CHAPTER 7: RENEWABLE AND SUSTAINABLE ENERGY

A Cost Effective Solar PV Power Solution for Rural Household in Tanzania: The case of Kondoa District

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ABSTRACT
A study on the cost effectiveness of solar photovoltaic as power solution has been conducted. This work was aimed at evaluating the economic viability of this technology for rural electrification in Tanzania. The study was conducted in Kondoa rural area where 7 villages out of 177 villages were considered with a total sample of 61 households. The research involved field visits, System inspection, Interviewing end users and Questionnaires. On the other hand, economic viability of solar PV systems was evaluated using replacement cost of kerosene, small petrol generators and disposable dry batteries. In order to determine the most cost effective solutions, the life cycle cost (LCC) analysis of the components was employed as well as the inflation rate. The research findings show that kerosene is the most dominant source of energy for lighting in Kondoa rural area while electric energy use pattern is characterized by low consumption. Nevertheless, comparison between a solar PV system sizing 40 W with other alternatives was found to be more cost effective than others. This observation suggests that a small stand-alone system can be more economical for rural electrification.

Keywords: Cost-effective, Renewable energy, Rural electrification, Solar PV

1.0 INTRODUCTION
Electricity improves the quality of basic services for the well being of people, such as clean water, education, medical care, entertainment and communication. While this energy is important for economic growth, only 2 % of Tanzania's rural population has access to grid electricity (HBS, 2007), which is generated mainly from hydropower, gas turbines and diesel generation plants (URT, 2003). Such a situation displays poor electricity-based services and commodities in rural areas.

Grid-based power is the least-cost option for large concentrations of household or productive loads. It offers substantial economies of scale, owing to the large fixed-cost investment in distribution lines and generation facilities. However, grid solutions require a minimum threshold level of electricity demand and certain load densities to achieve these economies of scale (Sørensen, 2004; Luque & Hegedus, 2003). Deciding whether the grid or off-grid power solution like solar PV is the least-cost option for supplying electricity to rural areas requires a consideration of many factors. These factors include distance from grid, resource availability, equipment availability, community organization, income level, household service level, total number of households to be served, load density, productive loads and load growth (Kalogirou, 2009; Patel, 2006).

2.0 BACKGROUND AND CASE STUDY AREA
Kondoa district has a population of nearly 428,090 individuals who live in 91,500 households according to National Bureau of Statistics, census of August 2002 (http://www.nbs.go.tz). About 87,500 (95 %) of these households are located in rural areas and the remaining are found in areas

classified as peri-urban (Sonya et al., 2005). The district poverty rate is 24 % compared to 6 % in peri-urban areas (Sonya et al., 2005). Additionally, this district has over ten ethnic groups with main activities ranging from crop production, livestock keeping, hunting and honey collection. Crop production and livestock keeping are the main economic activities. Various crops are grown both for subsistence consumption and for selling, namely; maize, finger millet, oil seeds, bulrush millet and sorghum. Other crops also grown include beans, pigeon peas, sunflower, castor seeds, sesame, groundnuts, sugar cane and sweet potatoes.

Among 2,995 district council employees, 2455 are teachers. 1918 out of the 2455 teachers reside in the rural area where there is no grid electricity or other stand-alone renewable energy systems. The need to substitute conventional sources of energy, for lighting and powering low power consuming appliances like radio, TV and mobile phone recharging is of great necessity.

2.1 Rationale for Use of Solar PV Technology in Case Study Area

Kondoa district has enough solar energy potential with an annual average insolation of about 6.14kWh/m^2/year. It is attractive for use of solar PV technology as an alternative source of rural household electrification. The district is characterized by semi-arid to sub-humid conditions. The mean maximum and minimum temperatures are 29°C and 16°C respectively which provide favorable conditions for solar module operation (Foster et al., 2010). Village population densities are characterized by small numbers of households located at considerable distances away from the grid; distance varying from 5km to 50km. This renders electrification by grid connection not economically viable for a number of villages.

3.0 METHODOLOGY

This Paper presents the findings of a research conducted on the economic evaluation of solar home systems for rural electrification in Tanzania, the case of Kondoa district in Dodoma Region (John, 2009). Economic evaluation of solar home systems was done using the replacement cost of kerosene, small petrol generators and disposable dry batteries. Rural household energy use pattern and characteristic data was obtained through interviews with the head of the relevant household or his/her representative. The questionnaires used in interviews provided information about type of energy sources mostly used for lighting, quantity of fuel consumed, appliances mostly used, problems encountered related to the energy used and also people's awareness of Solar PV technology. Secondary data was collected through visiting and reviewing various documents from government officials in the Ministry of Energy and Minerals, country offices of donor agencies, libraries, local and private dealers in Solar PV, the Tanzania Meteorological Agency and TANESCO.

The solar energy resource, load and system configuration data was used to size and evaluate system performance, energy output, and energy cost. Economic data was used to evaluate the economic viability of the system. The paper adopted a combination of Life-Cycle Cost analysis (LCC), and Net Present Value (NPV) methods for economic evaluation. The rural households were categorized into low, medium and high income based on respondent's annual energy consumption cost.The study obtained the number of households in each sampled village of Kondoa that are not electrified by grid then and then determined the appropriate number of samples accordingly. A quasi-random or systematic sampling was employed (Kothari, 1990; Dawson, 2002). A total sample of 61 households was used in this study.Criteria used to choose the case study area were; Low level of electrification, distance from the grid, rural communities with low family income, solar energy resource potentiality and data accessibility.

4.0 FINDINGS AND ANALYSIS OF RESULTS

The following is a summary of the findings and analysis of results of the study.

4.1 Kondoa Solar Energy Potential

Kondoa District has a Solar Energy potential whose average annual solar insolation is about 6.14 kWh/m^2/year (Figure 1). The amount of solar insolation influences size of solar module and hence its cost. The larger the amount of solar insolation, the smaller the size of solar module to be used, and hence the lower the cost.

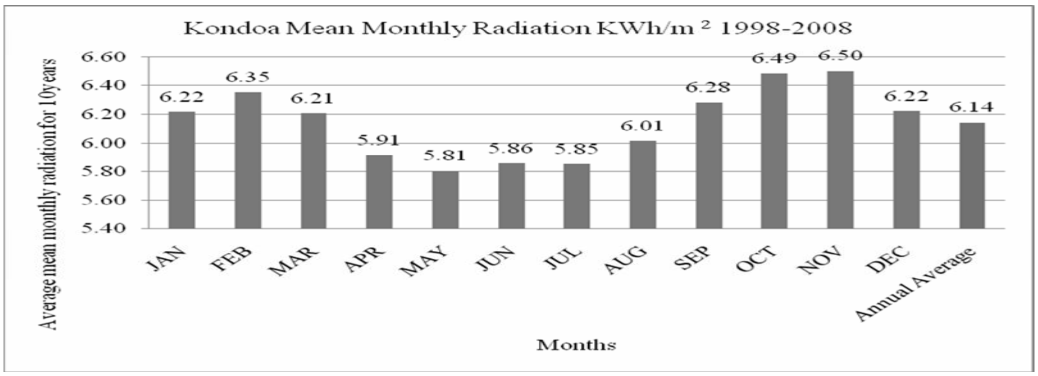

Figure 1: Kondoa Mean Monthly Solar Radiation for ten years (TMA, 2009)

4.2 Energy Sources

Field data concerning type of Energy sources mostly used for lighting and powering low-power consuming appliances found mostly in Kondoa rural households shows that out of 61 respondents surveyed, about 82% use kerosene, 77% disposable dry batteries, 13% petrol generators and 11.5% PV Solar Home System (Figure 2). The results clearly show that kerosene is the most dominant source of energy for lighting in the rural area followed by disposable dry batteries.

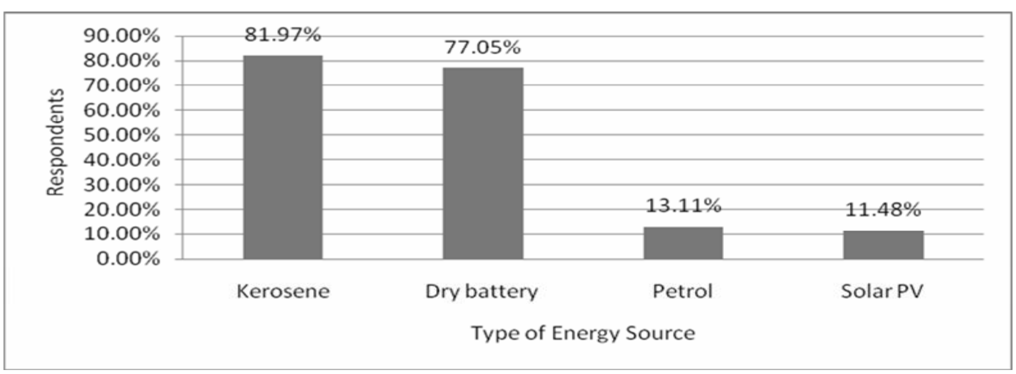

Figure 2: Types of Energy Source Used by Households

4.3 Kondoa Rural Energy Use Parttern

In Kondoa villages, power demand is low since most of the people are very poor and their energy needs are largely met by using biomass like firewood and charcoal for cooking, kerosene lamps for lighting and disposable dry batteries for torches and radio applications. Electricity can basically be used for lighting and powering low power consuming appliances like radio, TV, and recharging mobile phones. The result shows that lighting is the major dominant load for rural residents in Kondoa District. Figure 3 shows that about 60% of appliances use is lighting followed by radio at 14%, mobile phone recharging at 13%, torch at about 10% and TV at 4%.

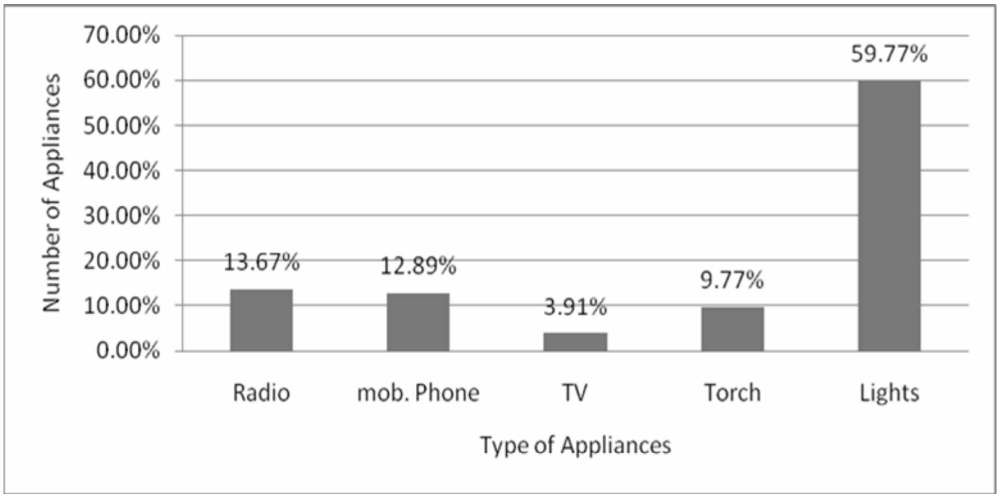

Figure 3: Households Appliances Used in Kondoa Rural

4.4 Size of Solar PV Systems Suitable for Kondoa Rural Area

In order to determine size of PV systems which will be affordable by Kondoa rural households, replacement cost of conventional energy with Solar PV system approach was used. As mentioned earlier, households were grouped into low, medium and high income rural households and likewise considered during system sizing. Normally the household's energy demand grows with their income rate (Luque & Hegedus, 2003 and Cabraal et al., 1996).

In this study, individual load energy demand is given as a product of the rated power of the individual appliance, and the appliance's use in hours per day.

$$E_i = P_i \times t_i$$

Where: E_i = Energy demand of individual appliance
t_i = time in use of individual appliance
P_i = Rated power of appliance

Total load energy demand is a summation of each individual load energy demand.

$$E_t = \sum E_i = \sum P_i \times t_i$$

Where: E_t = Total energy demand.

The following table below summarizes the load energy demands for low, medium and high income Kondoa rural households:

Table 2: Load Energy Demand for Low Income Rural Households

S/N	Location	Appliance	Qty	Rated Voltage(Vdc)	Rated Power(W)	Hours in use	Days/ Week	Wh/ day
1	Room 1	LED	1	12	4	4	7	16
2	Room 2	LED	1	12	4	1	7	4
3	Room 3	LED	1	12	4	1	7	4
		Radio	1	6	10	3	7	30
		Net energy demand in Watt hour per day						54

Table 3: Load Energy Demand for Medium Income Rural Households

S/N	Location	Appli-ance	Qty	Rated Voltage (Vdc)	Rated Power (W)	Hours in use (h)	Days/ week	Wh/ day
1	Room 1	LED	1	12	4	4	7	16
2	Room 2	LED	1	12	4	1	7	4
3	Room 3	LED	1	12	4	1	7	4
		Radio	1	12	30	3	7	90
4	Security	LED	1	12	4	8	7	32
Net energy demand in Watt hour per day								146

Table 4: Load Energy Demand for High Income Rural Households

S/N	Location	Appli-ance	Qty	Rated Voltage (V)	Rated Power(W)	Hours in use (h)	Days/ week	Wh/ day
1	Room 1	LED	2	12	4	4	7	32
2	Room 2	LED	1	12	4	1	7	4
3	Room 3	LED	1	12	4	1	7	4
4	Room 4	LED	1	12	4	1	7	4
5	Room 5	LED	1	12	4	1	7	4
		Radio	1	12	15	3	7	45
		TV	1	230	70	2	7	140
6	Security	LED	2	12	4	8	7	64
Net energy demand in Watt hour per day								297

The following formulae were used for system sizing:

(i) Solar PV module size is given by:

$$E_{gd} = \frac{E_{nd}}{\eta_i \times \eta_b \times \eta_w}$$

- Where E_{gd} and E_{nd} denote gross and net energy demand per day respectively. η is efficiency with subscripts *i*, *b* and *w* referring to inverter, battery and wiring respectively. Typical efficiencies are 85% to 90% for the inverter, 85% for batteries and about 98% for the system wiring in a well designed PV system (Messenger and Ventre, 2004).

$$System\ charging\ current(A) = \frac{E_{[illegible]}(Wh)}{\text{[illegible]}}$$

- Where PSH = Peak Sunshine Hours. The system voltage selection depends on the size of the load energy demand in kWh. If the load energy demand is below 1 kWh the appropriate system voltage is 12Vdc while for load energy demand greater than 1 kWh is 24Vdc or more (Messenger & Ventre, 2004).

(ii) The battery capacity is calculated according to the formula given below:

$$C_{batt} = \frac{E_{nd}\,(kWh/day)}{\eta_b \times DoD \times V_{batt}} \times Days\ of\ autonomy$$

- Where C_{batt} = Battery Capacity, DoD = Depth of Discharge, V_{batt} = System Voltage.

(iii) Size of charge controller is given by the formula bellow

$$Charger\ Controller\ (A) = \frac{1.3 * Array\ size\,(W)}{System\ Voltage\,(V)}$$

– Where A = Ampere, W = Watts, V = Volt, 1.3 = Factor of safety.

(iv) Inverter size is given by the following formula:

$$C_{inv} = 1.3 * Load(W)$$

– Where C_{inv}= Inverter capacity, 1.3= A factor of safety.

Solar PV modules obtained was 14W, 40W and 80W capacities, for small, medium and high income rural households respectively.

4.5 Economic Analysis Results

The Economic analysis was done based on the assumptions that all competing alternatives technically perform the same function. Annual Interest Rate and inflation rate of 13% and 10.3% respectively (BOT, 2009). Life cycle of PV module was taken as comparison time for LCC analysis. For proper sized small SHS with components properly selected; maintenance cost is so small that it can be neglected. (Galloway, 2004), Annual operating cost for petrol generators and kerosene lamps was considered as the annual fuel cost, petrol, kerosene and disposable dry batteries (A4) prices were Tshs. 1,620 per litter, Tshs. 1,200 per litter and Tshs. 500 per battery respectively; as per market price in Kondoa December 2009.

Table 5: Economic Results (1US$ =Tshs. 1,500)

Source		Initial Cost (Tshs.)	Annual Running Cost (Tshs.)	LCC (Tshs.)
PV	A	516,000	-	720,600
PV	B	1,081,500	-	2,060,800
PV	C	1,892,500	-	3,989,000
Generator set	A	130,000	487,200	4,065,700
Generator set	B	160,000	681,600	11,717,900
Generator set	C	160,000	973,200	16,477,400
Kerosene & Battery	A	-	55,200	434,100
Kerosene & Battery	B	-	131,350	2,143,900
Kerosene & Battery	C	-	340,800	5,562,500

From Table 5 above A, B and C represent low, medium and high income rural households categories respectively. The result revealed that for low income households who spend Tshs. 55,200 annually for kerosene and batteries, their LCC for 10 years life time is Tshs. 434,081, while it is Tshs. 720,566 and Tshs. 4,065,687 for SHS and petrol generator respectively (Table 5). Results show that for low income category, the poorest group of respondents who spend below Tshs. 96,000 annually for kerosene and batteries can neither afford to opt for 14W solar PV module which is the smallest SHS available in the market nor a small petrol generator; but for those who spend above Tshs. 96,000 annually; their best choice is SHS system (Figure 5).

The LCC result shows that for medium income rural households 40W solar PV system is cost effective compared to other alternatives. Also the LCC results for high income rural households show that solar PV option is cost effective (Table 5).

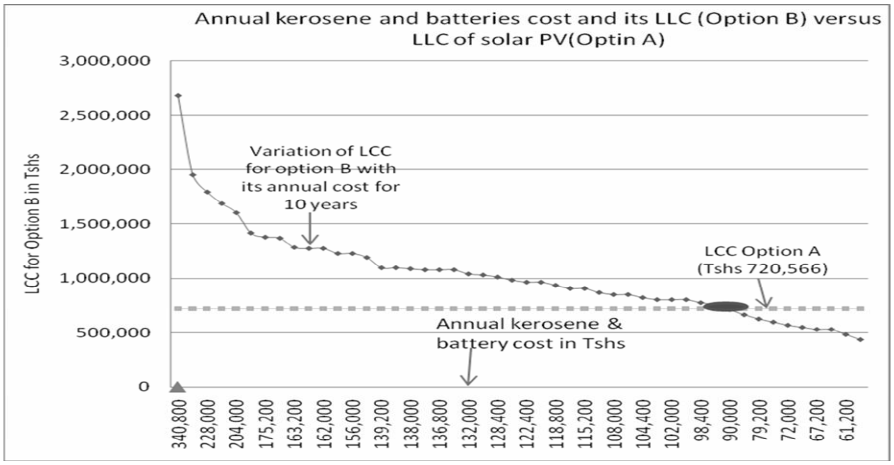

Figure 5: Annual cost option B and its LCC vs LCC option A

5.0 CONCLUSIONS AND RECOMMENDATIONS

(i) PV systems are more economical than conventional generators for equal energy demand for low energy consumption.

(ii) The study shows that households in Kondoa rural are characterized by low load energy demand and mostly for lighting which accounts for 59.77% for the 61 interviewed respondents.

(iii) Although Life-Cycle Cost of solar home systems is lower than for conventional energy systems, their initial investment costs are high, hence the poorest low income rural households who spend less than Tshs. 96,000 annually for energy could not afford even the minimum solar PV system which is 14W.

(iv) The considered inflation and interest rates are 10.3% and 13% for petrol and kerosene respectively. The lifespan can be 5, 10 and 25 years for a petrol generator, amorphous and crystalline solar PV module respectively. For a cost of Tshs. 1,200 for kerosene and Tshs. 1,620 for petrol per litre, an optimal and most cost effective SHS consists of 14W, 40W and 80W for low, medium and high income rural households respectively.

6.0 REFERENCES

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