

Agrovoltaics, An Innovative Solution to Reconcile Renewable Energy Production and Agricultural Yield in Côte d'Ivoire

Sampson Oladapo Oyedele^{1,2*}, Lancine Bamba¹, Mamadou Mariko¹, Raymond Kre¹, Boko Aka²,

¹Faculty of Fundamental and Applied Sciences, University Nangui Abrogoua, Abidjan, Côte d'Ivoire

²Institut de Recherche en Energie Nouvelle (IREN), University Nangui Abrogoua, Abidjan, Côte d'Ivoire

Email: *oyesamson2000@gmail.com, Souleymane.tuo@univ-man.edu.ci

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Abstract

Côte d'Ivoire has embarked on an ambitious energy transition aimed at increasing its share of renewable energy in its energy mix. At the same time, the country is facing the major challenge of electrification in rural areas, where abundant solar irradiation offers considerable potential. Côte d'Ivoire, thanks to its tropical climate and generous sunshine, is ideally positioned to take advantage of solar energy. However, the need to preserve agricultural land often limits the implementation of conventional solar parks. Agrovoltaic emerges as an innovative solution, allowing for the reconciliation of the production of clean energy with agriculture on the same surface. Indeed, thanks to solar panels, the soil on which they are installed is kept humid and protected from direct sunlight, thus offering a cooler and more prolific environment for plant development. With this combination, both parties benefit from each other's resource use. This article explores and illustrates the positive impact of agrovoltaic systems in Côte d'Ivoire as a sustainable solution to reconcile renewable solar energy production and increased agricultural productivity, and shows the commitment of Côte d'Ivoire towards renewable energies and examines how agrovoltaic integrates into this strategy, thus creating a dual opportunity: energy production and the preservation of arable land. In addition, the study highlights the crucial role of technological innovation in ensuring the economic sustainability of these production systems. These advances contribute not only to improving agricultural productivity, but also to increasing the profitability of agrovoltaic installations and reducing fossil fuels.

Keywords

Agrovoltaic, Renewable Energy, Solar Panels, Agricultural Production

1. Introduction

The direct conversion of solar light into electricity is possible thanks to the photovoltaic solar energy technique. This method is based on the use of photovoltaic cells, known as solar modules, which capture photons present in sunlight and transform them into current. Renewable energy is produced from various sources such as photovoltaic panels, small wind turbines for electricity production, and solar thermal sources for heat production [1]. More recently, the agrovoltaic system has become an alternative to conventional photovoltaic power plants. Agrovoltaic, an innovative installation, can simultaneously generate renewable energy and increase agricultural productivity by using a network of solar panels on existing farmland [2]. The crops are cultivated on the ground under the solar panels of the agrovoltaic system. To implement the agro-voltaic system, solar panels must be installed at a height allowing the passage of agricultural machinery for crop management [3]. This system could help alleviate food insecurity and become an alternative to fossil fuels, the main emitters of carbon dioxide. Sustainable agriculture is crucial to address food and energy challenges in Côte d'Ivoire. Given the country's active commitment to the development of solar energy and Agrovoltaics, aiming to reach 45% renewable energy in its energy mix by 2030, although solar energy still represents a small part of its current production. Several solar power plants, such as that of Boundiali (52 MWc, inaugurated in April 2024) and the future Ferké plant (52.42 MWc), are being built or commissioned, contributing to the country's energy transition and the "greening" of the agricultural value chain. Agrovoltaics, by combining agriculture and solar energy production, offers an innovative approach to improve agricultural productivity while contributing to the energy transition, as agriculture is a key economic pillar in Côte d'Ivoire, but it faces challenges such as soil degradation, water scarcity, the effects of climate change and dependence on fossil fuels for electricity. This article highlights the extent to which Côte d'Ivoire is committed to renewable energies and examines how agrovoltaic integrates into this strategy, in order to create a dual opportunity: energy production and the preservation of arable land. It should be noted that plants grown under the agrovoltaic system benefit from a better distribution of moisture [4], a reduction in evapotranspiration, an increase in carbon absorption and their reproduction [5], a decrease in soil and crop temperatures, an improvement in soil moisture, an increase in land productivity [6], an increase in pollinator foraging activity during hot, dry and late seasons, as well as protection against climate uncertainty and extreme events, such as hail and heavy rain [7]. The solar canopy provides protection that creates favorable microclimatic conditions [8], such as soil radiation and air temperature, without negatively affecting crops, which promotes agricultural productivity.

Objectives and research questions:

The main objective of this study is to analyze the potential of agrovoltaic in Côte d'Ivoire as a sustainable solution combining energy production and agricultural yield.

The specific objectives are to:

- 1) Identify the technical, economic and environmental conditions favorable to the implementation of the agrovoltaic system;
- 2) Assess the agronomic impacts on the main Ivorian food crops;
- 3) Examine the potential contribution of this model to the national strategy for energy transition and food security.

These objectives lead to the following research questions:

- 1) How can the agrovoltaic system simultaneously improve agricultural productivity and solar energy production in Côte d'Ivoire?
- 2) What are the technical and economic parameters essential to its viability?
- 3) To what extent can agrovoltaic be sustainably integrated into national agricultural and energy policies?

The structure of the article is organized as follows:

Section 2 presents the Ivorian context regarding access to electricity and agricultural development.

Section 3 describes the different types of agrovoltaic systems adapted to the tropical context and their applications.

Section 4 proposes an operational framework for implementing the model adapted to the national context.

Finally, section 5 concludes with technical, economic and political recommendations for the deployment of agrovoltaic on a large scale.

2. The Context of the Ivory Coast

2.1. Access to Electricity

Africa is about to enter a phase of sustained and unprecedented growth [8]. By 2050, its population is expected to exceed 2 billion people, double its current figure, with nearly 40% of its inhabitants living in rural areas [9] (Figure 1). However, about 645 million Africans remain without access to electricity. In sub-Saharan Africa, per capita energy consumption is currently the lowest of all continents, with an estimated 181 kilowatts per year, compared to that of Europe and the United States, which reach 6500 and 13,000 kilowatts per year, respectively. These figures highlight the significant economic impact of the electricity shortage, contributing to losses estimated at between 2% and 4% of GDP in Africa, which significantly hampers economic growth, job creation and investment [10].

If current energy trends persist, by 2030 Africa will still have 655 million people, or 42% of its population, without access to electricity, while 866 million, or 56% of the population, will be deprived of clean fuels and cooking technologies, thus depriving the majority of the population of a more productive and healthier life. Among these people, two-thirds live in rural areas without access to the national electricity grid. Network connection is often expensive and sometimes unreliable. Therefore, it is imperative to consider other alternatives [11].

Côte d'Ivoire very early developed a policy of access to electricity based on the exploitation of its hydraulic and thermal resources. Rural electrification is one of

the main axes of the economic and social policy of the Ivorian government. To this end, this sub-sector has benefited from constant historical support from the public authorities. The major programmes launched by Côte d'Ivoire, which had only 14 localities electrified in 1960, saw the number of villages supplied with electrical energy reach 2847 in 2011, then 4972 at the end of 2017, increasing the coverage rate (number of electrified localities/total localities) at about 54%, while the rate of access to electricity (population living in electrified localities/total population) is about 81%. These results are encouraging, but still quite weak. Moreover, from another point of view, even if progress is good, as confirmed by the sector authorities, they still encounter difficulties related to the allocated resources, difficulties that should be overcome by mobilizing more resources to accelerate the implementation of this program and then extend it to small rural communities.

Indeed, of the 8513 localities in Côte d'Ivoire, 4555 remain unelectrified. However, Côte d'Ivoire has varied and sufficient natural energy resources to meet its energy needs through the implementation of an appropriate energy policy and master plan.

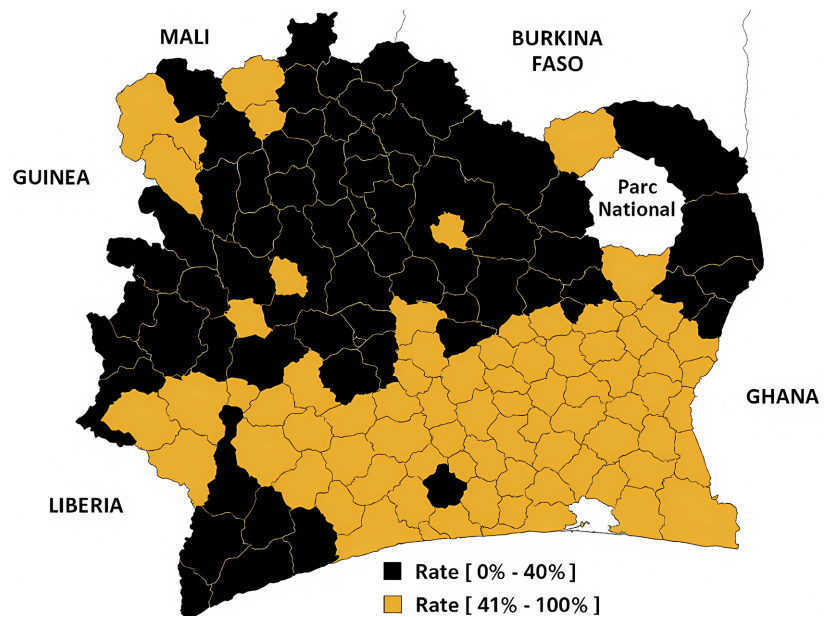


Figure 1. Electrified area rate [9].

Moreover, the Rural Electrification Program and a viable master plan remain at the heart of the country's concerns, which is committed to continuing and expanding the work at a rate of at least 500 new electrified localities each year, with the aim of achieving the goal of total electrification of Côte d'Ivoire by 2030.

2.2. The Agricultural Sector in Ivory Coast

Côte d'Ivoire does not want to depend on the rest of the world for food. Beyond cash crops, which contribute significantly to the Gross Domestic Product (GDP), the country intends to ensure its security and food sovereignty. For this, signifi-

cant investments and programs are currently underway. The cultivation and marketing of food products allow for the transfer of food products from the place of production to the place of consumption. It involves a series of activities deployed around the product, from its production to its acquisition by a consumer. These interconnected activities involve harvesting, sorting, packaging, transport, storage, distribution and sale.

Similarly, in 2022, the Government provided food cooperatives with agricultural equipment and inputs at a cost of more than CFAF 2.5 billion. This, with a view to improving production capacities and systems. Determined to go further, the Government plans, through the Ministry of Trade, Industry and Promotion of SMEs, the construction of 03 wholesale markets, 10 relay markets and 40 local markets on the national territory. It is also planned to implement the Support Program for the Food Sector in Côte d'Ivoire (PASVCI), funded to the tune of more than 13 billion FCFA [12]. Why not promote agro voltaic to accelerate the production and marketing of food products.

2.2.1. The Agro-Poles of Food Agriculture

The strategy for the development of food agriculture aligns with the overall vision of the Ivorian government, which aims to establish a sustainable, competitive and wealth-generating agriculture equitably distributed. This approach responds in particular to objective N° 2 of the Sustainable Development Goals, which calls for the elimination of hunger and all forms of malnutrition. To achieve this objective, the strategy provides for the grouping of regions into Agro-Poles, based on agroecological, administrative and socio-economic criteria (Figure 2). This grouping allows for optimizing the adaptation of crops to local climatic conditions by promoting the concentration of similar crops within the same areas. Nine Agro-Poles have been identified according to these criteria, as illustrated on the map below, indicating the areas dedicated to the food crops concerned [13].

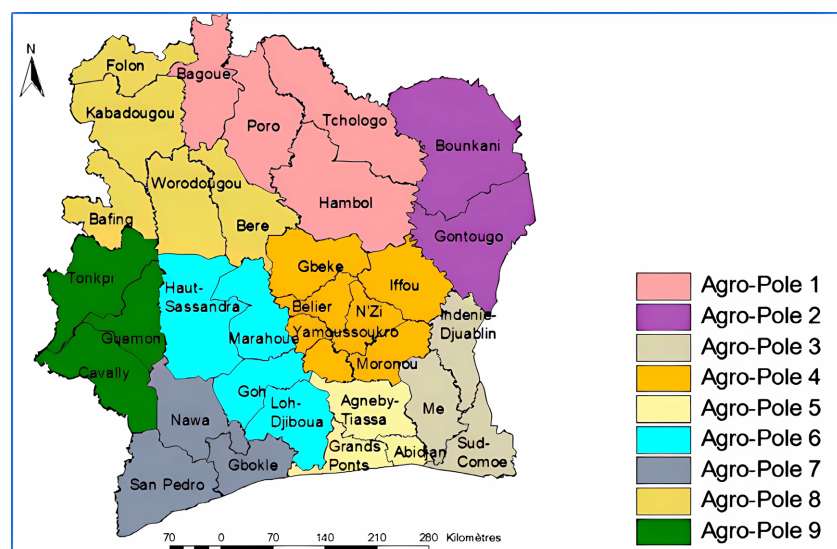


Figure 2. Proposed division of the agro-pole zones.

Table 1 below illustrates the proposed zoning and the food crops concerned.

Table 1. The food agriculture clusters.

Area	Food crops concerned
Agro-Pole 1	Corn, rice, onion
Agro-Pole 2	Yam, Market gardeners
Agro-Pole 3	Cassava, plantain, Market gardeners
Agro-Pole 4	Yam, cassava, rice
Agro-Pole 5	Rice, Market gardeners, Cassava
Agro-Pole 6	Yam, cassava, rice
Agro-Pole 7	Cassava, Banane plantain, rice
Agro-Pole 8	Rice, Corn
Agro-Pole 9	Rice, cassava

2.2.2. Cereal Crops

In Côte d'Ivoire, maize, millet and sorghum productions show average annual growth rates of 5.7%, 1.5% and 2.0% respectively between 2015 and 2023.

Maize cultivation benefits from the production and distribution of seeds, the distribution of inputs (plant material and fertilizers).

As for rice, one of the main staple foods, its production fell by 7.2% on annual average between 2015 and 2020. This decrease is due, among other things, to the insufficient supply of improved seeds, the limited capture capacity of processing units and the lack of funding for the paddy sector.

However, a recovery is observed from 2020 with an average annual increase of 10.7% between 2020 and 2023 thanks to the reforms undertaken, notably an extension of the planted area and intensification with better productivity (average yield increased from 2.3 tons/hectare in 2020 to 2.8 tons/hectare in 2023) [13].

Cereal crops such as millet, sorghum and fonio, although benefiting from the mechanization efforts of the sector for cultivation and harvesting, suffer from the effects of climate change, the lack of labor and the damage caused by livestock.

Agrovoltaic appears as a solution to strengthen the resilience of these crops in the face of climate stress: it reduces evaporation, protects millet and sorghum from wind and heat, and is effectively combined with solar irrigation to improve rice cultivation. **Figure 3** presents the evolution of these productions between 2015 and 2023, whose values are recorded in **Table 2**.

Table 2. Production of the main cereals in thousands of tonnes.

Cereals	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rice (paddy)	2152.9	2054.5	2119.6	2006.8	188.4	1481.2	1659	1703.5	2011.5
Corn	906.1	967.2	1025.2	1055	1102.4	1175.7	1139.6	1199.3	1416.2

Continued

Mil	55.2	58.3	61.6	63.8	66.2	69.5	67.4	70.1	62.1
Sorghum	55.1	58.8	63.1	65.8	67.9	72.2	70.2	73.3	65.4

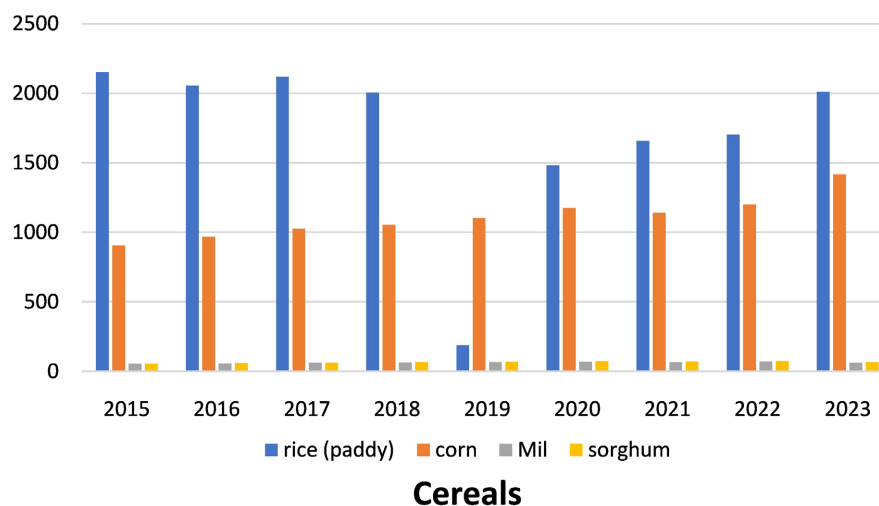


Figure 3. Production of the main cereals in thousands of tonnes.

There is a notable decline in rice production, while maize, millet, and sorghum show an overall upward trend, highlighting the interest of solutions such as agrovoltaic to secure and improve these yields.

2.2.3. Tubers and Plantains

The main tubers produced in Côte d'Ivoire are yam, cassava and plantain which recorded annual average increases of 1.5%, 8.2% and 3.6% respectively, between 2015 and 2023. Côte d'Ivoire also produces sweet potato and taro, which grew by an annual average of 2.4% and 1.7% respectively, from 2015 to 2023. The cassava sector represented more than 45% of tuber production in 2023. It benefited from several programs to increase production, notably the Support Project for the Development of Cassava and Market Gardening Sectors (PRO2M) and the PNIA 2. According to Tajeddin and his collaborators [13], the partial shading created by solar panels reduces evaporation and better retains soil moisture, which promotes the growth of these crops, especially in dry areas. **Figure 4** below illustrates the production of tubers in thousands of tonnes from 2015 to 2022, including the values recorded in the following **Table 3**.

Table 3. Production of the main roots, tubers and plantains in thousands of tons.

Roots, tubers and plantains	2015	2016	2017	2018	2019	2020	2021	2022	2023
Yam	6649.9	6894.5	7148.1	7391.1	7450.5	7654.6	7589.8	7786.1	7471.7
Cassava	4390.9	5269.1	5366.5	5608	5877.2	6443.6	6302.3	6804.1	8248.2
Plantain Banana	1739.1	1809.3	1882.3	1955.7	2030	2082.8	2030.6	2109.3	2311.7

Continued

Sweet potato	50.9	52.4	54.1	55.6	57.2	58.0	56.8	58.7	61.5
Taro	78.4	80.7	83.1	85.3	87.9	89.2	87.7	90.4	89.4

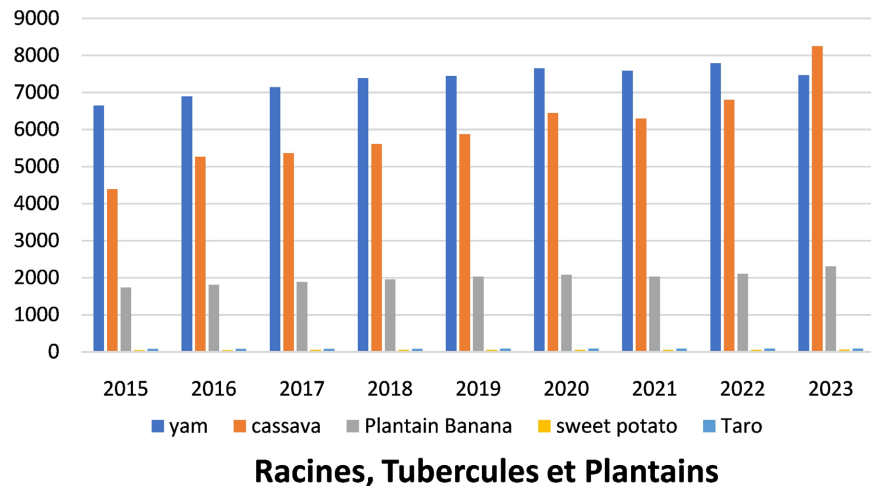


Figure 4. production of the main roots, tubers and plantains in thousands of tons.

Figure 4 shows that from 2015 to 2023 yam and cassava dominate tuber production in Côte d'Ivoire, while plantain, sweet potato and taro show lower but increasing volumes.

2.2.4. Market Garden Crops and Legumes

The main market garden crops produced in Côte d'Ivoire are okra, eggplant, tomato, and chili.

From 2015 to 2021, okra and eggplant productions increased on annual average by 4.2% and 2.1%, respectively.

However, in 2022, the production of okra and eggplant decreased by 58.8% and 18.1% respectively compared to 2021. This situation is explained by the attacks of “jassids” (pest insects) that occurred in July 2022 in the cotton basin. The productions of okra and eggplant rebounded in 2023 with respective increases of 114.9% and 34.4% thanks to the control of the invasion of the “jassids”.

Tomato production has increased continuously since 2015 with an average annual growth rate of 4.2%.

As for peanuts, the main legume of Côte d'Ivoire, its production increased between 2015 and 2023, at an average annual rate of 5.6%. The market gardening sector benefits from the spinoffs of the Hydro-Agricultural Development Project in the Folon and Kabadougou Regions (PAHA FK) which aims for an additional annual production of 4800 tons; the Agricultural Hydro Development Project in the Haut Sassandra and Fromager regions (PAHAHSF) which predicts between 4000 and 6160 tonnes of additional production [13].

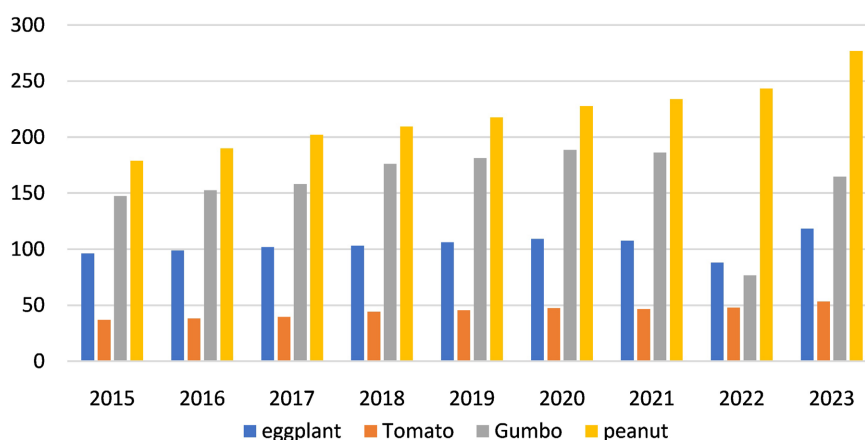
In addition, the PRO2M has made it possible to promote a more professional, efficient, organized and job-creating market gardening sector, an annual market

gardening production of about 8300 tons ensured in all seasons by over 2000 beneficiaries (including women and young people), 42 agro-entrepreneurs and 33 groups.

The integration of an agrovoltaic system can mitigate this type of stress by creating a more favorable microclimate: shading reduces evaporation and protects market gardening and legume crops against drought, while improving quality and yield. **Figure 5** presents the evolution of these productions from 2015 to 2022, and **Table 4** illustrates the data.

Table 4. Production of the main market garden crops and legumes in thousand tonnes.

Market gardeners and legumes	2015	2016	2017	2018	2019	2020	2021	2022	2023
Eggplant	96.3	99	101.8	103	106.1	109.1	107.5	88.1	118.3
Tomato	36.8	38.2	39.5	44.1	45.4	47.3	46.6	48.1	53.5
Gumbo	147.3	152.5	157.9	176.1	181.3	188.7	186.1	76.7	164.8
Peanut	178.8	190.1	202.1	209.5	217.6	227.6	233.9	243.4	277.1



Market gardeners and Legumes

Figure 5. Production of the main market garden crops and legumes in thousand tonnes.

We observe a gradual increase in peanut and tomato production, while okra and eggplant show a more irregular trend, with a sharp decline in okra in 2023. These variations highlight the interest in adopting practices like agrovoltaic to protect and stabilize yields against climatic and parasitic hazards.

2.2.5. The Ecology of Yam

Yam is a tropical crop requiring heat, requiring temperatures between 25 and 30 °C for optimal germination, and ideal rainfall between 1000 and 1800 mm. It prefers light, deep soils, rich in organic matter, well-drained, and at pH of 5 to 7. In addition to climatic and soil conditions, productivity strongly depends on cultural practices and varietal choice [14]. Although it tolerates high temperatures, irrigation is essential above 30 °C to avoid water stress. In this context, agrovoltaic

offers a relevant solution: by combining energy production and cultivation on the same plot, it allows to create a partial shading that reduces evaporation and thermal stress for yam. However, reduced rainfall reaching the soil may require adjustment of irrigation. Photovoltaic pile-on or greenhouse systems contribute to this cooler microclimate, while the electricity produced generates additional income for farmers, while reducing greenhouse gas emissions. Experiments, such as those of Dupraz *et al.* [15], have already demonstrated that agrovoltaic can improve the productivity of certain crops, thus opening new prospects for yam in hot areas.

3. The Different Agro-Voltaic Systems

Agrovoltaic systems refer to installations where agriculture coexists with photovoltaic solar energy production. These systems are designed to maximize land use by combining plant cultivation with solar panels. To date, three types of agrovoltaic systems, which simultaneously allow the production of crops and electricity on agricultural land:

1) The first type was proposed in the early 1980s, using the space between rows of photovoltaic panels for crops [16] (**Figure 6**).

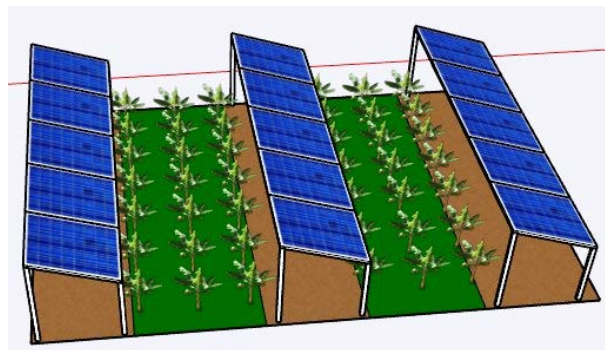


Figure 6. Ground-based central with single-metal panels using the space between crops.

2) The second type is a photovoltaic greenhouse, in which part of its transparent coating is replaced by photovoltaic modules (**Figure 7**).

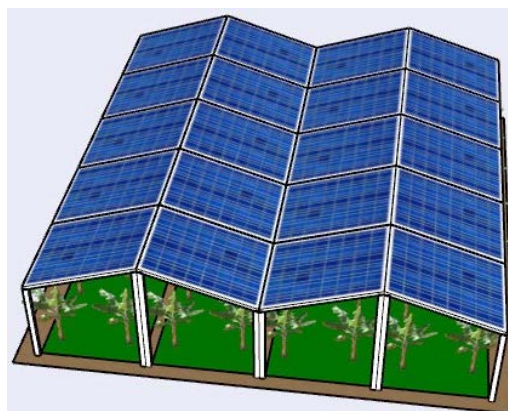


Figure 7. Photovoltaic greenhouse set.

The use of photovoltaics for greenhouses is a promising solution for land resources competition between food and energy production, as it allows continuous food production and electricity generation throughout the year.

3) The third type consists of photovoltaic modules mounted on stilts above the crops, allowing the reduction of sunlight on the crop [17] (Figure 8).

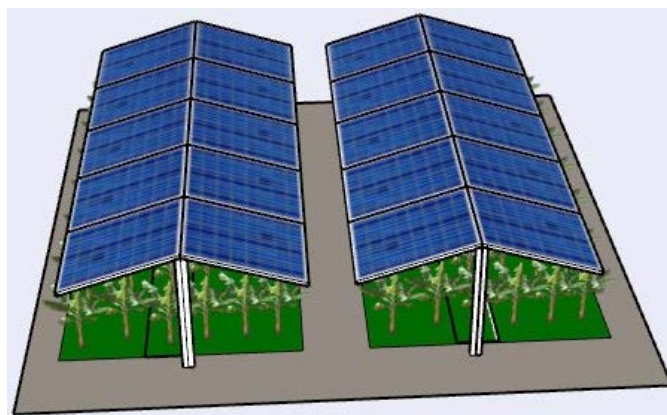


Figure 8. A set of solar panels raised on stilts.

The structure includes pipes and rows of photovoltaic panels installed above ground, with a spacing calculated to allow optimal solar exposure for photosynthesis. These systems are designed to ensure adequate sunlight for crops while providing sufficient space for agricultural equipment [18].

Each of these systems aims to combine agriculture and solar energy production in a synergistic manner, maximizing land use while contributing to environmental and economic sustainability.

4. Summary Table

The dynamics of vegetation growth were less disrupted in summer under the panels than in sunny areas thanks to the reduction of water, light and thermal stress induced by the protection of photovoltaic panels [19].

In this perspective, it is useful to specify, for each crop, the expected benefits, possible limits and optimal technical configurations allowing to maximize these effects under an agrovoltaic system. **Table 5** below presents the positive effects, potential drawbacks, the type of favorable agrovoltaic system and the recommended setup for each crop.

Table 5. Summary of the effects of agrovoltaic according to crops and associated technical recommendations.

Cultures	Positive effect	Potential downside	Recommended assembly	Type of favorable agro voltaic system	Reference
Tomato/chili/okra/ cabbage	-Less sunburn -Evaporation reduction -better quality of the fruits	-Risk of fungal disease -less light = reduced flowering	Raised and spaced structure for good light and ventilation	Monofacial panel spaced at medium height	Loan Madej, Luc Michaud <i>et al.</i> (2020); Valle <i>et al.</i> (2017) [19]

Continued

Carrot/Eggplant/ cucumber	-Cooler and moist soil -Well developed roots	Slower maturation if excessive shading	Fixed spaced or mobile structure	Monofacial panel spaced at medium height	Marine Blaise (2023); Elamri <i>et al.</i> (2018) [22]
Yam	-Moisture beneficial to the tuber -Stabilized soil temperature	-Air growth slowed down under shadow -Difficult supervision	Raised structure with free passage	Monofacial panel spaced at height	Dupraz, C. <i>et al.</i> (2011) [15]
mil	-Protection against heat -Less water stress	-High need for light -Risk of decline in return	Fixed spaced or mobile structure	Bifacial panels to maximize scattered or monofacial light spaced	Amaducci, S. <i>et al.</i> (2018) [20]
Rire	-Less evaporation -Good compatibility with solar irrigation	-Difficult on flooded ground -Difficult access for machine	Very raised structure	Monofacial or bifacial panel on raised stilts	Barron-Gafford, G.A. <i>et al.</i> (2019) [5]
Sorghum	-Less thermal stress -Improvement of resili- ence	-Reduction of light impacts the flowering	Raised and well-spaced structure	Raised bifacial or single-metal panel no clamp assembly	Amaducci, S. <i>et al.</i> (2018) [20]
Sweet potato/Potato	-Better conservation of humidity -Optimal underground development	Slowdown if too much shading	Spaced fixed structure, aver- age height	Monofacial panel	Marrou, H. <i>et al.</i> (2013) [21]
Banana tree	-Likes half shading -Stimulated growth in a warm climate	Great height	Very raised and stable structure	Monofacial or bifacial panel on raised and spaced stilts	Stoltzfus, R. J., <i>et al.</i> (2012) [23]

Table 5 above summarizes the main positive effects and potential constraints of integrating agrovoltaic systems for different crops grown in Côte d'Ivoire. It highlights that each crop specifically reacts to the shading and microclimate conditions created by solar panels. For example, crops like tomato or carrot directly benefit from reduced evaporation and moderate temperatures, which improves fruit quality or promotes root development, as demonstrated by Madej *et al.* (2020), Valle *et al.* (2017) or even Elamri *et al.* (2018). Similarly, for cereals such as millet or sorghum, shading contributes to reducing thermal stress, a key factor in stabilizing yields in an increasingly unpredictable climate context (Amaducci *et al.*, 2018). Other tropical crops, such as the banana, naturally benefit from partial shade, which makes their association with photovoltaic structures particularly relevant [23]. However, these benefits require careful design of the systems: the height, spacing and type of panel (monofacial or bifacial) must be adapted to each crop in order to avoid negative effects, such as excessive shading that can slow down growth or promote certain fungal diseases, particularly for fruit crops. Thus, this table provides practical guidance to optimize the technical design of agrovoltaic installations, taking into account local agronomic, climatic and economic specificities. It is therefore a decision-making tool for producers, technicians and decision-makers wishing to promote sustainable and resilient agriculture while developing renewable energy production. Such effects are supported by recent scientific

literature. Numerous studies confirm the benefits of agrovoltaic for various crops. First of all, partial shading helps reduce sunburn and improve the quality of tomatoes [19]. Then, several works point out that this shading also contributes to lowering the soil temperature from 2°C to 5°C and maintaining a humidity more favorable to the development of root vegetables [20] [22]. Furthermore, Dupraz *et al.* (2011) and Amaducci *et al.* (2018) confirm that moderate shading has a similar protective effect on tuberous and cereal crops, limiting heat stress and stabilizing yields. In addition, Barron-Gafford *et al.* (2019) demonstrate that a judicious combination of shading and irrigation effectively reduces evaporation, thereby increasing the efficiency of the system. Finally, it is interesting to note that Stoltzfus *et al.* (2012) point out that the banana, a tropical crop par excellence, also benefits from a slight shade when grown in association with other species, confirming the flexibility of agrovoltaic for various agricultural systems.

The integration of photovoltaic panels in agricultural greenhouses represents a promising solution to exploit renewable energies while preserving the agricultural vocation of the land. These greenhouses ensure quality food production throughout the year. An innovative device, combining raised solar panels to capture both solar energy and rainwater without compromising crops, this study was conducted in East Africa, particularly in Kenya and Tanzania [24] [25] (Figure 9).



Figure 9. Aerial view of the solar installations.

From an economic point of view, the viability of agrovoltaic systems strongly depends on financing and revenue sharing mechanisms. In Côte d'Ivoire, several models can be considered:

- 1) The sale of electricity to the national grid through Power Purchase Agreements (PPAs), allowing operators to generate a stable income;
- 2) Access to public subsidies or green credits intended to encourage rural renewable energies;
- 3) Public-private partnerships where solar operators invest in infrastructure while farmers retain land management;
- 4) The pooling of infrastructure (solar irrigation, storage, transport) in order to reduce operating costs;
- 5) These combined approaches strengthen the economic sustainability of the

agrovoltaic model and promote its adoption by small and medium-sized farmers.

5. Proposed Framework

To succeed in this project, it is essential to implement solid generic steps:

1. Feasibility study and integrated design:
 - 1) Carry out a comprehensive study to assess the feasibility of the project in terms of solar irradiation, local climatic conditions and soil characteristics.
 - 2) Design the system in an integrated manner, taking into account the needs of the crops, the requirements of the solar panels and the optimal spatial configuration.
2. Appropriate choice of crops and varieties:
 - 1) Select adapted crops that can thrive under partially shaded conditions or modified by the presence of solar panels.
 - 2) Opt for varieties resistant to variations in brightness and specific environmental conditions of the agrovoltaic system.
3. Management of shade and irrigation:
 - 1) Plan and implement an efficient irrigation system that takes into account the water needs of crops as well as the shadow effects projected by solar panels.
 - 2) Use appropriate shading techniques to minimize the negative impact of partial shading on crop growth and yield.
4. Land use optimization:
 - 1) Maximize land use by combining agricultural production with solar energy production.
 - 2) Explore different planting configurations and methods to optimize the overall productivity of the land used.
5. Monitoring and integrated management:
 - 1) Establish a regular monitoring system to monitor crop growth, solar energy production and environmental conditions.
 - 2) Integrate sustainable management practices to maintain soil and crop health in an agro-voltaic environment.
6. Continuous assessment and adaptation:
 - 1) Regularly evaluate the performance of the agro-voltaic system and identify opportunities for improvement.
 - 2) Be prepared to adjust management practices based on observed outcomes and new information available.

This approach maximizes the synergies between agriculture and solar energy production within an agrivoltaic system, ensuring both long-term sustainability and optimal productivity.

In Côte d'Ivoire, the implementation of the first feasibility studies could be prioritized in Agro-Poles 2, 3 and 4, identified for their high production of yams, cassava, rice and market gardening crops, which are particularly suitable for agrovoltaic systems. These areas have a high agricultural potential and stable sunshine throughout the year, making them ideal pilot regions to test and adjust integration models

between agriculture and solar production.

6. Conclusions

Agrovoltaic appears as a strategic and innovative solution to meet the energy and agricultural challenges of Ivory Coast. By intelligently combining solar electricity generation and agricultural activities, this model allows for optimizing land use, enhancing food security and supporting the country's energy transition towards renewable sources.

The analysis of solar potential, local crops, rural energy needs and different types of agrovoltaic systems confirms the relevance and feasibility of this model in the Ivorian context. This report highlights many agroecological, economic and environmental benefits: better conservation of soil moisture, reduction of heat stress on crops, diversification and securing agricultural incomes, and lower greenhouse gas emissions. However, the success of agrovoltaic requires a harmonious integration between technical choices, cultural management and a favorable political framework, supported by the commitment of local actors. To this end, it is recommended:

1) On the technical side: develop suitable prototypes (photovoltaic greenhouses, pile-mounted modules) and promote solar irrigation to secure soil moisture, with a measurable goal of reducing water losses by 20% to 30%.

2) On the political level: to set up tax incentives and subsidies for farmers wishing to invest in agrovoltaic, with a deployment plan targeting at least 500 pilot farms within five years.

3) In terms of training: strengthen the capacities of farmers through training programs on equipment maintenance and integrated management of agrovoltaic systems.

4) At the partnership level: encourage public-private partnerships to facilitate access to financing, technological innovation and the dissemination of best practices.

By combining these actions, Côte d'Ivoire has a strategic lever to modernize its agriculture, accelerate rural electrification, and move towards sustainable development that is resilient in the face of climate change.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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