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Ex Ante Economic and Nutrition Analysis of Alternative Small Scale Irrigation Systems in Dimbasinia Community-Kassena Nankana District in the Upper East Region of Ghana

Texas A&M University Integrated Decision Support System Team
USAID Feed the Future Innovation Laboratory for Small-Scale Irrigation

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Introduction

The Dimbasinia community/village is located in Kassena Nankana district in the Upper East region of Ghana close to the Burkina Faso border (figure 1) The Kassena Nankana district is dominated by a subsistence farming system where the majority of the population is engaged in agriculture to produce staple foods for consumption. The major crops grown in the community are maize, rice, groundnuts, and sorghum. Farming activities comprise both raising crops and livestock. The annual rainfall in the Dimbasinia watershed ranges from 523 mm to 1,358 mm, with a mean of 1,013 mm (Obuobie, 2015)

The farm level analysis to evaluate the adoption of agricultural technologies in Dimbasinia community was carried out using the farm simulation model (FARMSIM). Due to the lack of household data on Dimbasinia community, input information on crop and livestock used in the analysis was from the nearby community of Nyangua, not far from the Dimbasinia community and watershed.

The farm level information on crop and livestock fed into FARMSIM came from a household survey conducted by Africa Rising/IFPRI in 2014[1]. The survey shows that the major crops grown, by area, in Nyangua/Dimbasinia community are maize (129 Ha), sorghum (49 Ha) on an estimated total cropland of 556 Ha (rain-fed and irrigated). Vegetables such as tomatoes and red pepper are produced as well and their cropland can be expanded with the help of irrigation during the dry season (double cropping). However, some of the major crops such as rice and groundnuts were not discussed in the study due to the lack of enough information on the crop management and agricultural practices required to simulate them in the crop growth model, APEX (Agricultural Policy/Environmental eXtender). APEX generates 32 years of yields input into the FARMSIM model to capture the risk associated with observed weather conditions. The pastureland in Nyangua/Dimbasinia village was estimated to be around 20 Ha. The main types of livestock produced are cattle, sheep, goats, pigs and chicken.

A small number of farmers interviewed (about 5%) reported irrigating their crops according to the Africa Rising/IFPRI survey. Half of those who irrigate use mainly groundwater (wells) while the rest uses surface water. The use of fertilizer is as well low where around 42% of the households interviewed indicated to apply fertilizer, mainly the NPK (urea). The fertilizer application information from survey data show on average an application rate of 136 Kgs/ha in maize and sorghum fields.

[1] We would like to sincerely thank Cleophelia Roberts and Carlo Azzarri (IFPRI) for graciously providing the household survey we used in this analysis.

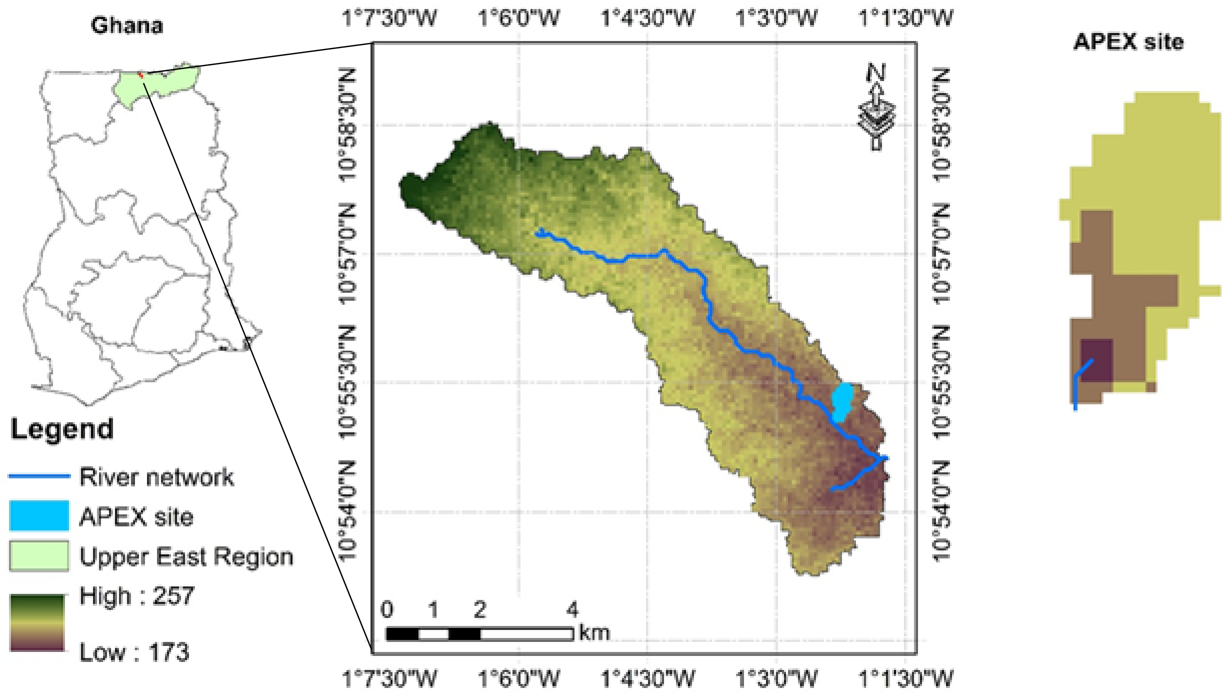

Figure 1. Location of Dimbasinia community and watershed in Kassena Nankana district

Farm simulation model (FARMSIM)

FARMSIM is a Monte Carlo simulation model to simulate the annual production, consumption, marketing and financial activities of a farm. Input information to describe a farm in the Dimbasinia community are collected from survey data. The model simulates stochastic prices and production for five years using a multivariate empirical distribution procedure. Stochastic prices are simulated based on a historical range of prices for the region. Stochastic crop yields are simulated from a multivariate distribution estimated from 32 years of APEX simulated yields that represent 32 possible weather conditions observed from a local weather station.

Crop production is used to meet family, seed, and livestock needs first and any surplus is assumed to be sold. Receipts are simulated as the product of stochastic prices and residual crop and livestock production. Expenses are calculated summing the product of hectares planted and initial costs of production from the survey. Cash expenses for the family are provided in the survey information. Net cash farm income equals receipts minus cash expenses; ending cash is a result of the net cash income minus family cash expenses and the net present value is the present value of family withdrawals and the change in real net worth over a five year planning horizon. The probable economic benefits from adoption of new technology are calculated by comparing the farm's net cash farm income, ending cash, and net present value for alternative scenarios.

Scenarios Analyzed

- ✓ **Baseline scenario: current fertilizer + no irrigation**

In the baseline scenario, the major crops grown in the wet season are maize and sorghum for the staple food category. In the vegetable category, tomatoes and red pepper are grown on a limited land (rain-fed or very minimal irrigation) alongside fodder (vetch/oats) and napier grass used for animal feed. The survey information shows that the agricultural inputs (fertilizer, irrigation, improved seeds) were applied at minimal levels.

- ✓ **Alternative scenarios**

For the alternative farming systems, the use of different water lifting technologies (pulley, diesel and solar pumps) along with the effect of dual cropping of maize or sorghum with vegetables/fodder on yield and net cash income were considered. With the help of irrigation water collected from shallow wells/ponds, vegetables (tomatoes and red pepper) and fodder (vetch and oats) were grown on larger areas due to double cropping during the dry season. Fertilizer application rates for maize and sorghum were increased slightly over the two thirds of the recommended levels of N-P-K (60-60-60) (Adu et al., 2015) by adding 50Kgs of Urea and 50 Kgs of DAP per Ha to the existing fertilizer levels (Baseline). It is expected that the yield differences between the baseline and the alternative scenarios for maize, sorghum, vegetables and fodder are mainly due to fertilizer and irrigation applications. The APEX model provided yield information for thirty-two years of weather observations (1983-2014). With irrigation during the dry season, double cropping is practiced between maize or sorghum and vegetables (tomatoes and red pepper) and fodder (vetch and oats). Total irrigable cropland, as determined by the SWAT model (Soil and Water Assessment Tool), is approximately 450 ha in the Dimbasinia community. Only about half of that cropland area was used for double cropping in the dry season, leaving other potential irrigable land to rice and groundnuts crops, which are not evaluated in this study.
The economic benefits of three different water lifting technologies are evaluated in this study: pulley/bucket; diesel and solar pumps. These methods of irrigation are evaluated as to their capacity to provide the necessary water to a maximum irrigable cropland of 450 ha as well as their costs of investment and returns. The pumping rates for a pulley/bucket, diesel and solar pumps are respectively 10, 170 and 20 liters/min.

***Alt. scenarios 1-5: irrigated vegetables and fodder + recommended fertilizers + dual cropping of vegetables/fodder with maize or sorghum**

In addition to growing maize and sorghum in the wet season, vegetables (tomatoes and red pepper) are grown alongside fodder (vetch and oats) during the dry season with the help of irrigation. However, based on APEX yield simulation results which indicate a higher yield level for tomatoes when they are dual cropped with sorghum instead of maize, an analysis was conducted to assess the impact of that combination on crop production and cash profit in alternative scenarios two and three (Alt. 2 & 3). In the case of pepper and fodder, there was no significant differences in associating them with sorghum or maize. Also the type of water lifting technology is tested in all five alternative scenarios and comprise a pulley/bucket, diesel (rented and owned) and solar pump systems. Two levels of fertilizer are applied to maize and sorghum: 1) no or current fertilizer level in the baseline scenario; 2) 50 Kgs/ha of Urea and 50 Kgs/ha of DAP for maize and sorghum in the alternative scenarios.

Except for maize and sorghum whose cropping area was not changed for the alternative scenarios, cropping areas for vegetables and fodder were significantly increased for the alternative scenarios due to irrigation. Land allocation for tomatoes and red pepper increased from 2 to 5 times between the baseline and alternative scenario one (Alt.1) involving the pulley/bucket system while the increase was 3 to 8 fold for alternative scenarios two to five (Alt.2-Alt. 5) which involved the use of a diesel and solar pumps. The land area for fodder increased 2 to 5 times for all alternative scenarios (Alt.1 under pulley system and Alt.2–Alt.5 under diesel and solar pumps systems). A perennial, napier grass, is included in this study but was not regularly irrigated and its cropland area did not change for the alternative scenarios. The combination of three water lifting technologies and two types of dual cropping/rotations between vegetables/fodder and grain crops resulted in five alternative scenarios that were compared with the current conditions or baseline scenario.The six scenarios (baseline and five alternatives) are defined below:

- ✓ Baseline: current fertilizer + no irrigation
- ✓ Alt.1 (Pulley-SV): irrigate vegetables/fodder with pulley + recommended fertilizers + dual cropping sorghum-vegetables/fodder
- ✓ Alt.2 (Diesel_PR-MV): irrigate vegetables/fodder with rented diesel pump + recommended fertilizers + dual cropping maize-vegetables/fodder
- ✓ Alt.3 (Diesel_PR-SV): irrigate vegetables/fodder with rented diesel pump + recommended fertilizers + dual cropping sorghum-vegetables/fodder
- ✓ Alt.4 (Diesel_PO-SV): irrigate vegetables/fodder with own diesel pump + recommended fertilizers + dual cropping sorghum-vegetables/fodder
- ✓ Alt.5 (Solar_P-SV): irrigate vegetables/fodder with own solar pump + recommended fertilizers + dual cropping sorghum-vegetables/fodder

<u>Note</u>: the solar pump does not have any other alternative on rental since it is a new system that is being introduced and does not have sufficient data for rental cost.

The farm level simulation results for the six scenarios showed differences not only between the baseline and the alternative scenarios but also among the alternative scenarios in terms of net cash farm income, ending cash reserves, and nutrition.

In this evaluation we did not include the capital costs of drilling wells or pond as these costs can greatly vary from household to household depending on the type of well/pond built (in-field, riverine and permanent shallow wells) (Namara et al., 2011). Only the capital costs related to the water lifting technology and the operating costs were included in the model.

Other simulation assumptions

First, to show the full potential of adopting new technologies, we assumed that the alternative farming technologies (alternative scenarios), analyzed in this study, were adopted at 100% by farmers. Second, the markets were assumed to be accessible and competitive with no distortion where the supply and demand determine the market prices. However, in the 5 year economic forecast, market selling price in each of the five years was assumed to equal the average selling price of year 1 for each crop sold. Last, given the lack of information on cost and revenue of growing fodder in Ghana we used information collected on the ILSSI-Ethiopia case study.

Assessment of water lifting technologies

To evaluate the benefits and costs of alternative irrigation technologies (pulley, diesel and solar pumps) this analysis considers the costs of the different technologies and the amount of land that can be irrigated without water stress to the crops. The assessment is based on costs (operating and capital) and capacity of the water lifting technology (pumping rate) to irrigate available land for a given crop, based on its water needs. The following assumptions are considered:

1) Number of active family members (adults) who will carry out the irrigation: 2
2) Number of irrigation hours per family member per irrigation day: 4
3) Number of days per season the farmers are irrigating if we assume 2 days per week of irrigation during a period of three and half months: 28
4) Total number of hours of irrigation per season: 2*4*28 = 224 hours
5) Pumping rates (liter/min) for the different water lifting technologies:
    - Pulley/bucket: 10 liters/min
    - Motor/Diesel pump[2]: 170 liters/min
    - Solar pump[3]: 20 liters/min

Based on SWAT model simulations, it was determined that there is enough available ground water to pump for irrigation. Crop yields were simulated by APEX for different levels of water stress. The irrigator's equation was used to estimate the total amount of water that can be delivered by a water lifting technology.

Irrigator's equation: Q*t = d*A

Q: flow or pumping rate (liters/min)

T: time (min) for irrigation

d: depth of irrigation water applied (mm)

A: area covered (m^2 or ha)

[2] IWMI field studies conducted in 2016 on behalf of ILSSI project
[3] Mzuzu University in Malawi: http://old.solar-aid.org/project_water_pump/

Knowing the total amount of water (mm) required to irrigate a crop for the entire dry season and the total amount of water delivered by each water lifting technology per hectare (based on pumping rate and irrigation hours), we compute the fraction of water supply provided by each technology. Given the total irrigable land available for a crop (e.g. tomatoes) and its water requirements, we use the fraction of water supply by each technology to compute the fraction of cropland that can be irrigated with minimal water stress for each water lifting technology.

For instance, due to its high pumping rate, a diesel pump would in most cases supply more than enough water to irrigate all available cropland. On the other hand, a solar pump or a pulley system, assuming the same number of irrigation hours, may not provide sufficient water to irrigate all of the available cropland leading to a reduction in total irrigated land.

Simulation results and scenario analysis

The results presented below in the stoplight chart and CDF graphs (except for NPV) represent the simulation results in year 5 for the net cash farm income and ending cash reserves respectively from a 5-year simulation and forecast period.

<u>NPV (Net Present Value)</u>

NPV is a measure of feasibility or profitability of an investment over a given period of time. In this study, a representative farm in Dimbasinia community, Kassena Nankana district in Upper East region of Ghana is simulated for 5 years to evaluate the adoption of new agricultural technologies (fertilizer and irrigation). A positive NPV in Ghana cedis (GH₵) indicates that the technology returns an internal rate of return greater than the assumed 10% discount rate. Overall, the NPV results clearly indicate that it is worth investing in irrigation, fertilizer application and dual cropping of vegetables/fodder and sorghum as shown by the cumulative distribution function (CDF) of the net present value (figure 2a). The application of recommended fertilizers and dual cropping between vegetables/fodder and sorghum or maize in combination with the use of a diesel pump to irrigate vegetables and fodder, shows outstanding performance as their CDF lines are much greater than the baseline (Alt. 2, 3 and 4). More precisely, all of the 500 simulated values for Alt. 2, 3 and 4 lie to the right of the other scenarios. The second best alternative scenario is alternative scenario five (Alt.5) that involves the use of a solar pump and a dual cropping system between vegetables/fodder and sorghum. Alt. 5 performed however, better than the Alt.1, which involved the use of a pulley system in irrigation and the baseline. The pulley system performed considerably better than the baseline. Notice the large increase in the NPV values from Alt. 2 to Alt. 3 representing the dual cropping system between vegetables/fodder and maize, and vegetables/fodder and sorghum respectively, all other conditions remaining the same.

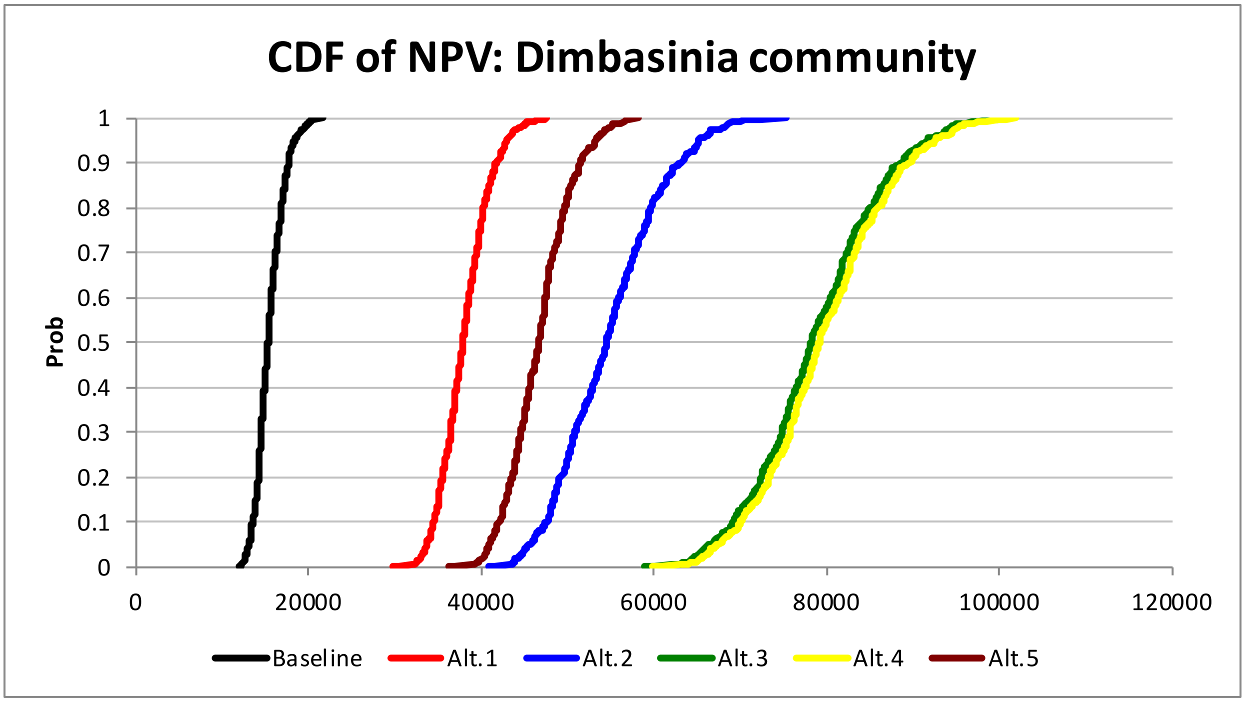

Figure 2a. Cumulative distribution function of the NPV in Dimbasinia community

Legend					
Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

The StopLight chart presents the probabilities of NPV being less than 38,000 GH₵ (Ghanaian Cedi) (red), greater than 78,000 GH₵ (green) and between the two target values (yellow) for the five year planning horizon (figure 2b). The target values are the averages of NPV for the pulley system (second lowest performing scenario) (lower bound) and the first two best performing alternative scenarios (Alt. 3 & 4) (upper bound). There is a 100% chance that NPV will be less than 38,000 GH₵ for a farmer who does not adopt any technology package (baseline scenario) and a zero percent chance that NPV will exceed 78,000 GH₵ (figure 2b). However, farmers who apply recommended fertilizers, irrigate using a diesel pump, and practice a dual cropping of vegetables/fodder with sorghum, have between 52% and 58% probability that NPV will exceed 78,000 GH₵. Note that the NPV values for a farmer investing in solar pump as well as those investing in diesel pump and practice a dual cropping of maize and vegetables/fodder are sure to have their NPV range between 38,000 and 78,000 GH₵. Although the solar pump system does not have the highest NPV, the results strongly suggest that investing in solar will pay enough dividends by increasing income and wealth in addition to being a clean energy source and a low maintenance technology.

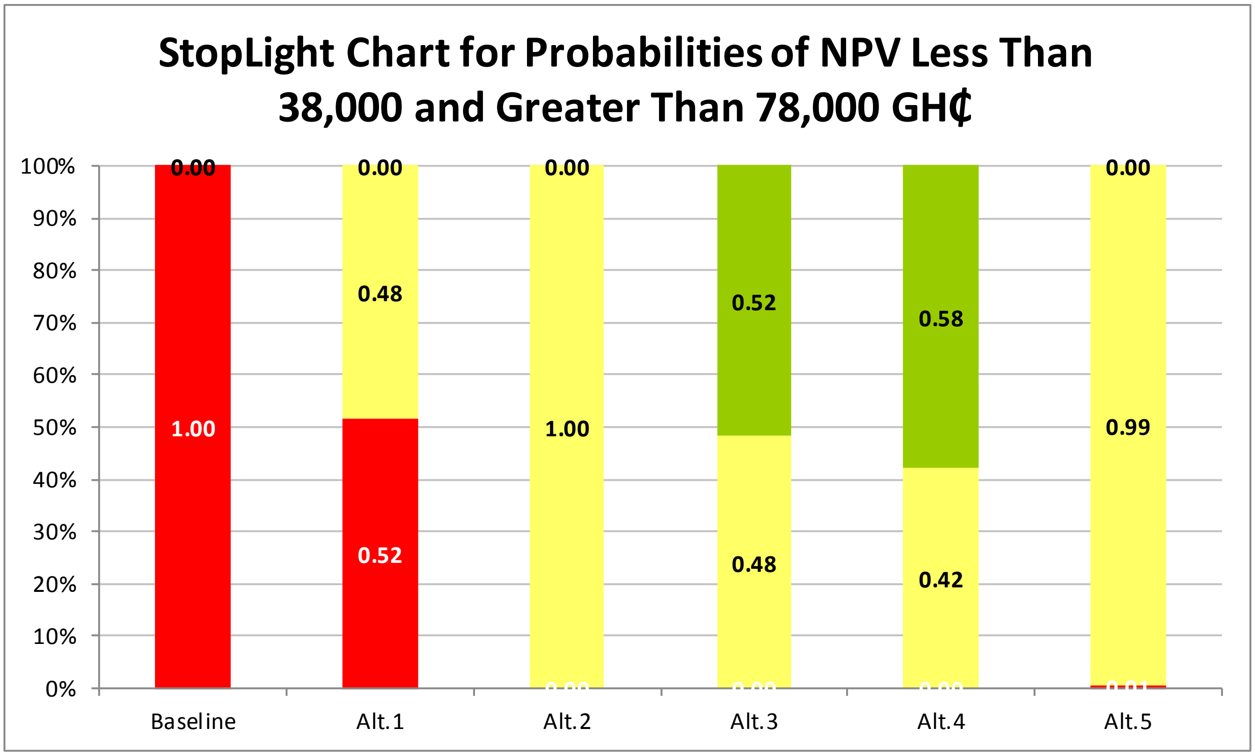

Figure 2b. StopLight chart of the NPV for the Dimbasinia community

Legend

Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

NCFI (Net cash farm income)

The NCFI cumulative distribution function shows a significant difference in terms of annual net cash farm income between the baseline and alternative scenarios (figure 3a). The alternative scenarios two, three and four (Alt. 2, 3 and 4) generated higher net cash farm income (NCFI) than the rest of the scenarios (Baseline and Alt.1 and 5) as their CDF values lie completely to the right of the other scenarios for all 500 draws for the simulated farm. Alternative scenarios two, three and four (Alt. 2, 3, and 4) represent the adoption of a diesel pump water lifting technology as well as a dual cropping system (rotation) that associates vegetables/fodder production with sorghum and maize. The difference in NCFI between Alt. 2 and Alt. 3 highlight the profit from practicing dual cropping of vegetables/fodder with sorghum instead of maize. Note that owning a diesel pump or renting it (Alt. 3 and 4) does not show any significant effect on the net cash farm income earned by farmers.

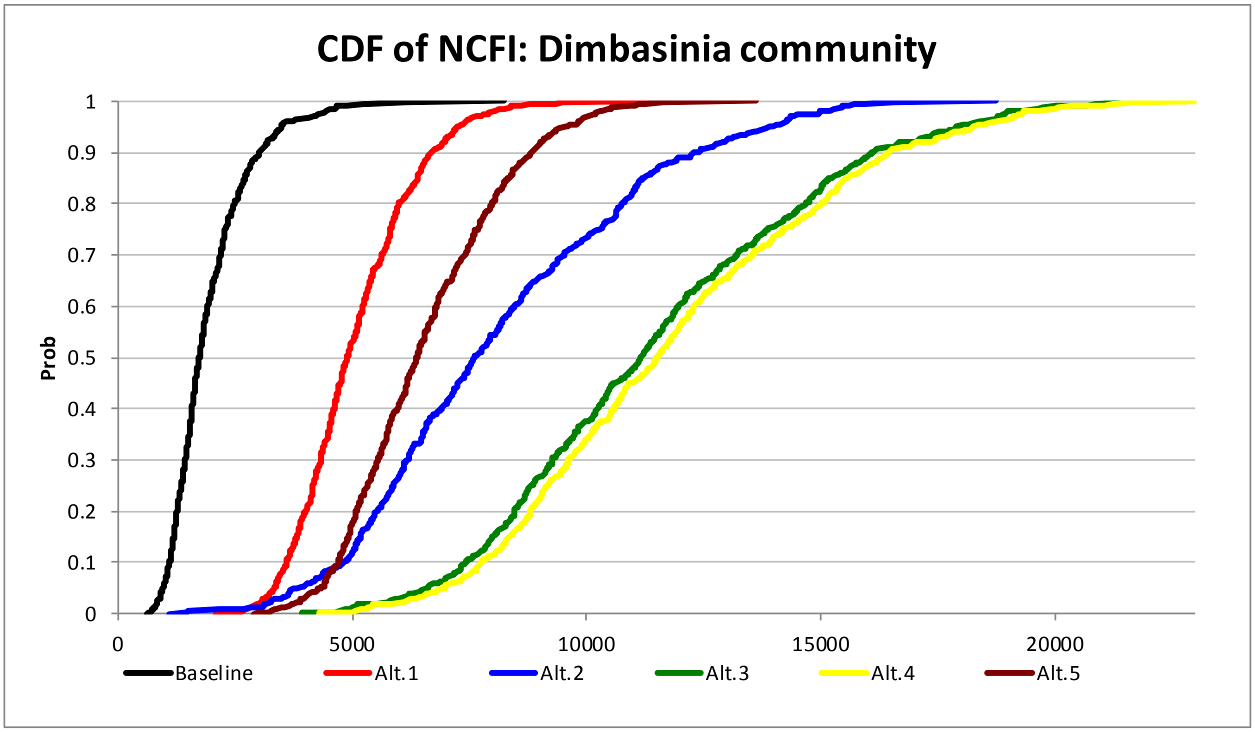

Figure 3a. Cumulative distribution function of NCFI for Dimbasinia community

<u>Legend</u>

Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

The NCFI StopLight chart shows a significant change in economic benefit in terms of the annual net cash farm income (NFCI) for the alternative farming systems scenarios (Alt.2, 3 and 4) in year five (figure 3b). There is between 62% and 66% chance that the NCFI will exceed 10,000 GH₵ and a zero percent chance that NCFI will be less than 2,000 GH₵ per year for a farmer who applies fertilizers, practice a dual cropping system between the vegetables/fodder and sorghum and irrigate with a diesel pump (Alt. 3 and 4). Alt. 3 and 4 that involve the use of a diesel pump (owned or rented) generated the highest profit (NCFI) compared to the alternative scenarios in which the pulley or solar pump were adopted. However, a representative farmer in the Dimbasinia community who does not adopt any technology (Baseline) has about 63% probability of having an annual net cash farm income less than 2,000 GH₵ in year five. Notice the large difference in net cash earnings among farmers who practice a dual cropping system between vegetables/fodder and maize (Alt. 2) vs. those who rotate vegetables/fodder and sorghum (Alt. 3). The farmers in Alt. 3 have 62% probability of having a NCFI greater than 10,000 GH₵ while those adopting Alt.2 have only a 27% chance of exceeding 10,000 GH₵, other things being equal. Using a pulley system to irrigate vegetables and fodder (Alt.1) earned less income compared to using a diesel pump for irrigation when vegetables and fodder are dual cropped or rotated with maize (Alt.2). Using a pulley or solar pump systems have almost equal cash profit with the solar pump system being slightly higher.

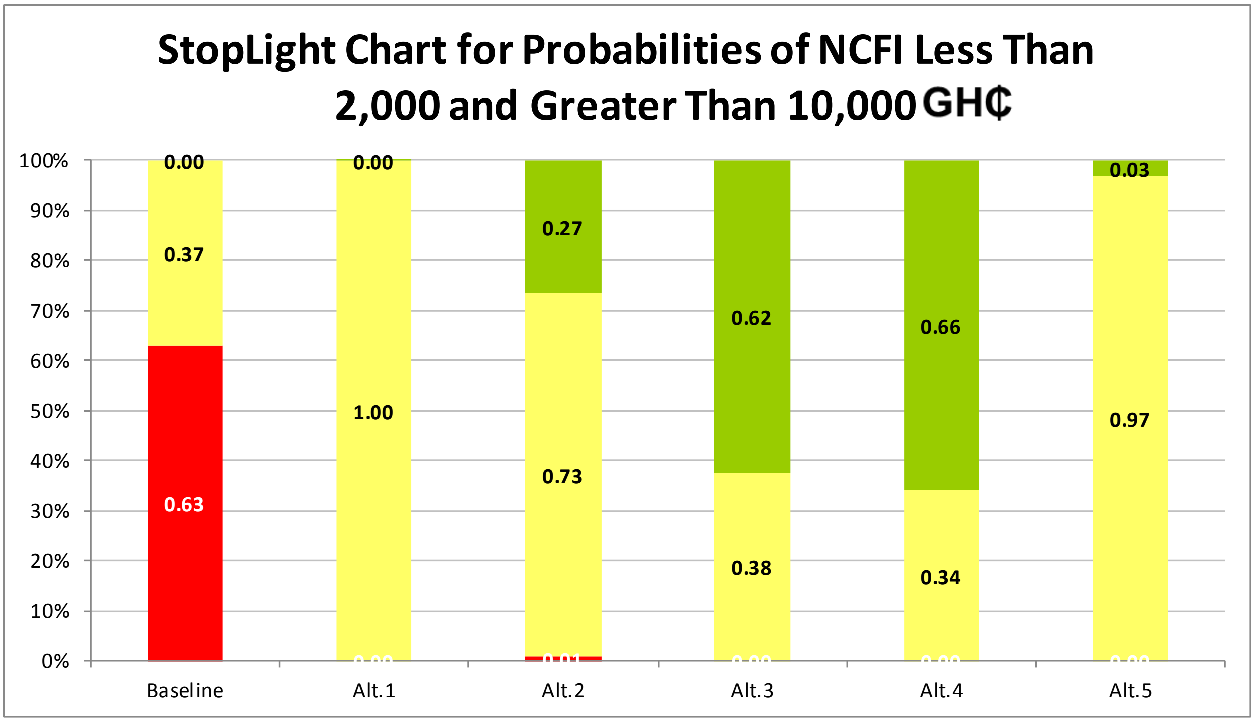

Figure 3b. StopLight chart of the NCFI for Dimbasinia community

Legend

Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

EC (Ending Cash Reserves)

The annual ending cash indicates the potential cash reserves a farmer can have in the last year of the five-year planning horizon. The simulation results highlight once again the performance of the alternative scenarios two, three and four (Alt. 2, 3 and 4) that involve fertilizer application, dual cropping of vegetables/fodder and sorghum and irrigation in the dry season with a diesel pump (figure 4a). The CDF values for alternative scenarios 2, 3 and 4, in which vegetables and fodder are dual cropped (rotated) with sorghum or maize, lie entirely to the right of the other scenarios (Baseline, Alt. 1 & 5) with Alt. 3 and 4 (diesel pump) leading the group. This result suggests that investing in water lifting technologies for irrigation and adopting best agricultural practices (dual cropping with sorghum) have a significant potential to increase farmers' cash reserves. The baseline scenario with no irrigation and current level of fertilizer application had the lowest performance.

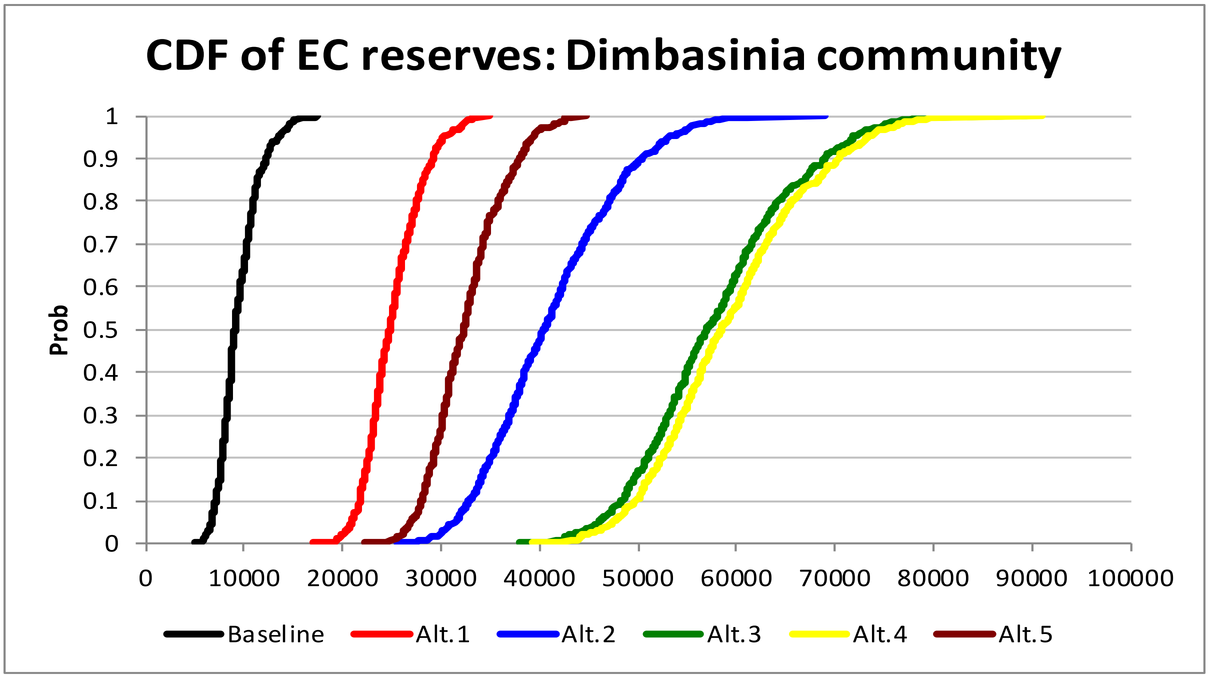

Figure 4a. Cumulative distribution function of the EC reserves for Dimbasinia community

Legend					
Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

The ending cash reserve StopLight chart (figure 4b) indicates between 50% and 57% probability of having an ending cash reserve in year 5 that exceeds 57,000 GH₵ for a representative farmer who adopts irrigation using a diesel pump, applies fertilizers and rotates (dual cropping) vegetables/fodder with sorghum (Alt. 3 and 4). Farmers who do not adopt the technology package (Baseline) have a zero probability of earning an ending cash reserve greater than 57,000 GH₵ and a 100% chance of having an ending cash reserve less than 25,000 GH₵ in the year 5 of the five year planning horizon. Alternative scenarios three and four (Alt.3 and 4) which involve the use of a diesel pump (rented or owned) are the most preferred in terms of generating higher cash reserves. There is a higher cash reserve generated when vegetables/fodder are dual cropped (rotated) with sorghum than maize (Alt. 2 and 3 respectively). In Alt. 3, farmers have a 50% chance of having an ending cash reserve that exceeds 57,000 GH₵ while in Alt. 2, that probability is reduced to two percent. Alternative scenario one (Alt. 1) that uses a pulley/bucket system generated less cash reserves than any other alternative scenario.

Note: Even though there is not significant cash reserves difference between rented and owned diesel pump, owning the pump has a slightly higher economic benefit not only in the short run (5 year planning horizon) but also in the long run since the ownership of the pump becomes an asset for the farmer.

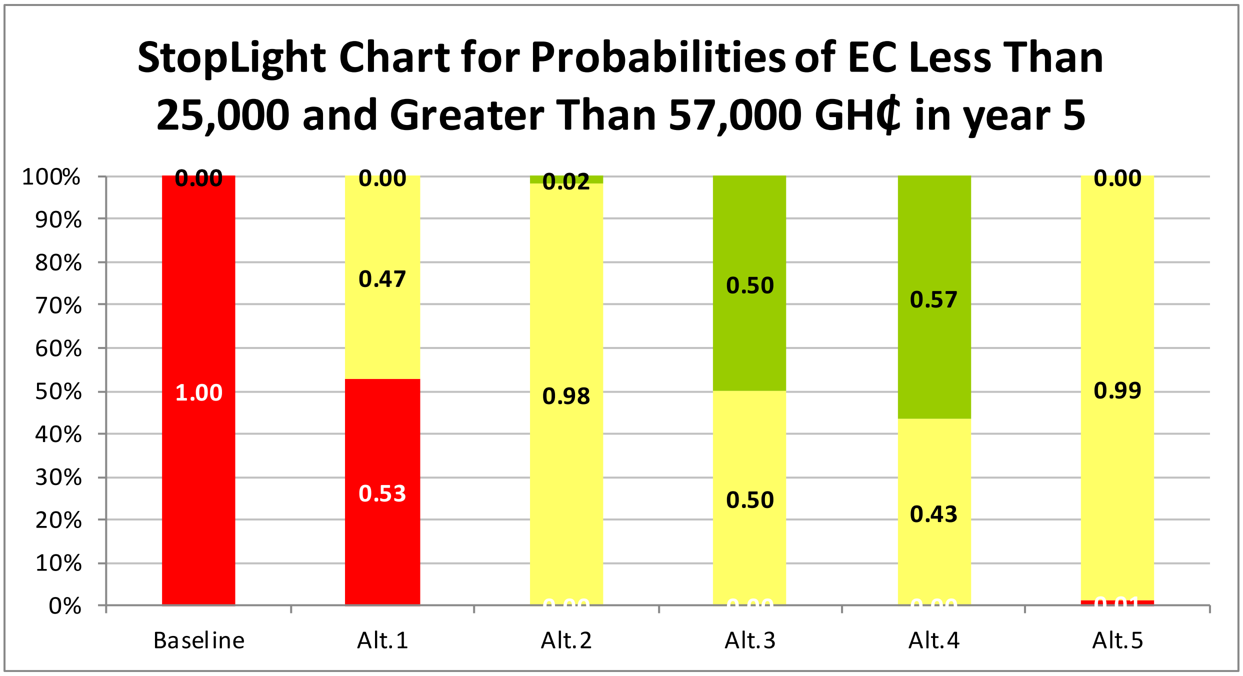

Figure 4b. StopLight chart of the ending cash reserves for Dimbasinia community

Legend

Baseline :	**No irrigation**	Alt.2 :	**Diesel_PR-MV**	Alt.4 :	**Diesel_PO-SV**
Alt.1 :	**Pulley-SV**	Alt.3 :	**Diesel_PR-SV**	Alt.5 :	**Solar_P-SV**

Nutrition

In this study the impact of adopting new agricultural technologies such as fertilizers and irrigation is analyzed, especially its potential to increase crop production and income, and improve nutrition. The implications of increased food production on nutrition however depend on the type and variety of crops grown and consumed. The farm simulation results for the Dimbasinia community, in Kassena Nankana district indicate that the quantities of crops and livestock products consumed by families under the alternative scenarios provided and even exceeded the daily levels of calories, proteins and fat required for an adult. There was a significant improvement from the baseline scenario, which recorded deficient levels of calories, fat and proteins required daily for an adult. The improvement in quantities produced and consumed in alternative scenarios were possible due to the increase in production and yield of the crops grown on the farm by the family following the adoption of small-scale irrigation technologies. Levels of calcium, iron and vitamin A showed a significant improvement as well (increase in quantity available and consumed) in the alternative scenarios jumping remarkably from deficient levels in the baseline scenario to adequate levels in the alternative scenarios in terms of the daily requirements for an adult.

Conclusions

The objective of the study was to evaluate the impact of adopting agricultural technologies (irrigation, fertilizers, and agricultural practices) on household nutrition and farm profitability in Dimbasinia community, Kassena Nankana district in Upper East region of Ghana. The baseline scenario, which consists of the current farming conditions (no or minimal irrigation and current fertilizer), is compared to five alternative farming systems comprising three water lifting technologies for irrigation, two agricultural practices and fertilization. The application of recommended fertilizers and dual cropping between vegetables/fodder with sorghum alongside the irrigation of vegetables and fodder using a diesel pump generated higher cash profit. A significant increase in revenue was as well projected when vegetables and fodder were dual cropped with sorghum rather than maize. All of the results strongly suggest that the investment in diesel pump is expected to pay large dividends by increasing income and wealth. However, even though the solar pump system did not generate the highest profit, the simulation results show it to be profitable and may be considered in future given its other advantage of being a clean energy source and low maintenance cost.

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<u>APPENDICES</u>: Water lifting tools

Solar pump installed in Ghana (Source: Bern University of Applied Sciences, 2013)

Solar pump in rice field, Rangpur-Bangladesh (Karin Imoberdorf, MSc thesis, 2012)

Prototype of a small-scale solar pump developed by BUAS (Rangpur, Bangladesh, 2012)

Source: Imoberdorf K., MSc thesis, 2012

Service provider transporting solar pump on a motorcycle (Source: Bern University of Applied Science, 2013)

Pulley/Bucket system, Bahir Dar, Ethiopia

Motor pump drawing water from river, Bochesa-Ethiopia