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Agri-Voltaic Farming: A Sustainable Approach for Climate-Smart Agriculture

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The fast pace of climate change and the growing number of people on Earth are two of the biggest problems that people face today. Agriculture, which feeds almost half of the world's people, is very sensitive to changes in the weather. In India, where almost 47% of the workforce works in agriculture, crops have been hurt by repeated droughts, unpredictable monsoons, and soil degradation. This has made food security worse. India's reliance on fossil fuels for energy production has also led to a lot of greenhouse gas (GHG) emissions, making it the third biggest emitter in the world. To fight this, the country has promised to reach net-zero emissions by 2070, which is in line with global climate goals. Agrivoltaics Farming, which combines photovoltaic (PV) systems with farming, is one promising solution that can help with both agricultural and energy problems at the same time. This method lets the same piece of land be used for both growing food and making renewable energy, which is a model of sustainability and resilience that works together.

The concept and Evolution of Agrivoltaics

The concept of Agrivoltaics (APV) or solar sharing, was introduced in 1981 by Adolf Goetzberger and Armin Zastrow in Germany. Their idea was simple yet revolutionary – to elevate solar panels above farmland to allow simultaneous solar energy production and crop cultivation. The key design principle of agrivoltaics is to optimize light distribution: solar panels capture part of the sunlight for energy, while the remaining light passes through or around panels to support photosynthesis in crops below. Modern agrivoltaics systems use elevated or adjustable solar structures that maintain appropriate spacing and tilt to balance shade and light availability.

Over the decade, agrivoltaics evolved through technological innovations such as:

. Transparent or bifacial panels that transmit diffused light,

. Adjustable tracking systems that optimize sun exposure, and

. Thin-film and polymer coating technologies that separate light wavelength beneficial for both crops.

Agrivoltaics optimizes land use by integrating solar panels with crops. The idea of agrophotovoltaics (APV) was initially conceived by Goetzberger and Zastrow in 1982 to modify solar power installations to allow simultaneous crop cultivation in the same area (13). For the technology, solar collectors were elevated 2 m above ground level and gaps were increased in the gaps between them to prevent excessive crop shading. These systems would require only one-third of the incoming solar radiation (14). It took approximately 30 years for this concept to be referred to as agro photovoltaic, agro PV, agri voltaic, or solar sharing. By generating both solar energy and agricultural products in a single location, it is possible to share light, enhance freshness and decrease moisture loss. The integration of solar technology with agriculture began in 1975 with the development of the first photovoltaic water pump.

Global Status of agrivoltaics

Agrivoltaic (AV) system categorized under agricultural 5.0 present a potential solution to the meet the growing needs of food and energy. These systems utilize power resources to support agricultural production, encompassing facility gardening, breeding and specialized pastoral structures thereby establishing a novel production model that integrates farming, power generation and agricultural activities (16). Research on solar energy applications in agriculture commenced as early as the 1960s in countries such as Britain, France, India, Portugal and the United States. The emergence photovoltaic technology gradually drew attention toward agrivoltaic applications The introduction of the first photovoltaic water pump in 1975 marked the inception of integrating photovoltaic technology with agriculture. However, this concept remained largely unexplored until 2004 when Akira Nagashima constructed the first system in Japan designating it as "solar sharing" (18). Subsequently AVS proliferated across Europe, Asia and the United States, ranging from small-scale family farming operations to extensive installations exceeding 700 MW in China, offering diverse benefits to farmers globally. China initiated large-scale agrivoltaic systems in 2014 and continues to maintain global leadership in installed capacity (19). France became the first European nation to support agrivoltaics, implementing regular tenders in 2017 systematically. By 2021 agrivoltaics had evolved into a market ready technology with a global installed capacity surpassing 14 GWp (20).

The role of agrivoltaics in advancing climate-smart agriculture

Agrivoltaic systems as emerged as an innovative and sustainable technology in response to escalating climate change, dwindling resources and increasing energy needs. These systems involve installing photovoltaic (PV) panels on agricultural land, enabling concurrent solar energy production and crop cultivation. Agrivoltaics systems optimize land utilization by combining energy generation and agriculture on a single plot. This dual-purpose approach mitigates the necessity for additional land conversion and attenuates the environmental impact. Some of the points highlighting the importance of the Agrivoltaics systems are listed below. 1. The shade provided by solar panels can reduce soil and water evaporation, resulting in more efficient water utilization in agriculture. This is particularly advantageous in arid and semi-arid regions with scarce water resources. By producing renewable energy, agrivoltaics systems decrease dependence on fossil fuels and reduce greenhouse gas emissions. This contributes to mitigating climate change and its effects on agriculture and ecosystems. The vegetation growing beneath and around solar panels can enhance carbon sequestration in soil and biomass, further reducing atmospheric CO2 levels. Solar panels can assist in minimizing soil erosion by shielding the soil surface from wind and water. This helps to preserve the soil structure and prevents the loss of valuable topsoil. Agrivoltaic systems can establish microhabitats that support the local flora and fauna. The solar panels and associated infrastructure can provide shelter and resources for various species. Enhanced soil health and decreased evaporation can lead to reduced need for chemical inputs such as pesticides and fertilizers. This can mitigate the environmental impact of agricultural practices and diminish the risk of runoff pollution. 7.The shading effect of solar panels can help crops withstand extreme weather conditions, such as heat waves and intense solar radiation, by moderating temperature extremes. This can enhance the resilience of agricultural systems to climate variability and severe weather events.

Impact of solar panel shading in agrivoltaic systems

Agrivoltaic systems contribute directly and indirectly to reducing greenhouse gas (GHG) emissions, primarily through the shading effects of solar panels. Agrivoltaic systems, which involve partially shading or covering the soil with photovoltaic (PV) modules, help to retain soil moisture and enhance its water-holding capacity. By reducing soil temperatures, these systems contribute to creating a more favorable environment for plant growth. Cooler soil temperatures help stabilize microbial processes, leading to a reduction in nitrous oxide (N_2O) emissions. Large-scale PV power generation is essential for mitigating climate change and agrivoltaics is emerging as a sustainable alternative energy source. It optimizes multifunctional land use by supporting both electricity generation and agricultural activities simultaneously. Additionally, the partial shade provided by agrivoltaic systems has been shown to benefit crop water balance and reduce evapotranspiration. The shading effects also support a broader range of plant and animal species, while cultivation practices under agrivoltaic systems further enhance soil quality.

Protection against heat and water loss, and increase in crop yields

As mentioned earlier, agrivoltaics can allow for the cultivation of crops by protecting them from heat stress and water loss. The shading the PV panels provide improves the microclimate beneath the solar panels and lowers the temperature on the ground, boosting agricultural productivity. A project in Algeria, for instance, has shown that agrivoltaics can lead to considerably higher yields, as well as size of the crops. Additionally, regions that have become infertile or that face progressive soil degradation due to extreme heat and drought can be restored with the help of agrivoltaics, while the favorable growing conditions also allow for a wider variety of higher-value crops to be cultivated, all whilst enhancing food security. The shading from the PV panels also lowers water demand by reducing water loss through evaporation. Meanwhile, agrivoltaic systems also allow for rainwater harvesting – this is particularly beneficial in dry and hot regions, where access to water is already limited.

New sources of income and jobs

The dual use of land for food and power production can also lead to a double income for farmers. The increased variety of crops already mentioned, as well as a potential income from the panels (e.g. through feed-in tariffs for surplus energy), can boost and diversify farmer incomes. Simultaneously, the installation, maintenance and operation of the PV modules also create jobs – even in structurally weak regions or in disadvantaged rural areas.

Conclusion

Accordingly, the advantages of agrivoltaics are enormous on the African continent, and thanks to high solar radiation, they might even be greater than in Europe. Political incentives and funding programmes that support the development of agrivoltaics could be a major lever to realize the multiple benefits the technology has. While agrivoltaics is still in the early stages on the African continent, the transfer of know-how and policy programmes, such as the Water-Energy-Food-Ecosystems Nexus, an approach focusing on integrated policy solutions that align water, energy and agriculture for mutual benefit, have the capability to improve food and energy security, all whilst benefiting the climate and the local population.

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