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Agrivoltaics: Solving Energy and Food Needs Together

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ABSTRACT: As world leaders gathered at COP27 amid a global energy crisis in November 2022, climate change and renewables were sharply in focus. According to UN General Assembly Presidents, increasing climate resilience across food systems will be needed to counter rising hunger and malnutrition. Agrivoltaic farming could solve both of these problems. In simple words, agrivoltaics is growing crops using solar panels. In 2021, the global agrivoltaics market was valued at USD 3.17 billion. With a CAGR of 12.15% from 2022 to 2030, the market is likely to reach around USD 8.9 billion by 2030.

KEYWORDS- climate, agrivoltaic, food, climate, energy, crops

I.INTRODUCTION

The vulnerabilities of our food, energy and water systems to projected climatic change make building resilience in renewable energy and food production a fundamental challenge. We investigate a novel approach to solve this problem by creating a hybrid of colocated agriculture and solar photovoltaic (PV) infrastructure. We take an integrative approach - monitoring microclimatic conditions, PV panel temperature, soil moisture and irrigation water use, plant ecophysiological function and plant biomass production within this 'agrivoltaics' ecosystem and in traditional PV installations and agricultural settings to quantify trade-offs. We find that shading by the PV panels provides multiple additive and synergistic benefits, including reduced plant drought stress, greater food production and reduced PV panel heat stress. The results presented here provide a foundation and motivation for future explorations towards the resilience of food and energy systems under the future projected increased environmental stress involving heat and drought.

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II.DISCUSSION

Agrivoltaic farming is the practice of growing crops underneath solar panels.

Scientific studies show some crops thrive when grown in this way.

Doubling up on land use in this way could help feed the world’s growing population while also providing sustainable energy.

As world leaders prepare to gather at COP27 amid a global energy crisis, climate change and renewables are sharply in focus. At the same time, increasing climate resilience across food systems will be needed to counter rising hunger and malnutrition, according to UN General Assembly President Abdulla Shahid.

Agrivoltaic farming could be a solution to not just one but both of these problems. It uses the shaded space underneath solar panels to grow crops.

This increases land-use efficiency, as it lets solar farms and agriculture share ground, rather than making them compete against one another.

And certain crops appear to thrive when grown in such environments, according to a number of recent studies.

Solar panels have to sometimes be elevated or suspended to allow plants to grow beneath them. Another option is putting them on the roofs of greenhouses. This allows enough light and rainwater to reach the crops, as well as providing access for farm machinery. Increasing the world's solar energy capacity will be a big part of solving the sustainability equation.

At the same time, the UN estimates that the global population is set to rise by an estimated 2 billion people in the next 30 years, and land is at a premium.

Agrivoltaics is one way of using the same area of land to produce more food while also rolling out more sources of renewable energy.

South Korea's renewable energy use is the lowest among International Energy Agency member countries. Its land is also in short supply, due to mountainous terrain spanning 70% of the country, so agrivoltaic farming could be a game-changing solution.

As Brite Solar CEO Dr Nick Kanopoulos puts it: "All of this has profound environmental implications and points to a new way of farming – one that is fully electric, runs on renewable resources, and is capable of sustainably producing the food we need to feed the future."

There are three basic types of agrivoltaics that are being actively researched:

- Solar arrays with space between for crops.
- Stilted solar arrays above crops
- Greenhouse solar arrays.[2]

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.[2]

In their initial 1982 paper, Goetzberger and Zastrow published a number of ideas on how to optimise future agrivoltaic installations.[4]

- 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.[4,5,6]

Experimental facilities often have a control agricultural area. 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.

III.RESULTS

Agrivoltaics solve at least two critical needs. Solar provides the renewable energy needed to mitigate climate change impacts while meeting global energy demand. And crops grown alongside solar help to feed the burgeoning global population, which is anticipated to grow to nearly 10 billion people by 2050, according to the United Nations.

Cornell University researchers have examined agrivoltaics to find out if there is merit to the perception that co-located sites will see major tradeoffs between food and energy production. Their study has shown how solar and crop production cannot only exist side by side, but how co-location improves the microclimates of farms and the surface temperature of solar modules.

The researchers have developed a computational fluid dynamics (CFD) microclimate model, which they evaluated against experimental data to investigate the effects of panel height, light reflection (albedo), and how much water is evaporated (evapotranspiration) in a PV site. They published their results in Applied Energy.

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"We now have, for the first time, a physics-based tool to estimate the costs and benefits of co-locating solar panels and commercial agriculture from the perspective of increased power conversion efficiency and solar-panel longevity," said lead author Henry Williams, a doctoral student in Cornell University's engineering department.

The team demonstrated an agrivoltaic facility with soybeans growing under solar modules mounted about 13 feet (3.9 meters) above the ground. The project resulted in solar module temperature reductions of up to 50 F (10 C), compared to solar farms mounted just 1.6 feet over bare soil.[7,8,9]

Fixed solar panels over crops

Tomatoes under solar panels in Dornbirn, Austria

The most conventional systems install fixed solar panels on agricultural greenhouses,[7] 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.[8]

Vertical systems

Vertically mounted agrivoltaic systems with bifacial photovoltaic modules systems have been developed. Most agricultural fences can be used for vertical agrivoltaics.[9] Overall, at least one PV module between posts is acceptable for most fences for $0.035/kWh for racking on existing fencing in the U.S.; although the yield for a vertical PV is only 76% facing south, the racking cost savings enable fence-retrofit agrivoltaics to often produce lower levelized cost electricity.[9] For fence PV, microinverters had better performance when the cross-over fence length was under 30 m or when the system was small, whereas string inverters were a better selection for longer fences.[10] Simulation results show that the row distance between bifacial photovoltaic module structures significantly affects the photosynthetically active radiation distribution.[8] Next2Sun has commercialized vertical agrivoltaic systems in Europe.[11] Open-source vertical wood-based PV racking has been designed for farms[12] that is (i) constructed from locally accessible (domestic) renewable and sustainable materials, (ii) able to be made with hand tools by the average farmer on site, (iii) possesses a 25-year lifetime to match PV warranties, and (iv) is structurally sound, following Canadian building codes to weather high wind speeds and heavy snow loads. The results showed that the capital cost of the racking system is less expensive than the commercial equivalent and all of the previous wood-based rack designs, at a single unit retail cost of CAD 0.21.[12]

Integrated systems

A standalone solar panel integrated system using a hydrogel can work as an atmospheric water generator, pulling 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).[13][14]

Dynamic agrivoltaic

The simplest and earliest system was built in Japan using a rather flimsy set of panels mounted on thin pipes on stands without concrete footings. This system is dismountable and lightweight, and the panels can be moved around or adjusted manually during the seasons as the farmer cultivates the land. The spacing between the solar panels is wide in order to reduce wind resistance.[15]

Some newer agrivoltaic system designs use a tracking system to automatically optimize the position of the panels to improve agricultural production or electricity production[10,11,12]

In 2004 Günter Czaloun proposed a photovoltaic tracking system with a rope rack system. Panels can be oriented to improve power generation or shade crops as needed. The first prototype was built in 2007 in Austria.[17] The company REM TEC deployed several plants equipped with dual-axis tracking systems in Italy and China. They have also developed an equivalent system used for agricultural greenhouses.

In France, Sun'R and Agrivolta companies are developing single-axis tracking systems. According to them, their systems can be adapted to the plant needs. The Sun'R system is east–west axis tracking system. According to the company, complex plant growth models, weather forecasts, calculation and optimization software are used. The device from Agrivolta is equipped with south-facing solar panels that can be removed by a sliding system. A Japanese company has also developed a tracking system to follow the sun.[18]

In Switzerland, the company Insolight is developing translucent solar modules with an integrated tracking system that allows the modules to remain static. The module uses lenses to concentrate light onto solar cells and a dynamic light transmission system to adjust the amount of transmitted light and adapt to agricultural needs.[19]

The Artigianfer company developed a photovoltaic greenhouse whose solar panels are installed on movable shutters. The panels can follow the course of the sun along an east–west axis.[20]

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.[21]

The difficulty of such systems is to find the mode of operation to maintain the good balance between the two types of production according to the goals of the system. Fine control of the panels to adapt shading to the need of plants requires advanced agronomic skills to understand the development of plants. Experimental devices are usually developed in collaboration with research centers.

Greenhouses with spectrally selective solar modules[edit]

Potential new photovoltaic technologies which let through the colors of light needed by the interior plants, but use the other wavelengths to generate electricity, might one day have some future use in greenhouses. There are prototypes of such greenhouses.[22][23] "Semi-transparent" PV panels used in agrivoltaics increase the spacing between solar cells and use clear backsheets enhancing food production below. In this option, the fixed PV panels enable the east–west movement of the sun to "spray sunlight" over the plants below, thereby reducing "over-exposure" due to the day-long sun as in transparent greenhouses, as they generate electricity above.[24]

Solar grazing

Perhaps the easiest use of agriculture and PV is allowing sheep or cows[25] to graze under solar panels. The sheep control vegetation, which would otherwise shade the PV.[26] Sheep even do a more thorough job than lawnmowers as they can reach around the legs of the structures.[26] In return, sheep or goats receive forage and a shady place to rest. Sheep may be cheaper than mowing.[27] In general PV system operators pay shepherds to transport sheep. Experimental sheep agrivoltaics found lower herbage mass available in solar pastures was offset by higher forage quality, resulting in similar spring lamb production to open pastures.[28] Agrivoltaics also can be used to shade cows.[29] Solar grazing is extremely popular in the U.S. and an organization has formed to support it[13,14]

Effects

The solar panels of agrivoltaics remove light and space from the crops, but they also affect crops and land they cover in other ways. Two possible effects are water and heat.

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.[31]

Water

In experiments testing evaporation levels under solar panels for shade resistant crops cucumbers and lettuce watered by irrigation in a California desert, a 14–29% savings in evaporation was found,[2] and similar research in the Arizona desert demonstrated water savings of 50% for certain crops.[32]

Heat

A study was done on the heat of the land, air and crops under solar panels for a growing season. It was found that while the air beneath the panels stayed consistent, the land and plants had lower temperatures recorded.[2]

Advantages

Dual use in land for agriculture and energy production could alleviate competition for land resources and allow for less pressure to develop farmland or natural areas into solar farms, or to convert natural areas into more farmland.[4] Initial simulations performed by Dupraz et al. in 2011, where the word 'agrivoltaics' was first coined, calculated that the land use efficiency may increase by 60–70% (mostly in terms of usage of solar irradiance).[2][33] The central socio-political opportunities of agrivoltaics include income diversification for farmers, enhanced community relations and acceptance for PV developers, and energy demand and emissions reduction for the global population.[3][34]

A large advantage of agrivoltaics is that it can overcome NIMBYism for PV systems, which has been becoming an issue.[35] A U.S. survey study assessed if public support for solar development increases when energy and agricultural production are combined in an agrivoltaic system and found 81.8% of respondents would be more likely to support solar development in their community if it integrated agricultural production.[36] Dinesh et al.'s model claims that the value of solar generated electricity coupled to shade-tolerant crop production created an over 30% increase in economic value from farms deploying agrivoltaic systems instead of conventional agriculture.[37] Agrivoltaics may be beneficial for summer crops due to the microclimate they create and the side effect of heat and water flow control.[38] Agrivoltaics is environmentally superior to conventional agriculture or PV systems; a life cycle analysis study found the pasture-based agrivoltaic system features a dual synergy that consequently produces 69.3% less greenhouse gas emissions and demands 82.9% less fossil energy compared to non-integrated production[15,16,17]

IV.CONCLUSION

At the recent Agrivoltaics Conference, hosted by Ivey Energy Policy and Management Centre, experts in renewable energy, farming and food systems came together in London, Ont. to discuss the potential for agrivoltaics to feed Canada's growing population while reducing its carbon footprint.

As climate change continues to exacerbate global food insecurity, speakers at the conference felt there was an urgent need for agrivoltaics, a practice where crops are grown under solar panels so the land simultaneously produces food and clean energy.

The conference included panel discussions on agrivoltaics research, small farming sustainability and transport, equipment suppliers and energy policy changes.

Acknowledging possibilities in Canada for agriculture, Brandon Schaufele, associate professor of business, economics and public policy and director of the Ivey Energy Centre, said the country hasn't done the best job of integrating renewables into the agricultural value chain.

"We need to get this right. We need to get it right for the energy system and we need to get it right for the agricultural system and events like this really help with that," he said. "The idea of this is to really start agrivoltaics on a path to success in Canada."

Transitioning farming to low-carbon pathways

Citing that greenhouse gas emissions from growing food alone match the emission reduction targets outlined in the Paris Agreement, Energy Consultant Claude Mindorff, the event's keynote speaker, said there is a dire need to transition farming to low-carbon technologies. Mindorff is director of development at PACE Canada, a global solar development and investment company that is currently building a solar farm in central Alberta and has proposed plans for a second one in the area. [18,19]

"This is not wishful thinking – the technology already exists. We can literally take the components off the shelf and make this happen," he said. "The opportunity exists and it's an urgent opportunity."

Mindorff discussed the benefits of agrivoltaics, which he described as a hybrid agricultural system that maximizes land use and reduces water consumption while providing clean and affordable energy. Among the benefits is the potential to increase crop yields, while reducing water and fertilizer requirements as well as provide growers with additional income generated through selling solar electricity.

Increasing food security

Mindorff said early agrivoltaics research shows that converting just four per cent of Canada's farmland to agrivoltaics can supply the country's electricity needs while creating a sustainable long-term food system for its entire population. He said this is especially important given that 5.8 million Canadians are food insecure, especially in Alberta and Northern Canada. It would also allow Canada to export more food to other parts of the world, particularly areas where extreme weather events, such as California's record-breaking droughts, are taking farmland out of production at a time when it's needed most.

"We can't buy more land so we have to do better with the land we have," he said. "And we don't have to cover every acre, we can strategically plan this."

During a panel on energy and agriculture, Patrick Gossage, managing partner of First Green Energy, an energy and sustainability advisory business, discussed the potential for agrivoltaics to reduce weather-related crop damage. He said certain crops such as broccoli, basil, ginseng and long-cane raspberries have been shown to thrive when grown in the partial shade of solar panels.

"With climate change, there is an increasing concern about crop failure so for all crops, having some limited protection from crop burn is useful," he said. "I'm excited to get this conversation going and see what we can make happen as an industry that I really believe is the win-win-win that we've been searching for."

Protecting Indigenous cultural values

Jeremy Dresner, founder and manager of Energy Redesign, a company focused on solar project development, told how agrivoltaics' ability to reduce water use in agriculture is particularly important in the Okanagan region of British Columbia where he is based due to the area's propensity for wildfires.

"You either have water for the fire service, or for irrigating crops, or for drinking, but not all three at once. We're not seeing people go thirsty, but one of those elements is always missing," he said.

Currently working on an agrivoltaics project on Indigenous land, Dresner discussed how agrivoltaic farming can help to regenerate the salmon population and grow berries in desert climates, therefore preserving some traditional elements that are important to the region's Indigenous people.

Calling agrivoltaics the next stage of agricultural adaption, Robert Sinclair, president of EnerStrat Canada, an advisory firm focused on the integration of distributed energy resources, said society has come full circle in relation to climate change.

"For 100,000 years, humans adapted to the environment and climate change and then about 300 years ago, we discovered through the evolution of technology that we can adapt the environment and the climate to some degree to us," he said. "I think we've realized that it was like stretching an elastic band and that elastic band has gotten to its tightest point and now we again have to adapt to the environment. To say that we can just stop with what we have I think is just laughing in the face of 100,000 years of our history."

Disadvantages

A disadvantage often cited as an important factor in photovoltaics in general is the substitution of food-producing farmland with solar panels.[51][31] Cropland is the same type of land on which solar panels are the most efficient.[51] Despite allowing for some agriculture to occur on the solar power plant, agrivoltaics may be accompanied by a drop in production.[31][52] Although some crops in some situations, such as lettuce in California, do not appear to be affected by shading in terms of yield,[2][51] some land will be sacrificed for mounting structures and systems equipment.[31]

Agrivoltaics will only work well for plants that require shade and where sunlight is not a limiting factor. Shade crops represent only a tiny percentage of agricultural productivity. For instance, wheat crops do not fare well in a low light environment and are not compatible with agrivoltaics.[2]

Agrivoltaic greenhouses are inefficient; in one study, greenhouses with half of the roof covered in panels were simulated, and the resulting crop output reduced by 64% and panel productivity reduced by 84%.[53][obsolete source]

A study identified barriers to adoption of agrivoltaics among farmers that include (i) desired certainty of long-term land productivity, (ii) market potential, (iii) just compensation and (iv) a need for predesigned system flexibility to accommodate different scales, types of operations, and changing farming practices.[54]

Agrivoltaics require a large investment, not only in the solar arrays, but in different farming machinery and electrical infrastructure. 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 mounting 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.[31]

Photovoltaic systems are technologically complex, meaning farmers will be unable to fix some things that may break down or be damaged, and requiring a sufficient pool of professionals. In the case of Germany the average increase in labour costs due to agrivoltaic systems are expected to be around 3%.[31] Allowing sheep to graze among the solar panels may be an attractive option to extract extra agriculture usage from conventional solar arrays, but there may not be enough shepherds available.[27]

Economics

The shade produced by systems located on top of crops can reduce production of some crops, but such losses may be offset by the energy produced. Many experimental plots have been installed by various organisations around the world, but no such systems are known to be commercially viable outside China and Japan.

The most important factor in the economic viability of agrivoltaics is the cost of installing the photovoltaic panels. It is calculated that in Germany, the subsidising of such projects' electricity generation by a bit more than 300% (feed-in tariffs (FITs)) can make agrivoltaic systems cost-effective for investors and thus may be part of the future mix of electricity generation[20]

The photovoltaic industry cannot make use of European CAP subsidies when building on agricultural land.[20]

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