



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 8, August 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

 9940 572 462

 6381 907 438

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Agrivoltaics: Opportunity and Challenges for India

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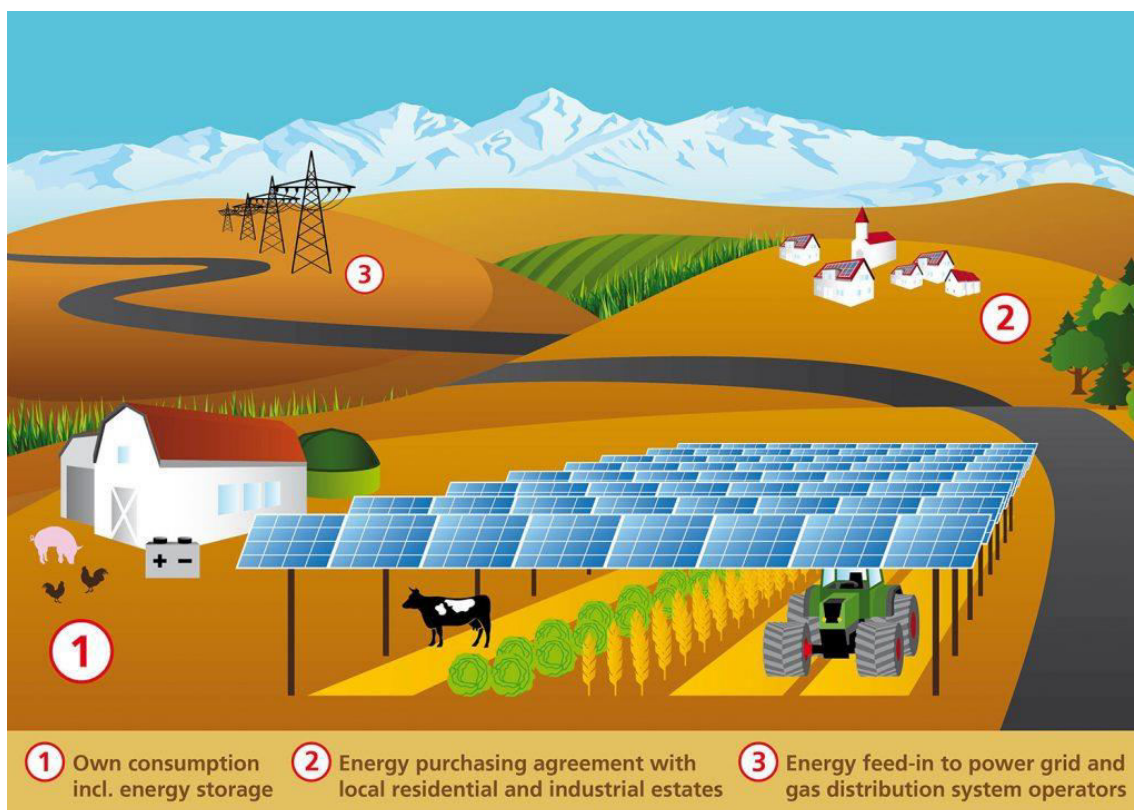
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ABSTRACT: Solar farm is a field filled with hundreds or maybe thousands of solar panels oriented into the sun. Instead of potatoes, beans or tomatoes planted in the soil, solar panels covers that land, while energy is being produced. It's obvious that traditional farming is relatively risky business because one is very much dependent upon the weather conditions. If there is just the right amount of sun, rain and if there are no extreme storms, strong winds and etc. Thus, not to worry about all these environmental factors and still get income is really uplifting and a bit too good to be true. Therefore, next to power generation, solar farms found another niche – agrivoltaics (or in other words APV). It is an amazing idea for environmentally conscious world, both agribusiness and society. However, it might haven't happened if traditional farming wouldn't be failing. Since 2010, when the cost of installing solar systems has dropped more than a half, solar farming started to bloom. Karlee Weinmann, a researcher at the Institute For Local Self-Reliance (ILSR), explains to Digital Journal the situation on American farmers why they chose to replace crops with solar arrays: "The prevailing reasons farmers decide to replace crops with solar are because the farmers are getting older or because it's easier and more lucrative for India too."

KEYWORDS: Agrivoltaics, solar, traditional farming, digital, crops, arrays, lucrative, easy, environmental

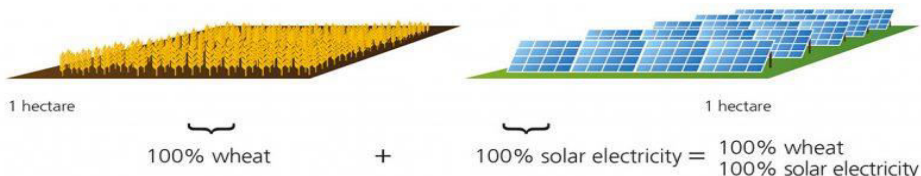
I. INTRODUCTION

A team of French scientists lead by Christophe Dupraz were the first to use term agrivoltaic. It basically means when solar panels and food crops are combined on the same land to maximize the land use. It's an idea which could bring food producing to the next level. Their research field in Montpellier, France, indicated that agrivoltaic systems may be indeed very efficient: the increase of global land productivity can be from 35 to 73 percent! Fraunhofer Institute's For Solar Energy Systems researchers carried out the study about the same topic. Their goal was to find out how solar radiation and food crops can be used and ended up with synergic solution. The examination took place near Lake Constance which borders Switzerland, Germany and Austria. For one year the pilot project used 720 bi-facial solar modules which covered around 1/3 of a hectare. [1,2] Researches decided to mount the panels high enough, so crops receive almost the same amount of sunlight as if they grow naturally. This also helps as proper farming technique could be used. When all calculations were done, promising results appeared. Researchers discovered that land's productivity could be raised by 60 percent. "The project results from the first year are a complete success: the agrophotovoltaic system proved suitable for the practice and costs as much as a small solar roof system. The crop production is sufficiently high and can be profitably sold on the market," explains Stephan Schindele, project manager of agrophotovoltaics at Fraunhofer ISE to Digital Journal. [3,4]

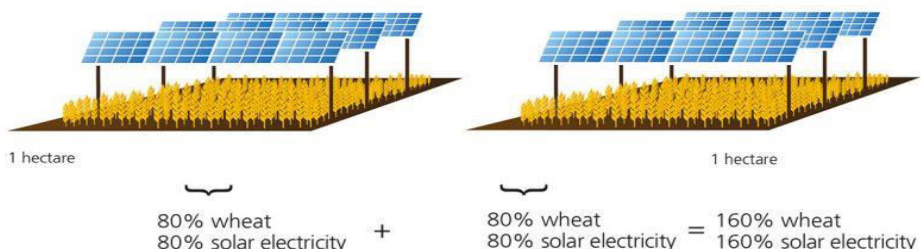


The examination proved that farming and PV can be compatible. It reduces competition for land and works efficiently too, while providing additional income for farmers. The last point is worth additional emphasis. As discussed above, one of the main reasons why farmers move to solar farming is a guaranteed financial gain and stress-free lifestyle. Fraunhofer Institute's researches discovered that PV installation can work along with traditional farming and bring income even if nature's conditions are incompatible grown culture's needs. With booming solar industry and applications, it's being used – agrovoltatics is one of them. Let alone incredibly higher land efficiency with solar modules being placed on top of growing crops, the greenhouse farming industry has its way to go solution: skylight solar glass. With partial light transmittance achieved by differentiating solar cell arrangement and placement, not only shading can be achieved but energy demand can be reduced drastically of such agrivoltatics greenhouses. So we believe agrophotovoltaic is a new way of using solar technology together with traditional farming. Of course, it still needs some discussions, testing and further development, but today it is obvious that such method – solar farming in its true sense – has big perspectives to benefit society and business more than it has ever been before in India also. [5,6]

Separate Land Use on 2 Hectare Cropland



Combined Land Use on 2 Hectare Cropland: Efficiency increases over 60%



Agrivoltaics, agrophotovoltaics, agrisolar, or dual-use solar is the simultaneous use of areas of land for both solar photovoltaic power generation and agriculture. The coexistence of solar panels and crops implies a sharing of light between these two types of production, so the design of agrivoltaic facilities may require trading off such objectives as optimizing crop yield, crop quality, and energy production. However, in some cases crop yield increases due to the shade of the solar panels mitigating some of the stress on plants caused by high temperatures and UV damage in Indian farming systems.[7,8]

II. DISCUSSION

There are three basic types of agrivoltaics that are being actively researched: solar arrays with space between for crops, stilted solar arrays above crops, and greenhouse solar arrays. All three systems have several variables used to maximize solar energy absorbed in both the panels and the crops.

The main variable taken into account for agrivoltaic systems is the tilt angle of the solar panels. Other variables taken into account for choosing the location of the agrivoltaic system are the crops chosen, panel heights, solar irradiance and climate of the area in India.

In their initial 1982 paper, Goetzberger and Zastrow published a number of ideas on how to optimise future agrivoltaic installations. [9,10]

- orientation of solar panels in the south for fixed or east–west panels for panels rotating on an axis,
- spacing between solar panels for sufficient light transmission to ground crops,
- elevation of the supporting structure of the solar panels to homogenize the amounts of radiation on the ground.

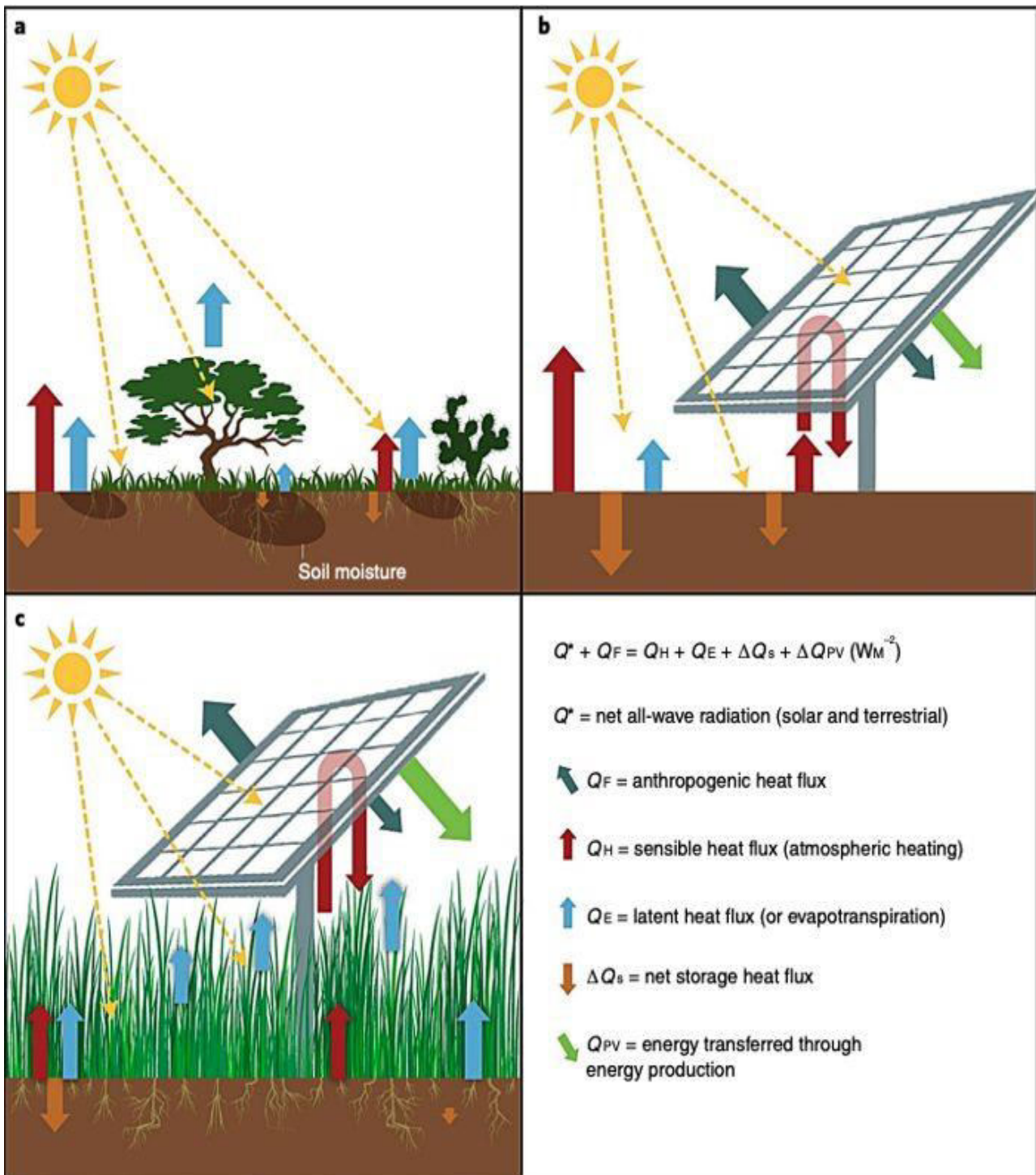


Experimental facilities often have a control agricultural area in India. The control zone is exploited under the same conditions as the agrivoltaic device in order to study the effects of the device on the development of crops. The most conventional systems install fixed solar panels on agricultural greenhouses, above open fields crops or between open fields crops. It is possible to optimize the installation by modifying the density of solar panels or the inclination of the panels. A standalone solar panel integrated system using a hydrogel can pull in water vapor (usually at night) to produce fresh water to irrigate crops which can be enclosed beneath the panel (alternatively it can cool the panel). In 2015 Wen Liu from the University of Science and Technology in Hefei, China, proposed a new agrivoltaic concept: curved glass panels covered with a dichroitic polymer film that selectively transmits blue and red wavelengths which are necessary for photosynthesis. All other wavelengths are reflected and concentrated on solar cells for power generation using a dual tracking system. Shadow effects arising from regular solar panels above the crop field are eliminated since the crops continue to receive the blue and red wavelength necessary for photosynthesis. Several awards have been granted for this new type of agrivoltaic, among others the R&D100 prize in 2017. The solar panels of agrivoltaics remove light and space from the crops, but they also affect crops and land they cover in more ways. Two possible effects are water and heat.[11,12]

In northern latitude climates, agrivoltaics are expected to change the microclimate for crops in both positive and negative manners with no net benefit, reducing quality by increasing humidity and disease, and requiring a higher expenditure on pesticides, but mitigating temperature fluctuations and thus increasing yields. In countries with low or unsteady precipitation, high temperature fluctuation and fewer opportunities for artificial irrigation, such systems are expected to beneficially affect the quality of the microclimate in Indian farms.

A 2016 thesis calculated that investment in agrivoltaic systems cannot be profitable in Germany, with such systems losing some 80,000 euro per hectare per year. The losses are caused by the photovoltaics, with the costs primarily related to the high elevation of PV panels (mounting costs). The thesis calculated governmental subsidies in the form of feed-in tariffs could allow agrivoltaic plants to be economically viable and were the best method to entice investors to fund such projects, where if the taxpayer paid producers a minimum additional €0.115 euro per kWh above market price (€0.05 in Germany) it would allow for the existence of future agrivoltaic systems

It requires a large investment, not only in the solar arrays, but in different farming machinery and electrical infrastructure in India. The potential for farm machinery to damage the infrastructure can also drive up insurance premiums as opposed to conventional solar arrays. In Germany, the high installation costs could make such systems difficult to finance for farmers based on convention farming loans, but it is possible that in the future governmental regulations, market changes and subsidies may create a new market for investors in such schemes, potentially giving future farmers completely different financing opportunities[13]



Food and energy security need not be competing objectives. In fact, taking a holistic, integrated approach to food-energy-water decision making can increase resiliency of both food and energy systems in India.

In a recent article for Nature Sustainability, the U.S. Department of Energy’s National Renewable Energy Laboratory’s (NREL) Lead Energy-Water-Land Analyst Jordan Macknick and co-authors from the universities of Arizona and Maryland investigated the potential benefits of co-located agriculture and solar photovoltaic (PV) infrastructure (dubbed “agrivoltaics”) on food production, irrigation water requirements, and energy production.

Across the globe, reductions in precipitation and rising air temperatures are increasing vulnerabilities in both the agricultural and energy sectors. Water scarcity concerns are shaping conversations and driving action in the agricultural sector while extreme weather events are impacting energy systems worldwide, reducing the reliability of energy generation. As such, the resilience of the global energy system is of growing importance. Drought-proof technologies such as wind and solar photovoltaics can satisfy both resilience and sustainability concerns.

However, studies of ground-mounted PV installations with gravel groundcover have found increased temperatures surrounding solar arrays, creating a “heat island” effect. This is particularly problematic due to PV panel sensitivities to temperature increases and resulting consequences for performance.[14]

The business-as-usual approach to PV installations is to employ gravel as ground cover. Swapping the gravel for vegetation via strategic planting can help counter the heat feedback loop in India.

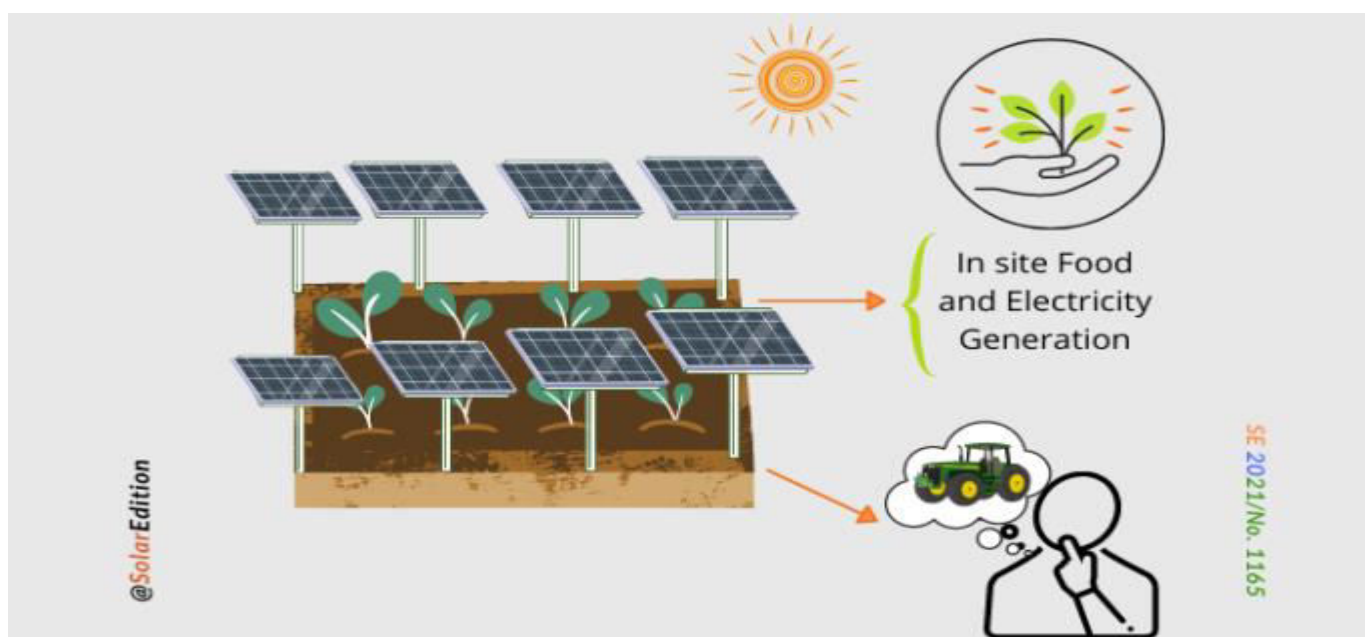
Applying a model derived from low-impact urban design, researchers looked to the concept of “novel ecosystems,” and how they might benefit renewable energy and food production systems in dryland ecosystems. Researchers considered the possibility of co-located agriculture and solar PV infrastructure to maximize crop yields, minimize water use, and produce resilient, renewable energy.

To test their concept, researchers planted three common plants (chiltepin pepper, jalapeño, and cherry tomato), representative of three different dryland environments, beneath PV panels.

During the three-month growing season, they monitored light levels, air temperature, and relative humidity using sensors mounted above the soil surface. They also measured soil temperature and moisture at a depth of 5 centimeters. Both the control and agrivoltaic systems received the same irrigation in two testing scenarios: daily irrigation and irrigation every two days in India.[15]

III. RESULTS

While impacts varied by plant type, the researchers found that the agrivoltaic systems held promising implications for food production, water savings, and renewable energy production. The reduction in direct sunlight exposure beneath the PV panels led to cooler air temperatures during the day and warmer temperatures at night, which allowed the plants under the solar arrays to retain more moisture than the control crops that grew in open-sky planting areas.



Results from in the study include:

Food production

- Total chiltepin fruit production was three times greater in the agrivoltaic system compared to the control
- Water-use efficiency for the jalapeño was 157% greater in the agrivoltaic system
- For the cherry tomato, water-use efficiency was 65% greater and total fruit production doubled in the agrivoltaic system

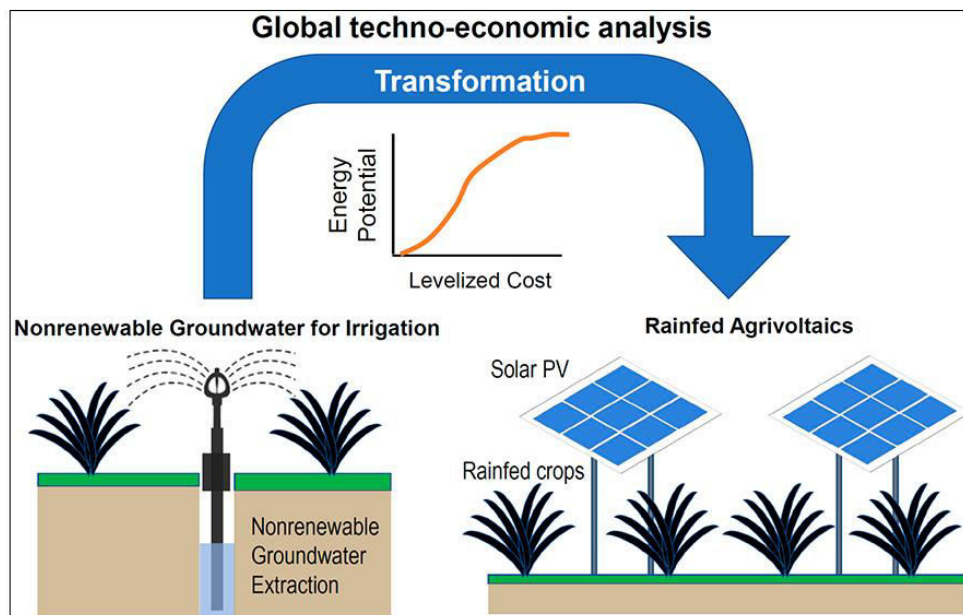
Water savings

- When irrigating every two days, soil moisture remained approximately 15% greater in the agrivoltaic system
- When irrigating daily, soil moisture in the agrivoltaic system remained 5% greater before the next watering

Improved renewable energy production

- Traditional ground-mounted PV panels were substantially warmer during the day than those with the plant-based understory
- The agrivoltaic PV panels were cooler during daytime hours compared to the traditional panel array by approximately 9°C, allowing for better performance.[16]

The co-location of PV and agriculture could offer win-win outcomes across many sectors, increasing crop production, reducing water loss, and improving the efficiency of PV arrays. Adopting such synergistic paths forward can help build resilient food-production and energy-generation systems in India.



As Macknick notes, “The promising results of this work have broad implications for how solar development and farming across the globe could be integrated to provide mutual benefits.”



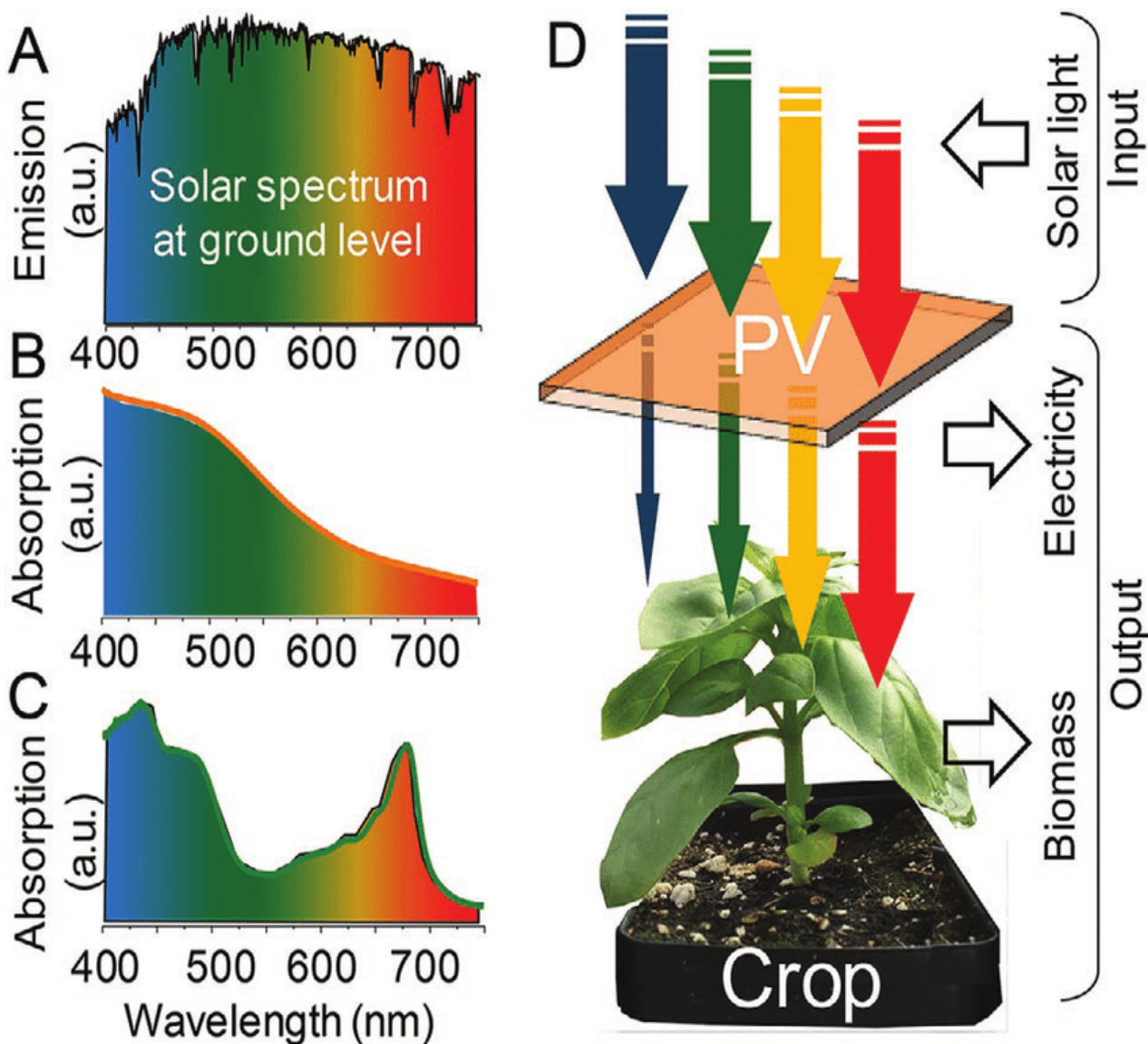
Plants have a limit to how much sun they can actually use. It’s called the light saturation point. Once reached, any light beyond that point does not increase photosynthesis or help the plant grow, it only increases the plant’s water demand. It simply makes the plant sweat, which in turn makes it more thirsty.

Solar panels can be positioned to allow plants just the right amount of sunlight, and then the excess sunlight can be harvested for electricity—and produce more than they would without crops below them.

That’s right. Plants help keep the solar panels cool, which makes them more productive. Our studies have shown that panels positioned above plants produce up to 10% more electricity in India.

Agrioltaics is a symbiotic relationship where both the solar panels and the crops benefit because they help each other perform better in India.[17,18]

The electricity can be used to run the farm with electric tractors and equipment, and to power precision ag technology that helps further reduce water usage. Surplus energy can be stored in battery banks or sent to the grid for consumer use in India.



It’s a win-win-win relationship between the three most foundational elements of modern life: food, water, and energy. In the Food-Energy-Water (FEW) Nexus, agrivoltaics delivers eco-friendly solutions:

1. The plants, protected by the solar panels from the worst of the midday sun's rays, become little evaporative coolers on the landscape. They take up carbon for photosynthesis by opening up their pores, or stomata, while letting water escape from their leaves and create a cooler microclimate.
2. The solar panel modules can lose efficiency while operating under the blazing sun. The panels perform at a higher level – thanks to this cooler microclimate afforded by the plants. The panels, in turn, protect the plants from sunburn and dehydration in India.[19]

The end results: a better crop yield and more efficient performance of the solar array in India.

IV. CONCLUSIONS

Most people would think that having solar panels take up farmland would be a negative thing. The reason that agrivoltaics technology is so beneficial to farmers, is because they can farm and use the same space to generate money from solar production. Some issues with this technology is that the topsoil of farmland is stripped and panels are mounted on concrete pads. This impacts the amount of food that the land can now produce. Vegetables such as peppers, broccoli, and Swiss chard can only produce about 60% of the volume that they would under full sun. In addition, the solar panels only offer about half the power-generation capacity per acre, and the costs are higher. However, the combination of farming and solar power generation pay for themselves in approximately eight years, and pay off together in the long run in India [20]

Global investment in solar power generation is growing very fast. Solar energy increased its share of global electricity generating capacity by 50 per cent in 2016 alone, overtaking growth in wind, gas and other renewable technologies. The cost of solar photovoltaic cells – the major capital cost in solar installations using that technology – has fallen 80 per cent since 2008. Agrivoltaics seems generally to be well suited to market gardening, perhaps less so to arable crops. The agrivoltaic system also reduces the maintenance issues associated with more closely-spaced solar panels and puts the land to productive agricultural use. However, there are still some issues with cultivation operations to be weighed up, such as limiting the size and efficiency of farm machinery that can be deployed under and between the frames. Only time will tell if agrivoltaics will take off in the farming industry. Agrivoltaics has both advantages and disadvantages to farmers, and perhaps more research and government adaptation of renewable energy rebates will push agrivoltaics to become more widespread in India.[21]

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