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ORIGINAL ARTICLE

Economic feasibility of using agrivoltaics for tomato farming

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Abstract

Agrivoltaics or agrophotovoltaics (APV), which simply describes farming under a canopy of PV panels, has been recently gaining a wider implementation to improve farming yields as well as generate electricity on the same piece of land. The presented study undertakes an economic analysis to justify the implementation of agrivoltaics in a tomato farm. Three research cases are investigated; Case 1 is the control scenario which is just ordinary tomato farming that is used as a baseline. And then there are Cases 2 and 3, which are low-density and high-density agrivoltaics, respectively. The farm is irrigated from a borehole using a diesel generator in Case 1 and solar pumps in the Agrivoltaics Cases 2 and 3. The study found that tomato harvest is reduced by a minimum of 16% in agrivoltaics setup. However, this reduced harvest is compensated by the PV output. The payback period has been calculated considering the capital costs of the PV system and other operational costs within the farm, and it is found that Case 2 and Case 3 have 3 years and 3.6 years payback periods, respectively. While on the other hand, ordinary tomato farming is unattractive with a lengthy payback period of 17.5 years. Net present value analysis is also used to determine the profitability of the three scenarios over a 10-year period, and the agrivoltaics scenarios are calculated to be profitable while ordinary tomato farming is not profitable. Therefore, this study justifies economic investment in agrivoltaics for tomato farming in Botswana.

KEYWORDS

Agrivoltaics, economic analysis, net present value, payback period

1 | INTRODUCTION

The world has been struggling with emergencies such as global warming, drought and energy and food insecurity which continue to put increased pressure on our natural resources (Carreño-Ortega et al., 2021; Marrou et al., 2013). Climate change impacts have made farming more difficult and unsustainable, and this coupled with the projected population increase up to 9.7 billion by 2050 will inevitably exacerbate global food shortages in the future (Maia et al., 2020; Trommsdorff et al., 2020). Land-based PV farms require a large area of land to generate electricity hence they often compete for this land with food production, thereby causing the infamous 'energy versus food' debate (Anatoliivna, 2021; Dinesh & Pearce, 2016; Feuerbacher et al., 2021; Ravi et al., 2016). However, it has been proven that the same piece of land can be used simultaneously for both energy production and agriculture through the innovative technology known as agrivoltaics (Anatoliivna, 2021; Dinesh & Pearce, 2016). This dual land use allows us to produce food as well as generate energy either for our consumption, to supply nearby homes/industries, or even to feed electricity to the grid on the same piece of land as depicted in Figure 1.

Agrivoltaics technology has been reported to bring about synergetic benefits for both the crops and PV modules (Proctor et al., 2020; Riaz et al., 2021). The principle of agrivoltaics takes advantage of the light saturation point of plants. Although all plants need light for photosynthesis, there is a particular light intensity limit for every plant beyond which photosynthesis stagnates. This limit is called the light saturation point, and further light beyond this point is not usable for crops or may even induce stresses on some crops (Trommsdorff et al., 2020). Shadow plants, otherwise known as shade tolerant plants, are the most suitable for growing under a canopy of PV panels. The plants are not disturbed by the shading from the PV panels; instead, the canopy of panels protects such plants from intense irradiation which can cause stress. Neupane Bhandari et al. (2021) collated several pilot studies from Germany, France, Italy, China and the USA to categorise many crops by their degree of shade tolerance as highlighted in Table 1.

The indifferent category has been shown to be unaffected by shading when the overall yield is considered. So, depending on the shade tolerance levels of the crops grown in agrivoltaics setups, the PV density may be reduced, or semi-transparent panels can be used to minimise shading effects (Dinesh & Pearce, 2016). This study assesses the economic viability of growing a shade tolerant crop, tomato, under different agrivoltaics scenarios in Botswana.

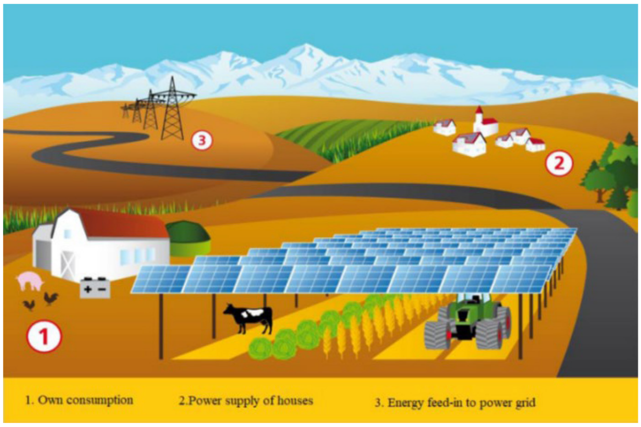

FIGURE 1 Typical agrivoltaics farm uses (Trommsdorff et al., 2020).

2 | METHODOLOGY

Three research scenarios were designed for this study, namely Case 1, Case 2 and Case 3. Case 1 was just ordinary tomato farming without any PV installations. This was used as a control setup to be compared with Cases 2 and 3. In Case 2 (Low-density agrivoltaics), tomatoes were grown under a canopy of PV modules hence making an agrivoltaics farm. A total of 25 PV panels were installed with a spacing of 2 metres from row to row. For Case 3 (High-density agrivoltaics), 40 PV panels were installed and spaced much closer to one another at 1 metre spacing. This increased the shading effect due to the panels. A typical agrivoltaics farm setup is shown in Figure 2.

After designing the three research scenarios, the STICS crop model was then used to simulate the growth of tomatoes in each of those scenarios. The STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) crop model was developed at the French national institute for agricultural research in 1996 (INRAE, 2022). The model uses a dynamic approach to predict crop growth on daily time steps with input variables relating to climate, soil, and cropping systems (Beaudoin et al., 2008; Corre-Hellou et al., 2009).

The software PV*SOL was used to simulate the PV energy generated from agrivoltaics farms in Cases 2 and 3. The PV panels that were selected for this study were 300Wp Si monocrystalline panels with an operational efficiency of 18.1%. 25 of those panels were installed in Case 2 to make a 7.5 kWp rated plant while in Case 3 there were 40 panels (12 kWp rated farm). They were installed facing north since Botswana is in the southern hemisphere and with an inclination angle of 25 degrees (latitude of Botswana). A soiling factor of 10% was estimated since farming activities and cultivation are likely to cause more

TABLE 1 Shade tolerance categories of crops.

Shade tolerant	Indifferent	Shade intolerant
Potato	Barley	Rice
Lettuce	Cabbage	Corn
Grape	Asparagus	Millet
Tomato	Carrot	Pumpkin
Berries	Celery	Sunflower
Spinach	Peas	Apple
Broccoli		Peach

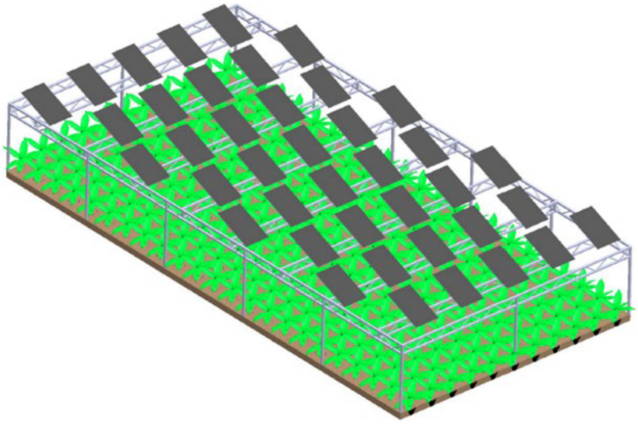

FIGURE 2 Agrivoltaics setup.

dust formation which reduces the panels' efficiency unless they are cleaned regularly.

The study used two approaches for economic analysis, namely simple payback and net present value calculations as described by Jenkins and Ekanayake (2017). According to the aforementioned authors, simple payback period is calculated by Equation (1), and it is an undiscounted way to calculate the period in years before a project becomes profitable. However, because we generally have a time preference for money, that is we would rather receive money today than later and prefer to pay out the money later, then a discounted cash flow appraisal was also used to discount future sums to the present date. This was achieved by calculating the net present value (NPV) for the proposed scenarios. The discount rate (r_d) was assumed to be 10% since that is the typical discount rate for energy projects (Jenkins & Ekanayake, 2017). The operational lifetime was taken as $n=10$ years, even though some components of the projects like the PV systems are expected to operate beyond the 10 years. Equation (2) was used to calculate the present value where V_n is the value of the sum in year n. If the NPV of a project is negative at the end of the operation period, then the project is not economically sensible.

$$\text{Payback} = \frac{\text{Capital cost}}{\text{Annual Net Revenue}} \tag{1}$$

$$V_p = \frac{V_n}{(1+r_d)^n} \tag{2}$$

TABLE 2 Costs and revenue summary.

Parameter	Case 1 control	Case 2 LD	Case 3 HD
Capital costs (£)	2886	15,156	20,756
Operational costs (£/year)	515	180	180
Total annual revenue (£)	680	5227	5981
Annual net revenue (£)	165	5047	5801

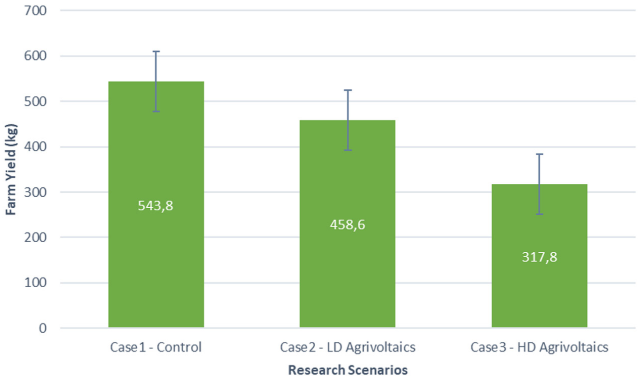

FIGURE 3 Tomato yield.

The cost of farming tomatoes is estimated to be around £4480 per hectare in Botswana. Therefore, for a farm of 0.02 hectares and with two growing sessions per year, then the cost becomes £180 per year. For Case 1, a diesel generator and a pump are used for irrigation and they both cost £2886 to purchase. The fuel cost of the generator which consumes 1.125 litres/day is £335 per year. The capital costs for the agrivoltaics cases include the cost of the PV system, solar pump and water storage tanks. To determine the revenue from tomatoes, the selling price per kilogram of tomatoes was approximated as £1.25 based on the current selling prices in Botswana, and the water rates were adopted from the Water Utilities Corporation of Botswana at £0.00051 per litre to calculate the value of water that was pumped from a borehole using a solar pump. A summary of the costs and revenue for the three study cases is shown in Table 2.

The NPV for the 10 years was calculated to indicate which of the projects is permitted to proceed from a financial viability perspective.

3 | RESULTS AND DISCUSSIONS

The farm yield results depicted in Figure 3 shows that shading does reduce the yield of tomatoes since the agrivoltaics cases produced less harvest than the control. A reduced crop yield on its own may appear unattractive for agrivoltaics, but the loss in crops may be compensated by the electricity generated.

The calculated economic metrics in Table 3 were used to appraise the agrivoltaics designs. The control scenario

TABLE 3 Economic metrics.

Parameter	Case 1 control	Case 2 LD	Case 3 HD
Capital costs (£)	2886	15,156	20,756
Annual net revenue (£)	165	5047	5801
Payback period (years)	17.5	3	3.6
NPV (£)	−1872	15,856	14,889

(Case 1) where there was ordinary tomato farming with diesel generator irrigation has a very long payback period which is unattractive. It is clear that some intervention is needed to make the farm profitable, and this comes in the form of agrivoltaics systems in Cases 2 and 3.

Agrivoltaics have a fairly short 3-year period to break even, which is less risky and ideal for investors. It is not sufficient to rely only on the simple payback metrics for analysis since it does not consider the discounting of future monies to the present value. Therefore, the net present value is also needed, and right away from Table 3, it is clear that Case 1 should not be considered for investment since its NPV is negative. A negative NPV shows that the project will still be unprofitable after 10 years of operation.

Low-density agrivoltaics (Case 2) will start becoming profitable in the fourth year, while Case 3 is a little later in Year 5. Since the NPV is positive in both cases, these projects are given the green light for investment. However, these economic analysis results must be used only as an indicative measure until experimental validation of the results. Some chosen figures like a discount rate of 10% may not necessarily present an accurate forecast of the future, especially in recent years where global conflicts and disease pandemics have distorted normal economic models.

4 | CONCLUSIONS

Two agrivoltaics scenarios together with the control were designed and simulated using the STICS crop model and PV*SOL software's. It is then concluded from the simulations that shading via PV panels in Cases 2 and 3 reduced the harvest yield of tomatoes. The use of agrivoltaics resulted in a 16% reduction in harvest for Case 2 and an even worse 42% drop in tomato harvest for Case 3.

Economic appraisals were performed through calculations of the payback period and the net present value for the research cases. Case 2 was proven to be the most profitable and preferred scenario. It has the shortest payback period of 3 years which makes it a less risky investment and also has the highest and positive net present value (NPV) which indicates profitability. Case 3 is also profitable but not as much as Case 2. It is concluded that tomato farming alone in Case 1 is not worth investing in since its NPV is negative and has a very long period of 17.5 years to break even.

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CONFLICT OF INTEREST STATEMENT

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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