Eco-agriculture and Renewable Energy System Concept for a Rural Community in Ghana

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Abstract. Eco-agriculture is the trend of rural development in this age. This research uses the moringa tree as an example to build up the eco-agricultural and renewable framework for a typical village in Ghana. An energy balance is analyzed using an urbs tool, while business and financial models are built up following MVP (minimum viable product).

1. Introduction
Ghana is a typical agricultural country in Africa, making it an appropriate site for studying eco-agriculture which is focused on sustaining the fertility of farmlands and maintaining ecosystem resilience [1]. The study site of this research is Kaaka village in the Brong Ahafo Region, in the middle of Ghana (figure 1). The village holds hundreds of cattle used for labor and manure collection. The major crops in the village are maize, groundnut, millet, rice, plantain, cassava and yam. These crops are mainly cultivated during the rainy season. The rice and maize are seasonal and harvested 2 times per year with 2.21 tons per acre per harvest. During the dry season the farming workload is light as the crops grow without assistance. Alternatively, in the dry season the land produces economic vegetables, like cabbage, cucumber, lettuce, pepper, etc. The irrigation during the dry season consists of diesel pumps and hand-made channels. The total size of the fields is over 600 hectares, but they are not all farmed due to the limitation of manual labor source as each farmer is only able to take care of 1-2 acres.

Figure 1. Satellite image of Kaaka village showing the locations of community resources
The moringa tree is a versatile plant that exemplifies the idea of eco-agriculture, as it can be utilized from roots to leaves for various purposes. Due to the drought resistance of moringa, and its production of nutritious edible leaves year-round, the plant can help stave off malnutrition within the community. The leaves can also be dried and ground into moringa leaf powder with a simple process as figure 2, adding to the marketable products of the region. Moringa is extremely fast-growing and can reach 2.5m within 1-3 months. Thus, villagers can quickly see tangible results from the quick production process.

Figure 2. Moringa tree, manual process and the finished moringa powder product

Despite the plant’s versatility, there exist several challenges for the development of organic farming in this village as it pertains to moringa production.

1. Market supply and demand. Under a circumstance of high production and low demand, the selling price might not even be able to recoup the initial investment involved.

2. Light. The only light source in the village is sunlight. Therefore life is dominated by the natural cycle of sunrise and sunset and community members must limit their labor to daylight hours.

3. Electricity. Without electricity, grinding must be done manually, which limits supply and increases production cost.

4. Drinking water. The current drinking water is untreated which can negatively affect the villagers’ health.

5. Education. Children from Kaaka drop out of school early to help in the fields, and most of the farmers don’t speak English and only possess a basic understanding of math. This lack of education may impact their management of income and hinder cooperation with overseas buyers. Additionally, the education about sustainability and potential use of resources is lacking.

6. Environmental impact. The farmers are making use of genetically modified seeds, chemicals and pesticides, which are expensive and impact the environment in the long run [2]. The use of chemicals and pesticides also prohibits the crops from being classified as organic when sold.

7. Self-motivation. Most of the farmers see farming as “what they do” and not their job.

To face these challenges, an integrated plan is proposed which focuses on clever utilization of resources, building of cooperation, and learning about simple technologies and cost-effective operations which can be implemented quickly. A solar lantern works by having a small PV cell and a small battery connected to an LED. This serves as a strong incentive to keep their solar panels clean and provides them with a good learning experience (no clean panels = no charged phones). Since a manual pump is also less prone to defects, one can be installed for clean drinking water at an affordable cost. Agricultural training to plant moringa provided by the Ghana Permaculture Institute (GPI) is suggested: 5-10 farmers can learn and spread the knowledge about moringa cultivation, biogas systems, solar panels and the risks of pesticides. The long-term partnership between farmers and the GPI is the cornerstone of a stable market. This could inspire more buy-in from locals in Ghana, increase interest from potential import partners in Europe, and train stakeholders to cultivate a wide variety of species to face the fluctuation of product prices.
2. Assessment

2.1 Resources assessment

Resources and economic features are essential references for long-term development in terms of sustainability, diversification and stability. The solar resource in the Kaaka village is abundant especially between May to October. In theory, the daily solar resource is 10.2kwh/m², and annually it is more than 3000kwh/m² [3] with the actual gainable energy being 1820kwh/m² [4]. Dairy cattle produce around 8 kg of volatile solids a day, of which one-fourth can be converted to biogas. Concerning the specific soil information in the village, table 1 illustrates the records from the in-situ study in November 2019. The soil in Kaaka is in general suitable for organic farming while only phosphate needs to be carefully monitored. In Ghana chemical fertilizers and manures on land causes phosphates to run off during heavy rainfall and pollute nearby water sources [5]. An assessment is needed to check whether the land is feasible for growing organic moringa by testing soil samples. If the chemical residues are still over the regulation limit, a 2-year restoration is needed to fulfil the organic standard.

| Parameters          | Red Soil | White Soil | Normal Standard [6] | Standard for Organic [7] | Comment   |
|---------------------|----------|------------|----------------------|--------------------------|-----------|
| pH                  | 8.25     | 7.55       | 5.5-7.5              | 5.5-7.5                  | alkaline  |
| EC (µS/cm)          | 68.26    | 30.15      | <200                 | <160                     | good      |
| Magnesium(mg/l)     | 1.945    | 0.972      | <8                   | <5                       | good      |
| Calcium(mg/l)       | 12.826   | 9.619      | <24                  | <19                      | good      |
| Sodium(mg/l)        | 7.769    | 14.889     | <60                  | <40                      | good      |
| Chloride(mg/l)      | 12.0     | 23.0       | <50                  | <30                      | good      |
| Ammonia-Nitrogen(mg/l) | 2.68   | 3.30       | <18                  | <10                      | good      |
| Nitrate-Nitrogen(mg/l) | 10.8   | 1.1        | <22                  | <13                      | good      |
| Phosphate(mg/l)     | 13.42    | 6.63       | <25                  | <15                      | need improve |

2.2 System sizing

To come up with the sizes of renewable energy systems and storage units, a linear programming optimization tool “urbs” for multi-commodity energy systems has been applied to define the minimum cost. Urbs focuses on optimal storage sizing and use [8] while in this research it takes the demand of electricity, cooking heat, and drinking water as inputs and gives out the sizes of biogas digester, capacity of biogas generator and photovoltaics. In the intermediate concept, there is electricity demand for 44 houses. These are given as inputs for urbs and the results are illustrated in figure 3.

![Figure 3. Electricity balance and the necessary size of the energy system](image)
Urbs gives an optimal distribution of renewable energy technologies based on overall costs and resources available—around 64% of electricity demand is met with photovoltaics of 9.59 kW size. This is because generating electricity from photovoltaics costs less than generating from a biogas generator. The biogas produced could be used for cooking instead of wood. The night demand could also be met with electricity from a biogas generator to reduce the usage of batteries. The results are encouraging, as manure from cows in Kaaka can inexpensively feed a 1-ton biogas digester every day with only 500 cattle. With stable electricity, the stakeholder can invest in a grinding machine to process cassava and maize into powder to sell at a greater profit. If more households and diverse activities are introduced in the future, a higher efficiency in collecting and managing the manure would be required.

3. Business model

The minimum viable product (MVP) model, subjected to customer feedback quickly to test a startup’s hypotheses about actual market needs [9], is the basis for processes to build up stable business. The goals are to avoid land ownership and management issues and to have a secure market for the products. To begin, 10 acres of highly abundant, unfarmed land should be given to the Kaaka community to grow moringa in addition to farmers’ own lands. Secondly, solar dryers and food processing machines could be greatly beneficial in maintaining product quality with the support from the renewable energy systems. With these foundations, three business focuses can be prioritized:

1. System scaling. Planning the system to be scaled up can bring huge gains in productivity and efficiency. New types of food, markets and demands require an expansion in agricultural processing machinery while capital expenses for new objects and operational expenses for salary and maintenance need to be planned.

2. Diversification. An active search for business partners is strongly suggested for the long run, as well as the diversification of crops and processing methods. These three things will ensure stability in fluctuating markets.

3. Mini grid. Adoption of a mini grid enables the system to balance specific shortages [10], for instance, the electricity can be sold to every household for private use via a Pay-As-You-Go process, offsetting the costs of other projects.

To achieve these focuses, a community-based cooperative will need to be built up that consists of one chairperson, one treasurer, and one secretary on a voluntary basis and one paid manager. The people chosen for these roles should be respected and trusted members of the community with full motivation to devote themselves to the village. The cooperative will generate revenue by keeping a portion of the earnings from the produce on the communal land and by the sale of electricity to households. Over time, with increasing communal land size and increasing availability of electricity, the “tax” on the communal land will be reduced. While a non-governmental organization (NGO) might provide the seeds and equipment to farm on the communal land at the beginning, the long-term goal is the total independence of the cooperative. It is proposed that the GPI could provide training and seeds as well as guarantee the purchase of moringa under the condition that the moringa comes from the communal land. The business structure and profits distribution can be traced by figure 4.

![Figure 4](image-url)
The main partner will be the purchaser of the agricultural products. At the first stages it will only be the GPI. This guarantees an income to the farmers and provides inputs and training. Due to the cooperative structure, the bargaining power of the farmers is increased, allowing them to negotiate better deals with buyers. To achieve long-term stability, it is imperative to secure multiple buyers. Other partners are crucial for the technical sustainability of the systems as well. These are on-call technicians and a network of suppliers who can assist if any equipment should have technical faults. The key activity is to manage the soil quality of the field, prohibiting the use of artificial fertilizers and other chemicals which will negate the organic farming principles or impact product quality.

The revenues are mainly from the communal land; the cooperative collects the output of the farmers and sells it to the buying partners, paying the farmer their part, minus a small transaction fee to maintain the cooperative. With this system, the farmers do not face any up-front costs, and the cooperative is guaranteed to receive the income from the transaction fee. The second revenue stream is the sale of electricity to rural households and for production. The main cost for the cooperative is the repayment of the original technical system or the expansion of the mini grid. The second cost driver is the manager of the cooperative. Additionally, the manager needs to hire technicians for the maintenance of the mini grid. Recruiting community members who have not yet joined the cooperative is expected to be easier once they observe the improved lifestyles of those involved. Since communal land is scarce to begin with, it can also be expected to invoke a scarcity mindset in the villagers, thus making a place in the cooperative very desirable.

4. Financial model and results
Planting and processing moringa are highly profitable. If treated properly, one moringa tree can produce up to 500g of leaves and 250g of seeds per year at the beginning and increase up to 4 times in subsequent years. One acre can accommodate 400 trees, providing economic revenues of around $35,000 USD for the 10-acre cultivation at the stable statue after processing (figure 5). In order to empower future development, a locally managed organization e.g. the Kaaka Community Bank (KCB) should strive to save around 20% of sales for future operation costs. Due to the low revenues expected in the beginning with only 10 acres of land, investment planning is not feasible until the operation has been scaled up to larger production values.

![Figure 5. The profit of moringa from the production process](image)

Following the MVP concept, the intermediate solution for the process is importing solar lanterns from local and overseas suppliers. The necessity for the first stage includes solar home systems, mechanical water pumps and general cost for travels and training (table 2).

**Table 2. Budget for village development following MVP**

| Center   | Element                | Description | Quantity | Price  | Total     |
|----------|------------------------|-------------|----------|--------|-----------|
| Village  | Solar Lanterns         | 600 mAh     | 117      | 20 USD | 2,340 USD |
| Village  | Solar Home System      | 6000 mAh    | 5        | 50 USD | 250 USD   |
| Village  | Hand Water Pump        | 10.1 m      | 1        | 2,500 USD | 2,500 USD |
| Farming  | Training at GPI        | People      | 4        | 250 USD | 1,000 USD |
| General  | Travel                 | Students    | 4        | 1000 USD | 4,000 USD |
| Total    |                        |             |          |        | **10,090 USD** |
The main future challenge is to ensure that the quality of the food produced will be able to meet the strict regulations in European countries. Additional machinery for food processing like grinding creates new products to broaden the market chain. Since the farming area has nearly no space limitation, the only potential restriction could be lacking motivation or labor force in the local community. The developed concept has to incentivize people to continuously seek wealth and sustainability. Therefore, salaries will play a much more essential role than in the beginning as a proper reference for key performance indicators (KPI).

5. Conclusion
After having implemented the vision for the community of Kaaka, there are no obstacles for the farmers to explore their potential and the knowledge can be transferred from the GPI through training. It is the villagers who know best what they need; through the establishment of a revenue share pay-back system, the community is able to invest in machinery, renewable energies and irrigation systems. A water-energy-food nexus can thus be implemented to operate eco-agriculture and renewable energy. From time to time, the farmers will also be introduced to concepts like sustainability and renewability. While the system discussed in this paper can potentially be utilized throughout Ghana, the outcomes may also be referential for international cooperation under the framework of The Belt and Road Initiative between China and African countries.

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