Consequently, the required amount of PV modules necessary for the design is expressed in equation (8).

$$PV_{total} = PV_{series} * PV_{parallel} \quad (8)$$

3.2.2 Estimated Rating of Battery

Certain backup battery is very essential to pump water because solar energy is not accessible at each of time during the day. The required battery power is calculated in equation (9).

$$B_{storage} = \frac{E_p * A_{time}}{V_{sv} * DOD * \eta_b} \quad (9)$$

In equation (9), the terms A_{time} implies the average time and it is valued as 3 days, DOD is 80% and η_b is 85% for the simulation. In case here 12V and 200Ah battery is chosen for the process then the number of battery needed to connects the PV parallel, series and total connections are expressed in equation (10), (11) and (12)

$$B_{parallel} = \frac{B_{battery}}{battery\ capacity} \quad (10)$$

$$B_{series} = \frac{V_{sv}}{B_v} \quad (11)$$

$$B_{total} = B_{series} * B_{parallel} \quad (12)$$

3.2.3 Estimated Rating of Solar Control

The process of solar charging is controlled using the voltages of PV module and battery system and this calculation is mathematically expressed in equation (13).

$$SC_{rating} = 1.25 * I_{sc} * B_{parallel} \quad (13)$$

In equation (13) the term $I_{sc} = 8.75A$. Using these calculations the total number of controllers necessary for parallel network construction is expressed in equation (14) and as well the controller charge is rated up to 24V with 60A for the simulation.

$$I_N = \frac{SC_{rating}}{Ampere\ per\ controller} \quad (14)$$

3.2.4 Estimated Rating of Battery Storage

The energy management system is introduced here to estimate the battery storage were the core state parameter which is used here to perform that operation is SoC. This SoC is mainly used to measure the residual energy of the battery and it is the ratio of existing power to nominal power. The ampere-hour integral approach is used here to measure this energy differences and it represented in equation (15).

$$SoC(t) = (1 - \rho) * SoC(t - 1) + \frac{1}{C_{bat}} \int P_{bat}(t) dt * SoC(t + 1) \quad (15)$$

In equation (15) the term SoC (t), SoC(t-1) and SoC(t+1) implies the states of charge at the present step, past step and future step respectively, ρ implies the self-discharge rate (%), C_{bat} implies the battery capacity and P_{bat} implies the battery power. The energy balancing process analysis about the power imbalance and according to that it operates to ON and OFF modes. Through this system the solar panels are charged in an effective manner at the time of load gets satisfied by the PV module. In some of the time that the PV power will be insufficient to meet the load requirements, on that time the stored battery is utilized to satisfy the load demand of the recent times. The mathematical expression to measure the battery power is given in equation (16).

$$Power_{bat}(t) = \begin{cases} (Power_{PV}(t) - Power_{load}(t)) * Eff_{bat}; & \text{On Mode} \\ -(Power_{load}(t) - Power_{PV}(t))/Eff_{bat}; & \text{Off Mode} \end{cases} \quad (16)$$

In equation (16) the term $Power_{load}(t)$ implies the load power which is measured in equation (17) and Eff_{bat} implies the battery efficiency. The essential parameters, which are required for the battery storage process, are given in table 3 below.

Table 3: essential parameters for battery storage

S.No	Description	Values
1	Nominal Voltage	15V
2	Capacity	25Ah
3	Weight	7.5±5% Kg
4	Depth of discharge at 50%	2000 Iteration
5	Self-Discharge	<5%

3.2.5 Estimated Rating of Power Load

In general, it is very critical to manage the power utilization and optimization of the load. The entire process of the crop cultivation and electricity generation is effectively monitored in all the IoAT layers to understand the working of the sensors at each instant of time. The sensor power utilization is periodically to store the working and standby time of the sensors. The sensors are equipped with required peripheral devices, storage devices, Arduino board and DC-DC converter so that data so that data sensing will be in highly effective manner. Two types of sensors are used in a process they are the voltage sensor and the current sensor, which is directly linked with the power supply. The mathematical expression to measure the load consumption is given in equation (17).

$$Power_{load}(t) = Volt_{load}(t) * Cur_{load}(t) \quad (17)$$

In equation (17), the term $Volt_{load}(t)$ implies the instantaneous voltage of the load and $Cur_{load}(t)$ implies the instantaneous current of the load. The power utilized by the load is linear, it is measured at each instant of time, and it is in its operational condition 24 hours a day. The mathematical expression to measure the load consumption with respect to the constant power is given in equation (18).

$$Power_{load} = \frac{\sum_{t=1}^N Power_{load}(t)}{N} \quad (18)$$

In equation (18), the term $Power_{load}$ implies load power consumption and N implies the utilization of total number of data.

3.3 Land equivalent ratio (LER) Calculation (P4)

LER calculation is it helps to estimate the efficiency of the land during the time of dual use such as crop production and energy generation. It is defined as the sum of crop and power generation and it is mathematically expressed in equation (19).

$$LER = \frac{FBM_{AVS}}{FBM_C} + \frac{EP_{AVS}}{EP_C} \quad (19)$$

In equation (19), the term FBM_{AVS} implies the AVS fresh biomass, FBM_C implies the control fresh biomass, EP_{AVS} implies the AVS electricity production and EP_C implies the control electricity production. It is very essential to get lower LER to attain smart AVS farm with optimal use of energy. The final LER values can be greater than 1 but it has to get maintained between 1.2 to 1.5 and not more than that.

3.4 Shading Ratio Calculation (SRC)

Since crop yield and solar radiation are tightly connected, when an agriphotovoltaic system is installed, the amount of solar radiation that accomplished at the ground is decreased. In order to concurrently accomplish energy production and agriculture, it is crucial to take into account insolation decrease. The solar radiation under agriphotovoltaic system depends on SRC, which is determined by dividing the area of PV modules (A_{PV}) in the system by the amount of cropland (A_{system}):

$$SRC = \frac{A_{PV}}{A_{system}} \quad (20)$$

Depending on the PV module's tilt angle, SRC may be obtained differently since, in certain circumstances, it is determined by the area of modules that are anticipated vertically onto the land surface. However, it is challenging to standardize the coverage area of shadow-cover in accordance with the different angles in these situations, which causes uncertainty during building. In this study, rather than utilizing the projection area, we estimated SR using the total module area [27].

A SRC in the 20–40% range is common for agriphotovoltaic system now in use and it shown that the SRC of 30% is acceptable for lettuce development and an SRC range of 30% to 40% is advised for sun plants. The majority of buildings in South Korea have an installed SRC of around 30%, which reflects the climatic conditions there. To construct a basic design for the AVS structure in this study, we employed an SRC of 30–40%; however, this might be used differently depending on different module configurations and crop kinds [28].

4. Proposed Internet of Agricultural Things (IoAT) Using Agrivoltaics

This proposed model is mainly developed to increase the crop yield and electricity generation so that Internet of Things (IoT) is combined with Agrivoltaics systems. The major categories of the section is that architecture of IoAT, crop field structure, energy production model, sensor localization, cost optimization and Fault Diagnosis. The workflow of the proposed energy based IoAT is given in figure 3.

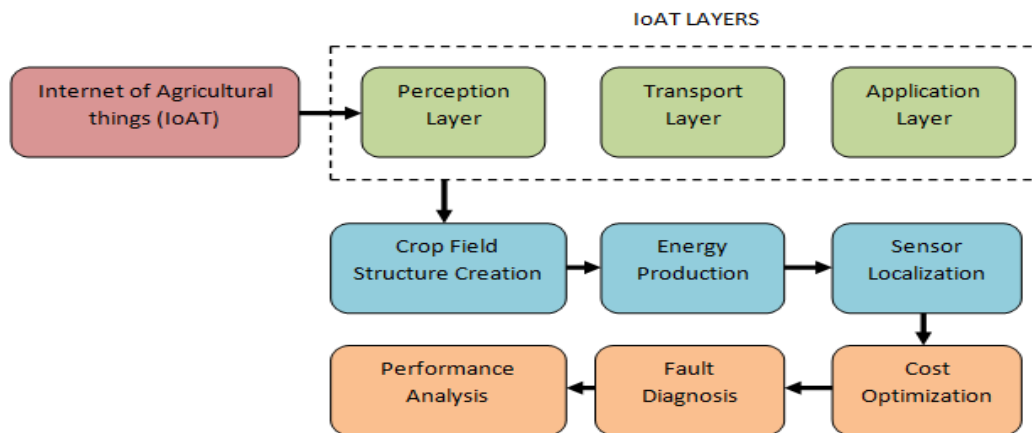


Figure 3. Workflow of the proposed energy based IoAT

4.1 Architecture of IoAT

We suggested a three-layer IoT design based on the knowledge of other academics. Below, three levels are briefly introduced.

1) Perception layer: This layer includes a variety of sensors that are utilized in the PA scenario to monitor important parameters and gather large amounts of agricultural data, including light sensors, temperature and humidity sensors, audio and video sensors, infrared sensors, RFID, GPS, and hall sensors. Additionally, a variety of technologies and unique standards are needed to suit PA's requirements, including technology for energy management, a unique sensor standard, communication, anti-interference, and adaptive coding. After the embedded device has done processing the data, the data is uploaded to the upper layer.

2) Transport layer: In PA, the primary job of the transport layer is to wirelessly transmit control orders as well as the data that has been gathered to the application layer. The wireless transmission type in use also relies on the PA's actual operational environment. ZigBee, WI-Fi, WLAN, and cellular mobile communications technology (GPRS, 3G, 4G, and 5G) are more examples of wireless technology used in Pennsylvania.

3) Application layer: To address the viability of PAIoT, five key application scenarios are thoroughly addressed in this layer. These scenarios correspond to multidisciplinary deep integration in PAIoT. Agricultural machinery, wireless communication, cloud/fog/edge computing, life science, and defect diagnosis are the core topics of multidisciplinary research. Their close integration will increase yield and manufacturing efficiency while lowering production costs.

4.2 Field Structure

The simulation software, which is used to construct the field scenario, is MATLAB. The yield of winter wheat is 8.4 tons per ha^{-1} and the farmland is around 1.3 km. For the purpose of crop rotation, sugar beet is cultivated after the wheat. The major process which are used in this wheat cultivation are providing fertilization, tillage, sowing, providing required pesticides, mineral fertilizer, and harvesting.

There is a specified planting distance for each crop variety, thus it is vital to base the column spacing of the agriphotovoltaic system arrangement on these cultivation area. The distance between plants in upland fields must be determined by the width of the furrows in the paved cultivation area. At the same time, the fruit trees are planted before many years and it is critical process to establish the new system in the same area with the equivalent for the current planting distances. Therefore, it becomes very essential to modify the system according to the current design and on-site construction, so that the column spacing should be modified.

As the first crop to be grown in fields and vineyards, respectively, lettuce and grapes were chosen for this investigation. For lettuce, a furrow distance is fixed for 1m to 1.5 m and as well, the planting distance is fixed for 3.5m to 4m were taken into consideration. As a result, the planting distance was multiplied by the column spacing, and it is otherwise known as its minimal spacing process.

4.3 Energy Production Model

According to the selected field and PV density, an agriphotovoltaic system is developed which includes the ostensible power of 250 kWp for the used 800 model assemblies with the module azimuth of 200° and a module angle of 35° . As I mentioned earlier this agriphotovoltaic model is constructed in MATLAB simulation platform, its power utility is based on the system-specific nominal power, and is electrical efficiency and inverters and sun's site-dependent radiant energy, and it is otherwise called as physics-based approach. The photovoltaic modules are situated according to certain criteria they are weather model, diffuse, direct, and reflecting irradiation components. In terms of the simulation, the cultivation planned for 1 year, which is from 1st May 2022 to 1st May 2023. The time is chosen to analysis the power utility and production for the whole year and according to the simulation, it is carried up to 30mins for the overall simulation time [29].

For the process of agriculture, certain demand is present in terms of energy, which is also considered in this simulation. Therefore, it becomes very essential to calculate the energy demand and for this purpose only the partial times of the machines are taken into consideration and the required electrical energy is provided with the help of an agriphotovoltaic system. Here in this farming the energy utilization is on two ways they are during road travel and at the time of farming operations. These utilizations can be measured using the farm power connections and the battery. Several energy parameters are calculated at the end of the simulation they are total energy required, energy utilization of the field and energy utilization per ton of harvested material. The input energy provided for the battery operation is 0.65% and for the cable-electric operation is 0.75%. It is very essential to determine the power utilization and load coverage of the electric agricultural machines for those purpose cable-connected agricultural machines are developed with exchangeable mobile storage. Here this absorbs peak loads to store the required energy on the machine. In some scenario huge energy, consumption occurs at that time battery replacement becomes a highly complicated issue. For that purpose, exchangeable batteries are used so that battery replacement can be avoided. The required number of battery capacity is very essential for the battery storage system and that can be attaining with the help of the optimization calculation. Through this optimization calculation the battery, powered agricultural machines share three spare batteries; each includes the capacity of 100 kWh with 95% of discharge depth.

4.4 Sensor Localization and Cost Optimization

The lack of integration between the agricultural information-monitoring node and the solar module-monitoring node in PA has significantly increased the implementation cost. As a result, when establishing the wireless sensor network nodes, the following limitations must be taken into account:

- Making sure the sensor network has constant communication coverage;
- Keeping an eye on the farming protocol;
- Sensor's practical detection range;
- Interference caused by photovoltaic power plant electromagnetic noise;
- Uneven terrain obstacles and farming boundaries.
- Farmland critical monitoring zones' typical layout.

Despite the fact that the aforementioned IoAT restrictions are far more complex, the present research might nevertheless offer some fascinating insights. The current agricultural information gathering system has full functionality, but because of the wide occupied area and hefty initial investment, there are promotion issues. Additionally, three aspects (namely, electromagnetic interference, weather, and heterogeneous network) need to be considered while building the model on network transmission channels and connection during the deployment of nodes. After that, we can further realize node fault tolerance configuration and global communication redundancy coverage, which would increase the invulnerability of wireless sensor networks in PA. Finally, we may let the IoAT to operate steadily.

4.5 Fault Diagnosis of PVs in IoAT

The technology, namely fault diagnosis, will effectively support the stable operation of the IoAT (Fig. 10), particularly the maintenance of the power grid, further providing a foundation for solving the security and safety issues in IoAT. This is because faults of photovoltaic modules can be precisely detected and identified. According to our observations, solar module defects often stem from the following three causes:

- Shadows: transient shadows (such as snow, blown-over leaves, or birds), site shadows (such as topography, trees), architectural shadows (such as building structure, electric towers), and self-shadows (such as photovoltaic component shadows, other device shadows)
- Deterioration of device performance or aging due to externally high temperatures; inconsistency in photovoltaic module performance leading to Hot Spots and accelerated aging; photovoltaic component limitations due to unfavorable operating conditions; lack of equipment reverse control;
- Deterioration of device performance or aging due to externally high temperatures; inconsistency in photovoltaic module performance leading to Hot Spots and accelerated aging; photovoltaic component limitations due to unfavorable operating conditions; lack of equipment reverse control;

However, the impact of the security and safety issues brought on by the aforementioned flaws and sensor flaws in agricultural production in IoAT may not be immediately apparent, especially in agricultural production where the crop can exhibit some tolerance to the unfavorable environmental conditions, but eventually results in the severe yield reduction. Then, we discovered that while creating unique defects detection technology for IoAT, every difficulty offered to researchers must be taken seriously.

5. Simulation Environment and Performance Analysis

5.1 Shading Ratio and Temperature Calculation

In figure 4 the shading ratio performance is calculated with respect to the column spacing. Here the values of column spacing varies from 0.5 to 6m and it measures the shading ratio and power generation. At the initial stage at 0.5m, the shading ratio attained is around 62% and at the increase of column spacing the shading ratio performance is gradually reduced and finally at 6m it reached up to 32%. In terms of power generation initially at 0.5m column spacing the power generation is attained is around 42% and at the increase of column spacing it reduce to 18% at the final stage of 6m. So it is proven that the percentage of both the shading ratio and power generation with the increase of column spacing but it is gradually process there is no sudden reduces in the performance.

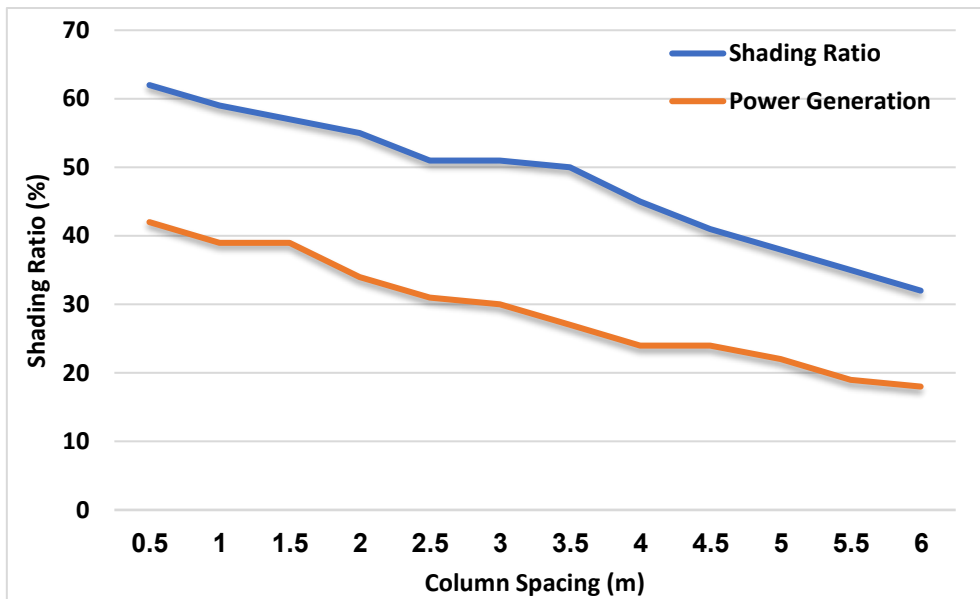


Figure 4. Shading ratio calculation

In figure 5 the temperature attained by the solar cells on the east face and the west face is calculated with respect to the time. The time duration considered for this calculation is 5th hour to 17th hour in railway time and both the performance of east face and the west face is calculated. According to the rising of sun, the performance of the east face is high at the noontime and it is normal in the other time. At the noontime, it reaches up to 41 °C and it is very low in other times. In case of west face, the temperature variation is very gradual and there are no sudden changes in it.

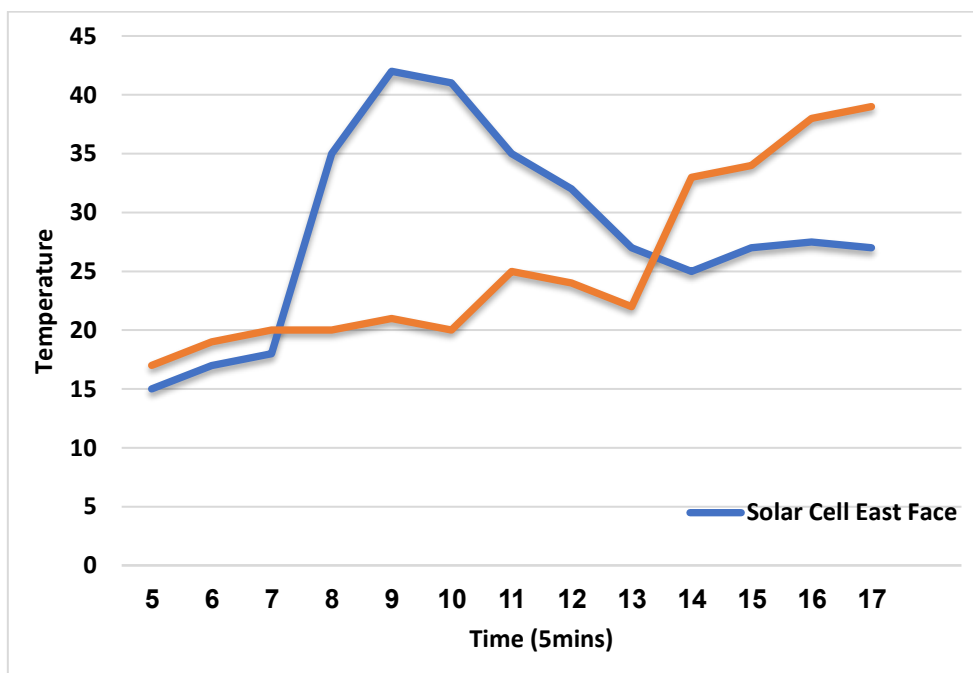


Figure 5. Temperature calculation

5.2 Crops based Analysis: In a section three parameters are considered for the crops based system head analysis, they are discharge ratio, pump power and unit cost of water and its values are analyzed in table 4. The figure 6 deals about the discharge ratio of the crops like melon, bean, millet and cucumber here the system head varies from 5m to 50m. All the crops provides gradual discharge ratio but comparative the performance of millet is little lower than other crops.

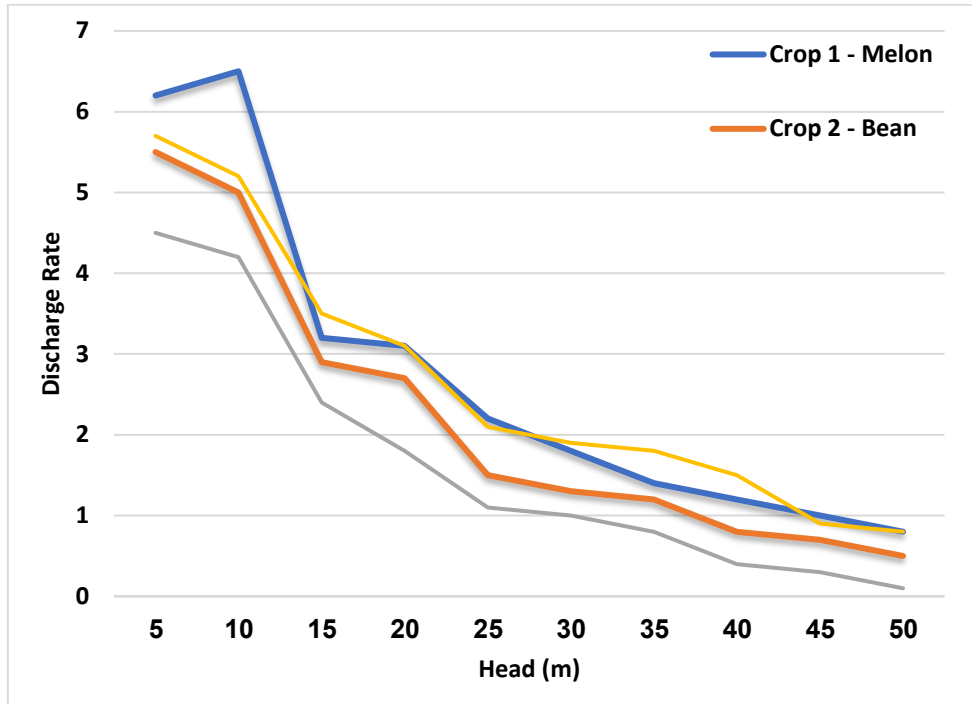


Figure 6. Discharge ratio vs system head calculation

In figure 7 the pump power variation is calculated with respect to the system head, it varies from 5m to 50m, and the crops, which are considered in this calculation, are melon, bean, millet and cucumber. All the crops attain gradual increment in the pump power variation with the increase of head length but the power pump variation of melon is very lower than the other.

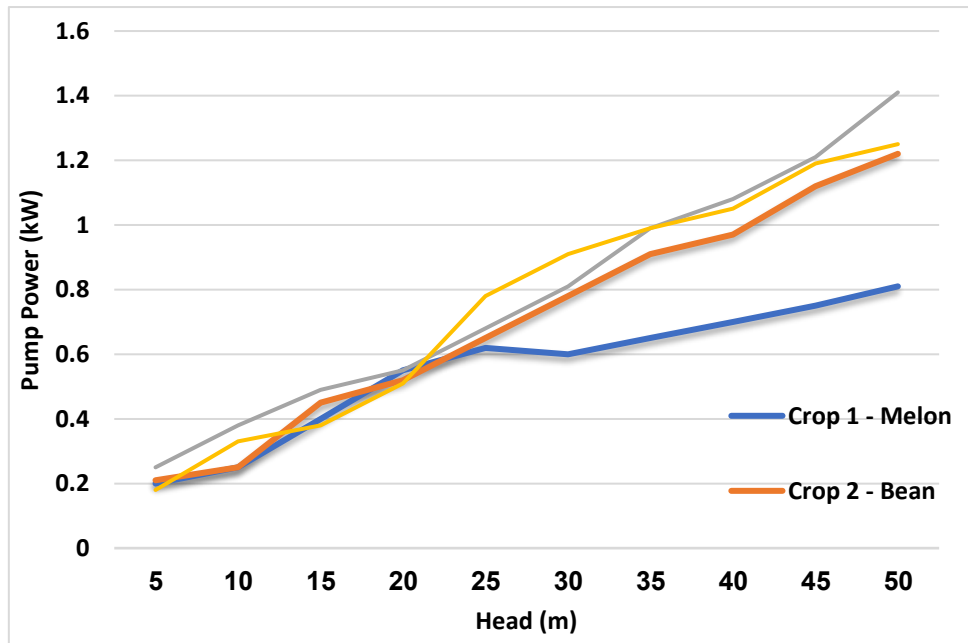


Figure 7. Pump power vs system head calculation

In figure 8 the water cost per unit is calculated with respect to the system head, it varies from 5m to 50m, and the crops, which are considered in this calculation, are melon, bean, millet and cucumber. All the crops attain gradual increment in the water cost with the increase of head length. At the initial stage from 5m it is 0.025(\$/m³) and finally for 50m it is around 0.250(\$/m³). All the crops attain exactly same results in terms of water cost.

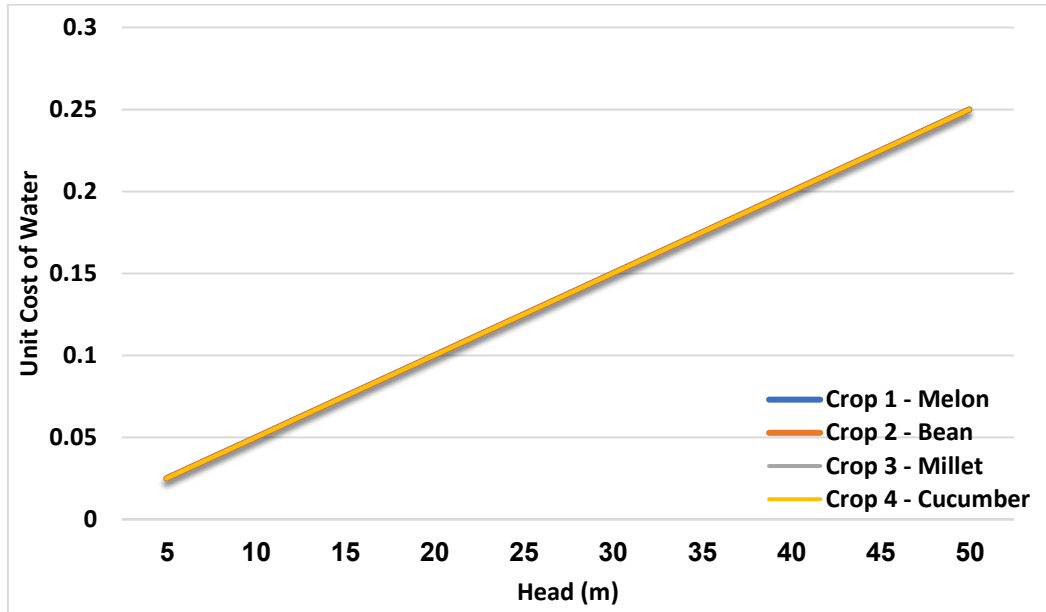


Figure 8. Unit cost of water vs system head calculation

Table 4: values of discharge ratio, pump power and unit cost of water concerned with system head

Head (m)	Crop 1 Melon	Crop 2 Beans	Crop 3 Millet	Crop 4 Cucum ber	Crop 1 Melon	Crop 2 Beans	Crop 3 Millet	Crop 4 Cucu mber	Crop 1 Melon	Crop 2 Beans	Crop 3 Millet	Crop 4 Cucum ber
	Discharge Rate (m ³ /hr)				Pump Power (kW)				Unit Cost of Water (\$/m ³)			
5	6.2	5.5	4.5	5.7	0.2	0.21	0.25	0.18	0.025	0.025	0.025	0.025
10	6.5	5	4.2	5.2	0.25	0.25	0.38	0.33	0.05	0.05	0.05	0.05
15	3.2	2.9	2.4	3.5	0.4	0.45	0.49	0.38	0.075	0.075	0.075	0.075
20	3.1	2.7	1.8	3.1	0.55	0.52	0.55	0.51	0.1	0.1	0.1	0.1
25	2.2	1.5	1.1	2.1	0.62	0.65	0.68	0.78	0.125	0.125	0.125	0.125
30	1.8	1.3	1	1.9	0.6	0.78	0.81	0.91	0.15	0.15	0.15	0.15
35	1.4	1.2	0.8	1.8	0.65	0.91	0.99	0.99	0.175	0.175	0.175	0.175
40	1.2	0.8	0.4	1.5	0.7	0.97	1.08	1.05	0.2	0.2	0.2	0.2
45	1	0.7	0.3	0.9	0.75	1.12	1.21	1.19	0.225	0.225	0.225	0.225
50	0.8	0.5	0.1	0.8	0.81	1.22	1.41	1.25	0.25	0.25	0.25	0.25

In figure 9, the PV array calculation is performed and it is measured with respect to solar radiation (kWh/m²/day). The solar radiation varies from 1 to 5(kWh/m²/day) for this values the PV array varies from 14kW at the initial stage and at the final stage it reaches up to 2.5kW for melon, 11kW at the initial stage and at the final stage it reaches up to 3.5kW for Bean, 9kW at the initial stage and at the final stage it reaches up to 2.2kW for millet and finally 12kW at the initial stage and at the final stage it reaches up to 3kW for cucumber.

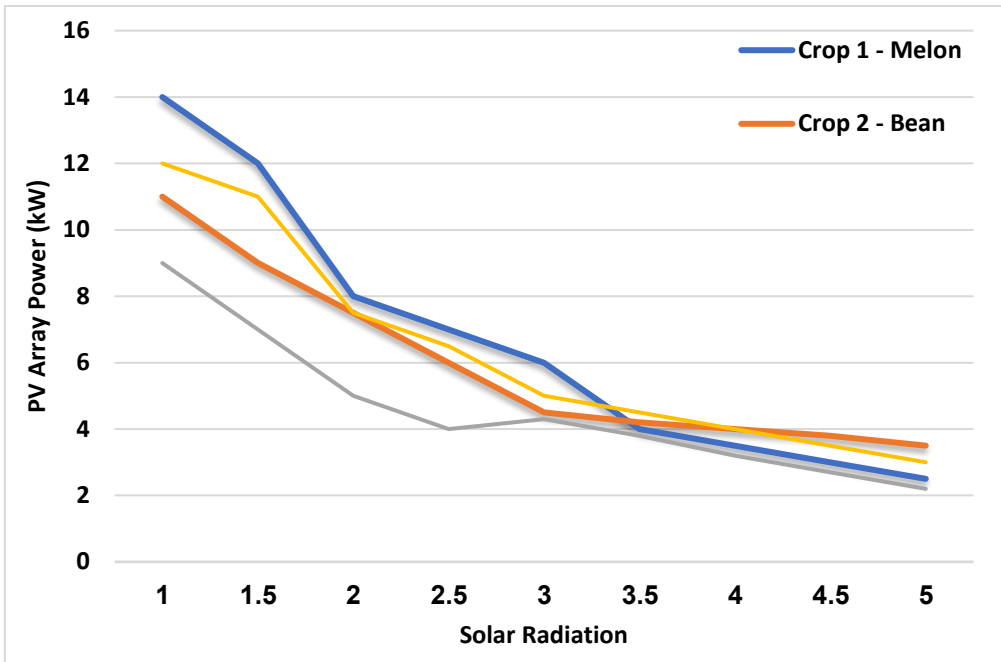


Figure 9. PV array power calculation

5.3 Energy based Analysis: In this section all types of energy calculations are performed which includes daily average PV energy calculation, PV generated energy and demand calculation and finally SoC level and battery energy calculation. In figure 10, PV energy generation is calculated from January to December and it explained about the measured and modeled values. There is only very small variation is present when comparing the measured and modeled values.

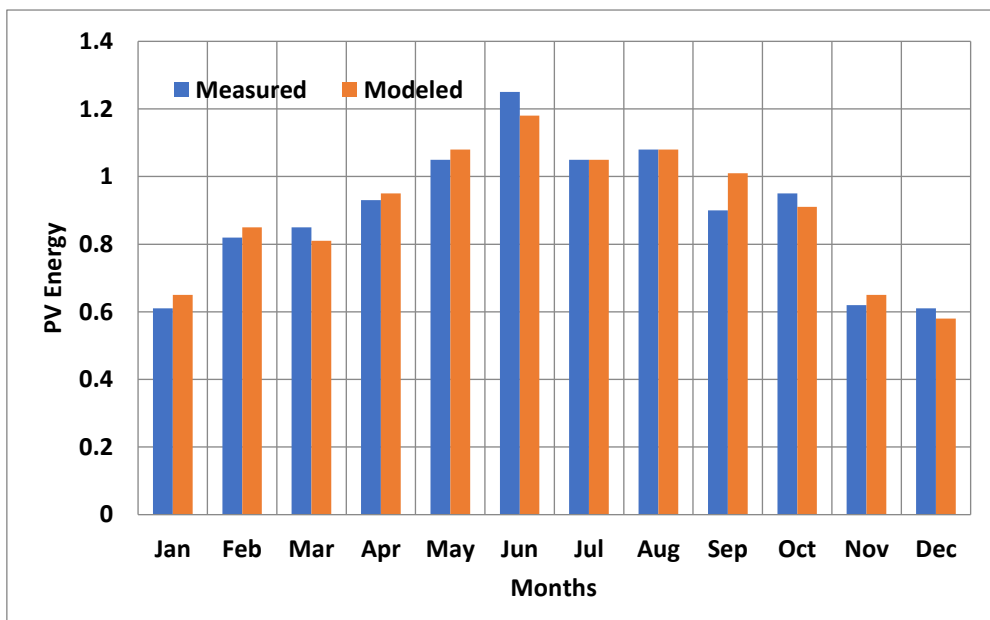


Figure 10. Daily average PV energy calculation

In figure 11 the calculated is performed with respect to the energy generated and the demand in (kWh/year). The generated energy is low high even compared to the demand and the crops, which are considered for the calculation, are melon, beans, millet and cucumber.

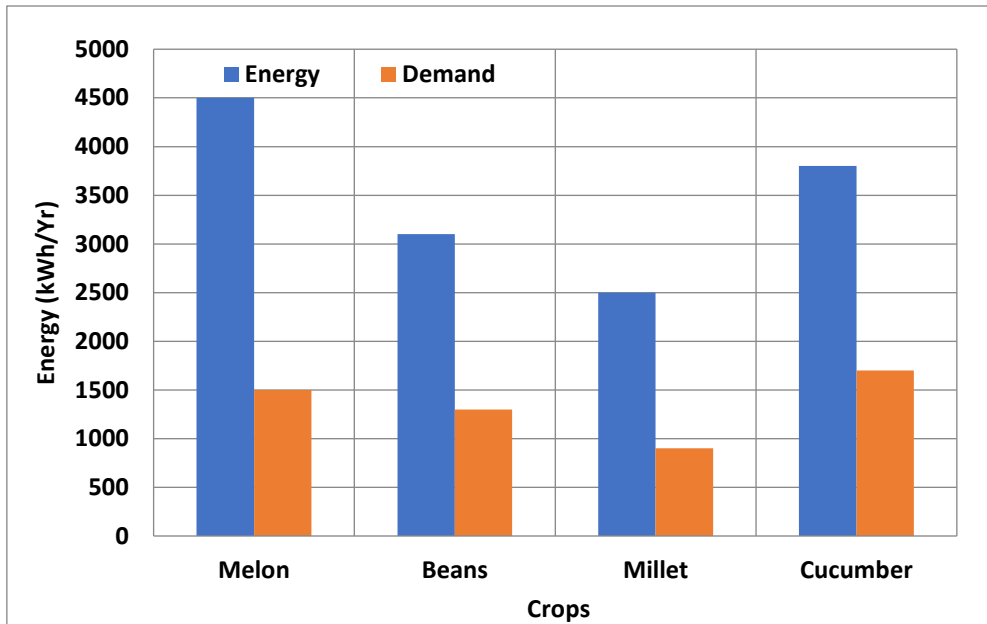


Figure 11. PV energy vs demand calculation

In figure 12, the performance of SoC level and battery power calculation is measured with respect to the time (hours) from 0 to 48hours. For this time duration the SoC, level ranges from 68% to 80% and power range from 25W to 22W. In table 5 the calculated values for soc level and battery power is described.

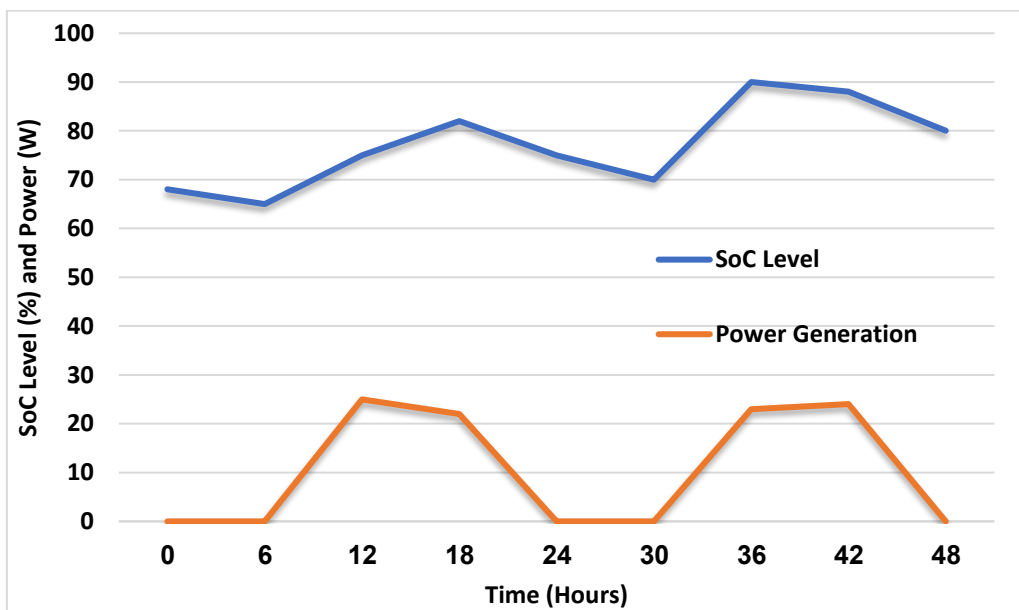


Figure 12. SoC level and battery power calculation

Table 5: values of SoC level and battery power concerned with time in hours

Time (Hrs)	SoC Level	Battery Energy
0	68	0
6	65	0
12	75	25
18	82	22

24	75	0
30	70	0
36	90	23
42	88	24
48	80	0

Through this calculation is gets understood that the proposed IoAT system provides effective results in terms of reducing the power utilization and that leads to the increase of crop yield and electricity generation.

6. Conclusion

This study briefly explained about the process of agrivoltaic system, effectiveness of PV modules and the process of IoAT systems are elaborate. This IoAT system mainly concentrates on cost optimization, fault diagnosis and energy production and that provides the way to the creation of agricultural Internet of Things (IoT) technology. Here the agrivoltaic system and IoT is effectively combined and using the sensor deployment the water utility and power consumption is managed in an excellent manner. Using all the methods, the quality of system management is improved and that leads to increase the yield of the crops like melon, bean, millet and cucumber. This kind of farming process increases the smartness in agriculture, which increases the level of agricultural informatization.

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