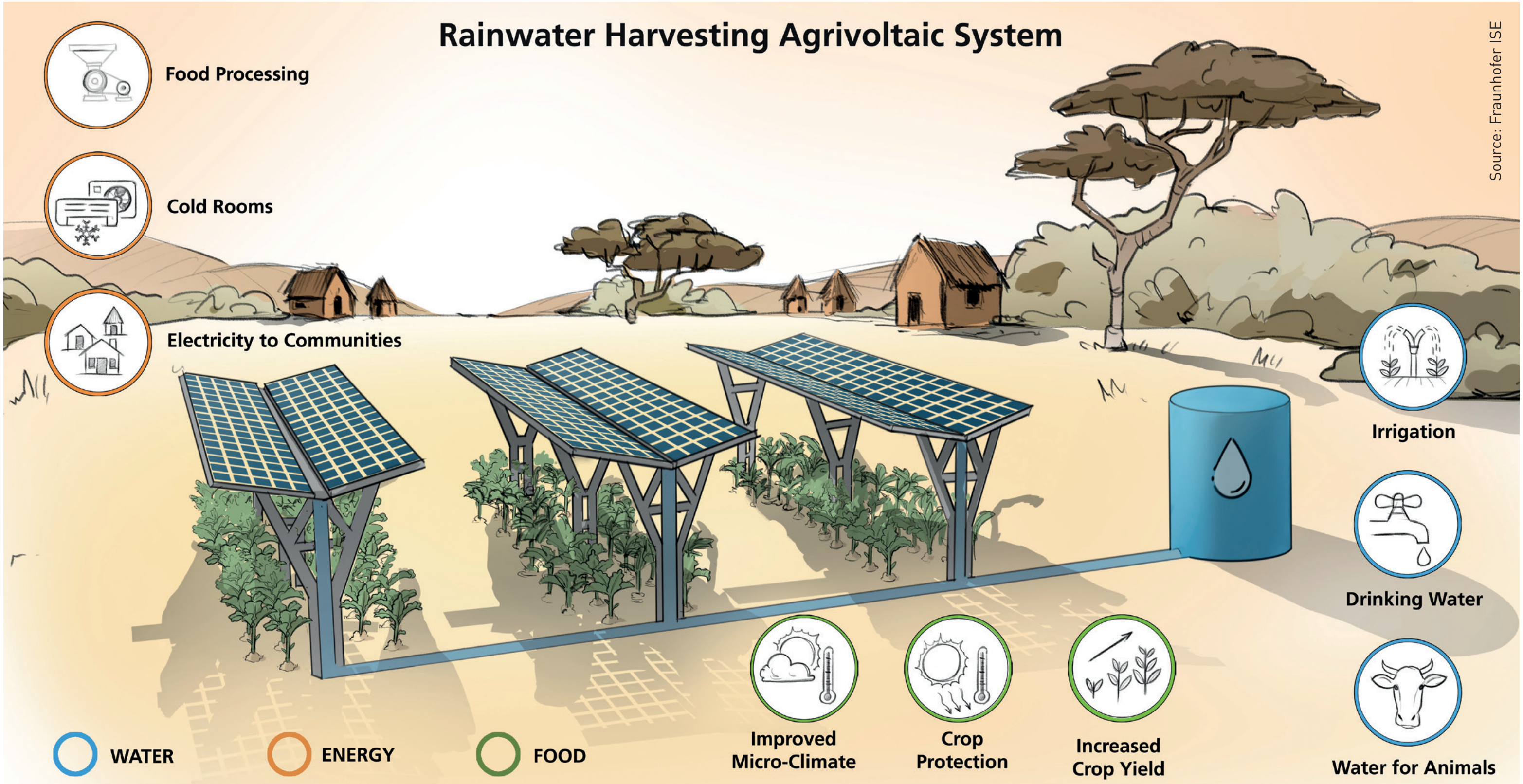

Unlocking the potential of agrivoltaics

Agrivoltaics is a concept that combines photovoltaic electricity generation and agricultural production, providing the opportunity for a more efficient land use and contributing overall to the integration of food, energy and water systems. This can be particularly interesting for countries in the Global South, where rural electrification rates are often low and food security needs to be improved. A research project in Mali and The Gambia is to explore the potential of the system, with a focus on community integration and integrative funding.

By Henriette Stehr, Nora Adelhardt, Brendon Bingwa and Susanne Wolf

Agrivoltaics is a concept based on dual land use, where a single area is used both for agricultural production and photovoltaic (PV) power generation. Although first mentioned in 1982, development has gained momentum only in recent years. As of 2021, there are 14 gigawatt-peak (GWp) of installed capacity world-wide. In agrivoltaic systems, PV panels are mounted on a substructure on the agricultural land and generate sustainable electricity, while agriculture production takes place underneath or between the PV module rows. When installed above, the increased height of the installation provides enough space for farming activities underneath. This has many potential advantages, including higher land-use efficiency as well as shading and physical cover provided by the panels altering the microclimate and protecting crops and soils, possibly leading to higher crop yield and quality. A field trial conducted by the Fraunhofer Institute for Solar Energy Systems in Germany has shown that the simultaneous use of land can increase land-use efficiency by up to 84 per cent (depending on the crop type) and can therefore be considered as a resource-efficient way of improving land productivity and enhancing food security.

The APV-MaGa project – combining traditional and non-traditional research

Most current agrivoltaic systems are located in the Global North, with the first pilot plant in Germany being installed in 2016. However, the potential for agrivoltaics in the Global South is extremely high as the potential advantages and opportunities could be especially significant in these regions (see upper Box). Against this background, the APV-MaGa project (see lower Box) was launched in 2020. In its context, five agrivoltaic systems will be installed in Mali and The Gambia, two countries with which the project partners are already cooperating in the context of the water-energy-food nexus. Both of them are located in the Sahel Region, one of the areas most vulnerable to climate change, and at high risk of droughts. High solar radiation levels and the population's dependence on agriculture put even more stress on the need for sustainable water management, especially with fertile arable land becoming increasingly scarce. Because of the increasing impact climate change is having on agriculture and growing energy demands, both countries need innovative and sustainable energy solutions and improvements in food security. The agrivoltaic systems are to provide food, water and electricity to local communities and simultaneously increase the resilience of the agricultural sector to climate change effects.

There are plans for the construction of one 200-kilowatt-peak (kWp) system in Mali by the end of 2023 and four smaller systems, up to 62.5 kWp, in The Gambia, by the end of the first quarter of 2024. While in Mali the system will be installed in the grounds of the Rural Polytechnic Institute of Training and Applied Research in Katibougou, the systems in The Gambia are intended to be set up at the University of The Gambia, a small private farm and two community farm sites. The mix of different farm types will allow both traditional scientific research, in which conditions are more strictly controlled, and non-traditional research, where community involvement will require flexibility in the scientific approach (e.g. local farming practices will be implemented, social interaction with the system will be considered, etc.). The photovoltaic (PV) modules are to be installed at a height of 2.5 metres to enable the use of farming machinery underneath the system and to obtain a higher energy gain from the used bifacial PV modules, which also generate electricity from their rear side. Some of the demonstrators include a rainwater harvesting system, with the rainwater being collected in a gutter between the modules and stored in tanks at a height of about five metres. Solar pumps will be used for the distribution to the target areas.

The electricity generated by the systems is planned to power supplementary equipment such as cold-rooms, post-harvest processing equipment and irrigation systems, which will be built as part of the project. The crops underneath the agrivoltaic systems are to include those already commonly cultivated by local farmers, such as onions, tomatoes, potatoes, okra and green beans, as well as high economic value crops that may not have previously been possible to cultivate because of the harsher climatic conditions, such as strawberry and broccoli. Research data will be collected and supplied by the local partners beyond the life of the project, providing long-term data, which is essential to accurately assess the impact of the agrivoltaic systems in the local climatic and socio-economic conditions.

What effects are expected?

Economically, multiple short- and long-term effects are to be expected. For instance, farmers' income may be increased in general through the sale of higher yields and higher quality crops, as well as better timing of the market allowing crops preserved through cold storage to be sold at higher prices at times of high demand/low availability. Also, the more efficient irrigation and the increasing availability of self-generated electricity lower the expenses needed to run the farm. In the long run, additional income may lead to investments and enable the expansion to non-local markets. The additional equipment connected to the agrivoltaic system also allows farmers and farming communities to diversify revenue streams and increase income through the sale of services to the surrounding communities.

One important aspect of the project is the realisation of a community-based approach, especially in The Gambia. This has multiple implications, starting with an active communication with local partners and community members. Participatory schemes and acceptance studies are used to evaluate this exchange. Secondly, the project team plans group discussions with local farmers and other potential smallholders, to be able to understand and consider individual needs and ideas. Thereby, technical know-how and engagement of the farmers can also be integrated into the project. A co-design workshop with important stakeholders will be organised to ensure that the system is adapted to regional factors. The focus lies on developing a sustainable business model for the long-term success of the agrivoltaic systems. Additionally, a local organisation will be established in both countries to include financial stakeholders and community members in the decision-making process. These organisations will take care of the long-term maintenance of the systems.

The challenge of sustainable funding

While the project is still in its planning phase, funding has proven to be a significant challenge. One of the goals is to include local partners' own financial contributions. The idea is to include both public and private funding and move away from the traditional model of donor funds with little input from local partners, as this often leads to long-term problems or failure of projects. In-kind contribution (labour, equipment, use of existing infrastructure, etc.) by the local partner is also considered a form of funding. But as APV-MaGa is a research & development project, it is hard to secure the investment of private companies. These conflicting interests between private and public funders require a lot of communication. The project aims to bridge the gap between these two interest groups for a new, more integrative and sustainable financing approach in accordance with the overall goal of the project. Based on their experiences with previous failed projects, the local partners agree that this approach could be a way to mitigate the problems and are therefore keen to also explore ways to secure their contributions, either in cash or in-kind.

Water, energy, food, income: agrovoltaic's potential

Over 759 million people, most of whom live in rural sub-Saharan Africa, do not have access to persistent and affordable electricity. In these rural, off-grid locations, agrivoltaics can provide access to electricity and thereby improve energy security. The solar electricity can be used directly for self-consumption on the farms, lowering the costs associated with use of alternative forms of energy (e.g. diesel generators), or used to provide energy services and thereby increasing income diversity.

In addition, globally, about 2.3 billion people live in water-stressed countries, and most countries in the Global South are not on track to fulfil the UN sustainable water management goals. Also, 72 per cent of all water withdrawals comes from the agricultural sector, demonstrating the need of increasing water-use efficiency. Agrivoltaics offer the option to integrate a system to collect rainwater from the solar panels; additionally, through the shading caused by the PV panels, water losses through evapotranspiration by the plants can be decreased. In this manner, water use can be lowered and collected rainwater can be used for a more efficient irrigation, such as drip irrigation or other farm-related purposes. This alternative water supply and water-use reduction can therefore reduce the overextraction of groundwater resources.

Savings on irrigation costs, an increase of crop yield through drought protection, sale of electricity to nearby communities and higher income through improved crop quality are among the financial assets offered by agrivoltaics.

Agrophotovoltaics for Mali and The Gambia: Sustainable Electricity Production by Integrated Food, Energy and Water Systems (APV-MaGa) was launched in August 2020. The four-year project is being funded by the German Federal Research Ministry in the context of "Client II – International Partnerships for Sustainable Innovations" and comprises 15 partners from research, politics and the private sector. It incorporates five agrivoltaic systems with a total capacity of between 400 and 450 kWp installed.

While the potential of agrivoltaics for the Global South is high, much research data is still required. In the crop-farming sector, this applies to the impact of shading on the micro-climate below the PV modules, the subsequent effect on the crops and the most suitable crops that can be grown under these altered conditions. As the upfront costs of the systems may be a barrier to their wide-scale implementation in the Global South, further research is also needed on solutions that could reduce costs and/or provide a positive return on investment. Suitable finance and business models have to be examined, with some of them possibly being transferrable from other settings. For the African context, the models described e.g. by Horvath ("host-owned" or "community-owned", but also "pay-as-you-go", to name some) could be appropriate. The use of alternative construction materials (such as bamboo and wood) and material use-efficiency through innovations including the integration of rainwater harvesting into the substructure are further examples of current and future research focus. Higher upfront costs and uncertainty over the effect of shading on crops serve as the main points against agrivoltaic systems in the target regions. It is difficult to justify higher system costs, given the extremely low electricity access rates, while not all crops respond positively to shading and changes in micro-climate, hence crop yield could be reduced, rather than being increased. And last but not least, one of the key factors for the success of the system is to gain more insights on its acceptance among the local population.

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Brendon Bingwa is Project Manager in the Agri-PV group at Fraunhofer ISE and is focused on agrivoltaic research projects in Africa.
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References: **www.rural21.com**

"We want to create training and employment opportunities for the coming generations"

The German provider of solar systems SUNfarming has set up agri-PV systems in various countries in Africa, Asia and Latin America in public-private partnerships. For Edith Brasche, director of international projects, the potential of these dual-use systems is far from being exhausted. The sticking point, however, remains financing, she maintains.

Edith Brasche is Managing Director for Project Development of the SUNfarming Group for German and international projects. Previously, she worked for a business consulting group for 25 years, where she was a member of its board of directors.

Ms Brasche, SUNfarming has already been developing agri-PV plants for almost 20 years. What makes the concept so interesting for you?

All across the world, agri-solar plants can considerably contribute to energy and food security. The raised solar plants generate renewable energy on farmland while fruit and vegetables or even grapes for wine can be cultivated below them. Livestock can also be kept in pastures with agri-solar systems, where they are protected from the weather or attacks by birds of prey. Especially in countries with high solar radiation, where climate change is increasingly destroying harvests, agricultural solar plants – also known as food & energy plants – can help secure harvests and minimise famine. Farmland and livestock grazing thus receive multiple benefits for agriculture, energy production, and animal welfare, but also to provide an economic and social base for people to live in regions they would otherwise have had to leave in the wake of climate change impacts.

So it's a holistic concept ...

Yes – very much unlike the ground-mounted solar plants, which generate renewable energy in a one-dimensional way, but cover or even seal the land, ruling out any further use.

What do your plants feature?

The plants' steel substructure is rammed straight into the ground, and only the transformers stand on concrete foundations, resulting in less than two per cent of the ground being sealed. The tables for the modules are mounted on pillars, with the lowest point of them at a height of 2.10 m and the highest at 3.60 m. The semi-transparent double glass modules have a light transmission of 15 per cent. The mounting profiles for the modules serve as a rainwater distribution system underneath. They are designed to evenly distribute the rainwater under the module tables. Together, these two aspects protect the soil from erosion and promote optimum plant growth. In addition, the modules are resistant to hailstorms and can also withstand cyclones, as our plants in the Bahamas, the Dominican Republic and Madagascar have proven for many years.

Is 15 per cent of daylight sufficient for the plants to thrive?

Yes, because the 15 per cent goes straight through the modules and additional light comes in from the sides of the module rows; plants sensitive to light or those requiring an especially high amount of sunlight cannot be cultivated so well below them. That is why we are concentrating on growing vegetables, herbs and fruit, which works very well.

You set up the first Food & Energy plant in the Global South in South Africa in 2012. What was important to you in this context?

A main part of our concept is to integrate the people in the areas where we build our plants. You always need to involve the local people and see what their needs are. Most countries want to have renewable energy, but in most cases there are more fundamental things on the priority list – education, unemployment, water and food shortages. Within our Food & Energy concept, we can provide appropriate countermeasures for all these challenges. With our partially shaded systems equipped with water-saving drip irrigation, food is produced with minimal water use, with the harvest protected by the structure even in extreme weather conditions. Our plants are operated in cooperatives by local people who have previously been trained by us.

What exactly does this training look like?

With our subsidiary SUNCybernetics, we have created a recognised and certified training programme for electricians and community service staff as well as people from poorer rural areas. In cooperation with regional educational institutions, certified trainers train people on site in the planning, installation and operation of solar plants as well as sustainable agriculture. This train-the-trainer principle promotes knowledge transfer and thus creates access to education and training in the respective region. Various programmes have been developed for this purpose, lasting between four and twelve weeks; the trainees are selected via local scouting processes in cooperation with local cooperation partners as well as co-operating NGOs.

You also collaborate with universities for this purpose ...

In 2014, on the Potchefstroom Campus of North-West University in South Africa, we set up a SunFarming Food& Energy Training centre. It serves both as a production unit and a nodal point for interdisciplinary research and development projects with the University's agriculture and electrical engineering departments as well as with external partners from the food sector. Currently the Potchefstroom plant consists of three greenhouses with netting areas, where together with vegetables – tomato, cucumber, cabbage, spinach and others – and medicinal herbs such as *artemisia annua* being grown, sustainable energy is generated by means of roof-integrated photovoltaic modules. The facilities are also being used for research purposes and nurseries to identify what kind of crops can be grown best under the structure. The Training Project provides knowledge transfer in train-the-trainer programmes for master trainers and students. Moreover, workers from local communities are trained as foremen in special food production under greenhouse conditions and gain a basic knowledge in PV solar production. Around 500 trainees are being trained each year, and so far, roughly 4,000 people from all over the country have been trained. In addition, 3,600 kilograms of food is produced there each year.

What about women's participation?

Around half of the trainees are women. We want to give them the opportunity to become self-employed in agriculture and thus generate a – second – income for their families. To achieve this, local companies in the food production sector are also involved. The women are also trained in energy production, but primarily in sustainable agriculture.

South Africa is a popular cooperation partner regarding renewable energies. Does the concept also work in other countries?

It does, although the focus of course varies according to local needs. For example, our Food & Energy facility in Turkey has been producing food with refugees from the neighbouring camp since 2019 and supports the development of social contacts between the refugees and the local population through joint business activities that focus on the sale of products from fruit and vegetable cultivation and poultry farming. The initiative thus contributes to a better integration of people and to the sustainable maintenance of livelihoods. In Madagascar, the products grown under the agri-PV plant are intended primarily to ensure the survival of the bitterly poor population, providing them with healthy food and medicinal herbs to strengthen their immune system.

You mentioned the drip irrigation system – is it also part of your offer?

Yes, we develop the respective irrigation systems in addition. For this purpose, we take a look at the individual local water situation, at what cultures are grown, etc. In Madagascar, for example, we are at the moment developing a second plant for which our engineers have worked out a special water management concept.

Agri-PV plants are more expensive than ground-mounted solar plants. How are they financed?

Via our company's own investments and also in co-financing schemes with development cooperation funds from the German Federal

Greenhouses with roof-integrated photovoltaic modules at North-West University's Potchefstroom Campus in South Africa. Vegetables and medicinal herbs are cultivated in them.

Photos: SUNFarming

Government, with the aid of international development banks or also internationally operating charitable organisations campaigning for climate protection and food and development cooperation. Furthermore, we closely work together with the respective governments of the countries in public-private-partnership projects. The F&E Centre in Potchefstroom, for example, is a partnership with North-West University and the Deutsche Investitions- und Entwicklungsgesellschaft, DEG.

What about the economic viability of the plants?

In economic terms, the green electricity generated and fed into the national grid must be remunerated at a rate of at least 0.10 eurocents per kilowatt-hour. However, the remuneration is often much lower – if it is granted at all. The minimum purchase price has been calculated to ensure that with a subsidy of around 350,000 euros from the communities or the government, we can create up to 24 new jobs and 50 training places per megawatt-peak (Mwp) of plant output and year.

And what if there is no guaranteed purchase?

If the countries are not bankable, in other words, if government guarantees of payment of renewable energy are not recognised by international financiers as secure and not accepted, then the holistic plant concepts can only be put into practice by private investors purchasing the electricity at the minimum purchase price. These are companies who want to achieve CO_2 neutrality and energy security independently of government grid infrastructures or that are seeking to produce green hydrogen or ammonia with renewable energy or ammonia together with us and make it available to the European market.

Given your experience in different countries throughout the world, what are the biggest problems you face in implementing the schemes?

Now and then, major investment ventures fail because of a lack of financial feasibility in politically unstable countries or also owing to the monopoly position of the grid operators, who are usually government-run, which block the feed-in of renewable energy in order to use their grids for fossil energy, which they generate, for example, with obsolete power stations. Here, we would very much desire changes in the framework conditions and having the opportunity to feed agri-PV electricity into the grids. Even in African countries in which blackouts are part of everyday life and renewable energy could be optimally generated with agri-solar plants and wind power, ventures are thus delayed or even rendered impossible. And of course, in addition, there are countless regions without any grid infrastructure. Here, agri-solar plants operating independently from the grid could not only secure power supply for companies or even entire villages but could also safeguard agricultural yield below the plant.

Have you got an example of this?

One example is the installation of a Food&Energy system with a rated power of 13 kWp to supply electricity to a small outpatient health clinic in the community of Suwareh Kunda in The Gambia. This facility was constructed in March 2022 and is equipped with a battery storage system and a backup generator. On average, the plant produces more than 56 kWh per day. Most of this goes directly into the operation of the health station. During the day, the surplus electricity is used to charge the battery storage system, which even covers the energy demand during peak daytime hours or when solar yields are poor during the rainy season. To make the system fail-safe, a 6 kVa diesel generator is also available as an emergency generator, which is automatically switched on when demand is high or the battery charge is low. In the dry season, the area under the solar modules is used as a chicken coop or to provide shade for the staff and patients, while in the rainy season, local vegetables are grown there.

What is local acceptance of the F&E plants generally like?

As a rule, both the governments and the locals are very enthusiastic because they can see for themselves that the plants provide a solution to many of the existing problems. But of course they can also see the cost – and understandably, they try to lower them by awarding contracts to the most favourable bidders in calls for bids. Of course, a standard ground-mounted PV-plant can be built at a very low cost – and it may work for some years. Our agri-solar plants have a guaranteed life span of at least 30 years. We try to convince the regions and local communities that it makes more sense to invest a little more but in return get a high macroeconomic effect. We want to create training and employment opportunities for the coming generations with sustainable agriculture and energy production.

How do you assess the prospects of agri-solar plants for the future energy mix in the Global South?

I see enormous potential here. Due to the strong solar irradiation and the simultaneous high availability of arable and pasture land, for example in sub-Saharan Africa, large solar parks can be developed which, when coupled with existing wind energy parks, can make the use of electrolysers significantly more economical than in Europe. In South Africa or Brazil, for example, green hydrogen can be produced much more cost-effectively than in Germany. If ammonia is produced on site from green hydrogen, a solid energy carrier with high economic potential is created that can be used as a chemical feedstock, as fuel in shipping or for stationary power generation plants. Both Brazil and South Africa are currently in the process of developing large marine terminals as hydrogen hubs for loading ammonia to ship the locally produced ammonia to customer markets, including Europe. Biomethanol, on the other hand, which is also produced from green hydrogen and preferably green CO_2, such as from sugar cane production, can not only store green hydrogen, but also significantly reduce CO_2 emissions from road transport as a biofuel.

Interview: Silvia Richter

SUNFarming and FEED

Founded in 2004, SUNfarming GmbH is seated in Erkner, in Brandenburg, close to Germany's capital of Berlin. This family enterprise with its own research and development department operates in 15 countries and has so far installed roughly 1,300 PV plants with an output of 650 MW. In 2020, company founder Peter Schrum initiated the charitable association Food, Education, Energy & Development, reg. Ass. (FEED). Donations are used to train people from the South African townships in cultivating fruit, vegetables and medicinal herbs below agri-solar plants for their own needs but also for regional sales. The medicinal herbs are sprinkled into a pre-cooked maize porridge and processed as "Vitality Porridge", which is then handed out to school and kindergarten children. Every day, more than 15,000 children join the Vitality Porridge meals; in 2022, over 600 women were trained in sustainable agriculture by FEED in cooperation with partners in South Africa.
More information: www.sunfarming.de; www.feed-ev.de