IS PHOTOVOLTAIC POWER A COST-EFFECTIVE ENERGY SOLUTION FOR RURAL PEOPLES IN WESTERN SUDAN?

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ABSTRACT

Sudan like most poor countries suffers from a deficiency in the supply of electrical power, especially for rural areas. Less than 10% of the total population, can benefit from the national grid connection.
The paper evaluates the economic, environmental and social issues associated with electrification in western Sudan for rural and nomadic peoples, by assessing three different systems for off-grid electricity supply; stand alone systems powered by diesel generator (gen-set), photovoltaic cells, and a larger distributed generator system (mini-grid).
The study indicates that, although photovoltaic might be the best source of electricity from an environmental and social view, unfortunately it currently cannot compete economically. The research identified that Sudanese customs and tax policy adds a significant cost to PV, making diesel generators the best power choice for rural and nomadic regions in Sudan. Other important factors include fuel supply problems and availability of spare parts for generators.

1. INTRODUCTION

In developing countries around the world more than 2 billion people do not have access to electricity, partly as a result of the high cost of grid extension (1,2). This lack of the power affects national development and services. Renewable resources offer the chance not only of limiting greenhouse gas (GHG) emissions but also for providing electricity in rural parts of the developing world. But renewable energy systems have to compete with the small-scale gen-set fueled by diesel or gasoline.
Recently global warming linked to GHG emission are reducing the appeal of the gen-set option from an environmental view, but increasing the popularity for using stand-alone renewable resources such as photovoltaic (PV) and wind technologies.
Studies, (2,3,4) of stand-alone renewable energy systems in, Kenya, China and Thailand, have indicated that these technologies can provide reliable and comparatively low cost electricity services to rural households and communities. The supply of electricity from such systems brings tangible social and economical benefits to rural population, including the ability to refrigerate food and medicine, and light the households.
In parts of Sudan where the population density is only (5-10 inhabitant/km^2) distributed energy resources (DER) are really the only solution for rural electrification as transmission and distribution infrastructure represents a significant cost in initial capital and continuing operation and maintenance (5,6). DER systems have reduced transmission losses and can have a rapid installation time. They also lend themselves well to expansion as demand increases.
This paper examines the economic, environmental and social issues related to three types of electricity generators; stand-alone PV modules (50 W_p), two imported gen-sets (0.5, 2.4 kW) and a small mini-grid system (313kW peak) as the main electricity suppliers for normal rural houses and the tents of nomadic tribes in two locations in Sudan.

2. BACKGROUND AND CASE STUDY AREA

The study concerns the electricity supply for: the Al-Kababish: a group of people who are both Arab and African. These nomadic people herd their camels across the Sahara Desert in search of food and water. The Kababish territory (Northern Kurdufan) is located in Northwestern Sudan and in the beginning of the Libyan Desert. Like other nomadic African-Arab tribes, they live in tents with their camel herds, in search of vegetation and water. They have a complex system of migration, in which different parts of the family move to different places during certain times of the year. Some of them have become semi-nomadic and live in villages most of

the time, which are located to the west of Khartoum, the capital city. They live in dikkas; camps. Their homes are tents made with camel hair roofs and cotton sides held up by wood or baked mud structure. While Kababish men move across the desert with their camel herds, the women and children stay home. Some women tend to the gardens, while some other women go to sell some handcraft products in the market. Their main travels in the year are to the south in the dry season (November to March) and to the north in the rainy season (April- October).
The tribe does not have access to electricity services except when near the big towns like Dongola in the north or Al-Obied in the Kurdufan province. Their main methods of lighting are kerosene lamps and firewood.

3. METHOD

The study makes economical, environmental and social assessments through evaluating the inputs and outputs of three types of electricity sources. The input data consists of a solar energy profile, household load data, mini-grid load, system configuration, system cost, financial data and policy scenario information.
The resource load and system configuration data are used to evaluate system performance and energy output, and energy cost.
Economic and policy data are used to evaluate the economic viability of the system. (The model, which is made for the economical evaluation is adapted from a Chinese model called RREAD (Rural, renewable energy analysis and design) (2).
Before using the model a questionnaire was developed and was used to survey a village of 30 houses to investigate the lighting system used in rural areas, the people's current situation and their actual needs. Questions cover houses both with and without electricity (gen-sets or PV for lighting).

3.1 The Economic Analysis Model

Since the comparison will be between the solar, mini-grid and gen-set systems, the comparison time will be the lifetime of the photovoltaic modules, which is the longer lifetime; about 30 years. For individual components lifetimes quoted by the manufacturer are used. The assumed scrap value is zero. We assumed that there is no loss through the wiring systems. More detail can be found in (13).

3.2 Electricity Loads for Each System

For the PV, three different systems have been assumed to symbolize three levels of loads (high, medium and low loads). The gen-sets are assumed to be working at maximum capacity for a number of hours, see table 2, 2 loads (313kW, 175kW) are assumed for the mini-grid system.

3.3 Load Analysis

Three assumed load levels of PV stand-alone system are made, see Table 1. Assumptions made are based on questionnaire answers. The number of lamps is the average number for houses with generators.

TABLE 1: THREE LOAD LEVELS FOR THE PV SYSTEM

Sys level	Equipment	Oper-ation time (hours)	Daily typ. load (W)	Sys total loads kWh / day	Sys total load kWh / year
Low (A)	3 DC lamps (20W)	3	60	0.18	65.7
Med (B)	2 DC lamps (20W), 1 TV (60W)	3	100	0.3	109.5
High (C)	1 refrigerator (160W), 1 fan (40W), 5 DC lamps (20W), 1 Air conditioner (1040W)	5	1340	6.7	2445.5

TABLE 2: LOADS FOR GEN-SET

Generator type	Operation time (hours)	Total daily load (kWh)	Total yearly load (kWh)
0.5 Kw	3	1.5	547.5
2.4 kW	5	12	4380

3.4 System Configuration

Sizing the three different PV systems was carried out using BP Solar PV system sizing tools (7). The efficiency of balance of system (BOS) components in this study was assumed to be 0.90. Daily cleaning is assumed. The I-V curve of the BP SX50 (50W) module was used to calculate the final PV output (kWh/m2) (8). Information for the mini-grid system was taken from a feasibility study made by The Sudanese National Electricity Corporation, (NEC) (9) for installing one in Wad-Ashana village.

3.5 Economic data

All the monetary values in the economic section are quoted in US dollars. In this study: 1$ (US Dollar)= 260 SD (Sudanese Dinars). Most of the data about solar lighting systems has been collected verbally within Sudan, including the custom duty office. Some cost data has been taken from the Energy Research Institute, which manufactures and sells modules for rural areas (10).
Data about electricity in Kurdufan(Al Obied) has been collected from the NEC and data about gasoline and diesel generators are collected from the local market.
The market price for gasoline and diesel in northern Kurdufan is approximately (1.35$/gallon), the cost in villages is about (1.44$/gallon), and usually generators use 1 gallon to produce 10kWh electricity (10). The diesel price is subsidised by the Sudanese government.
A discount rate of 10% with no fuel saving is assumed, future work would include sensitivity testing of this value. The cost per kWh of each system is calculated using net present cost (NPC) and also levelized cost (LEC) and compared. The cost per kWh for each system is calculated firstly under the current situation; PV and gen-set costs include customs and taxes and the mini-grid has fuel subsidization. In the second case there is an assumed situation where there is no custom and taxes.

3.6 Solar availability

Hourly solar irradiation data for the north of Kurdufan (Al-Obied) where Al-Kababish spend the dry season and (Dongola) where they spend the rainy season was taken from MeteoNorm v4.0 (11). Analysis of the maximum yearly irradiation achievable for both stations can be achieved with clearly south facing and tilt angle of about 20°. In Al-Obied it is approximately 3137 kWh/m2 and in Dongola it is about 3252 kWh/m2
A dynamic building simulation program TAS (12) was used to determine average module temperature for the different months for both stations. The temperature of the cell is assumed to be the average of the top and bottom surface temperatures. Modules are assumed to be supported on the roof and totally exposed from the upper side to the sun and are well ventilated from the lower side.

4. QUESTIONNAIRE RESULTS

Almost all homes (97%) are occupied by extended families, sharing facilities. Most children (7 to18 yrs) attend schools, unlike the previous generation. More education leads to more sophisticated needs, which in turn often need electricity; this means the electricity demand is likely to increase.
More than half of the sample use electricity for lighting, the others use oil lamps. The main source for electricity is gen-set, however 2 houses use PV.
Electricity supply is a local trade, generator owners; about 6% of the whole sample, sell electricity to other people in the area. The owner runs the generator for 4 hours daily forces clients to use low energy lamps (20W) for 3.46 $/month (1.44$/kWh). All who do not have electricity said that they need it for lighting only. But it seems that they do not know exactly what they need it for. People who use PV system rate its reliability higher than gen-sets. PV system users create an extra demand to use the extra kWh generated by the system on sunny days. A PV user said that she started to like the sunny days as she enjoys watching TV for more hours.
People’s awareness towards PV technology is very good especially women who gain the maximum benefit from the system. They clean it daily and keep the loads at the accurate amount to avoid using all the electricity stored in the battery. Knowledge of PV spreads effectively through word of mouth.
From the questionnaire, it can be noticed that funds are very limited. People, who succeed in installing a PV system, use cheap car batteries that must be changed every 6 months to store electricity.

5. ECONOMIC RESULTS

Economic results for the two sets of calculations with and without subsidies and taxes are given in tables 3 and 4.

TABLE 3: SYSTEM COSTS AT CURRENT CONDITION OF SUBSIDIES AND TAXES.

System	Generated electricity	Initial cost	Annual running cost	NPC	LEC
	kWh / year	$	$	$	$ / kWh
PV (A)	129	865	29	1141	1.63
PV (B)	257	1250	29	1526	1.09
PV (C)	5661	22692	721	29490	0.96
Gen-set (0.5 kW)	548	446	192	2260	0.76
Gen-set (2.4 kW)	4380	1396	989	10717	0.45
Mini-grid (Max)	1370940	208797	115631	1298966	0.17
Mini-grid (50%)	766500	208797	115631	1298966	0.31

TABLE 4: SYSTEM COSTS WITH NO SUBSIDIES OR TAXES.

System	Generated electricity	Initial cost	Annual running cost	NPC	LEC
	kWh / year	$	$	$	$ / kWh
PV (A)	129	540	21	733	1.05
PV (B)	257	775	21	968	0.69
PV (C)	5661	14250	505	19009	0.62
Gen-set (0.5 kW)	548	338	178	2012	0.67
Gen-set (2.4 kW)	4380	1058	937	9895	0.41
Mini-grid (Max)	1370940	208797	194266	2040338	0.27
Mini-grid (50%)	766500	208797	159450	1712095	0.41

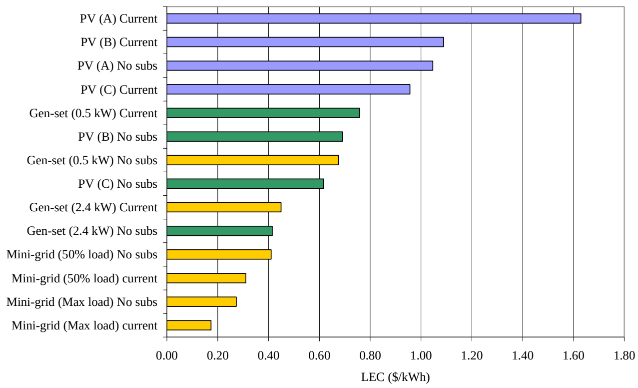

Fig. 1: Levelised economic cost for each system with and without subsidies.

6. ENVIRONMENTAL ANALYSIS RESULTS

In the economic assessment, PV was found the most expensive way to generate electricity, but in terms of carbon dioxide emissions, it is more favourable as it emits no CO_2 during electricity production. Values for the gen-sets are about 0.91kg CO_2/kWh and for the mini-grid are about 0.53kgCO_2/kWh, for a large MW capacity power station in Sudan the emissions are about 0.28 kg CO_2/kWh (13).

7. CONCLUSIONS

Under the assumptions in this study, we can find the following:

7.1 Economic assessment

Across Sudan the electricity tariff is the same (about 9.4 cent/kWh), the cost of electricity from different power stations found a range of (9.86 to 14.7cent/kWh) (14). Sudan is a low-income country where the annual GNP/capita is below 650$. Installing stand-alone systems, with a high initial cost without having soft loans from banks or subsidization from the government, could be impossible. This means the best economic choice for users is to pay the subsidised tariff for a mini-grid system. PV technology under current conditions is the least adequate electricity supplier. To let it compete with the other sources of electricity, customs and duty should be removed and soft loans given to the users.

Taking a wider view this is not the case, although PV is more expensive than the gen-set, it could be the best solution for nomadic tribes and isolated rural areas because, fuel can be unavailable for part of the year, or more expensive in the rainy season, regular maintenance for generators can be difficult because of a lack of spare parts and technicians.

Economies of scale present for the mini-grid system are not considered for the stand-alone PV. The government fuel subsidy makes other types of electricity suppliers uncompetitive and very expensive for villagers. Most small villages just need lights for the primary school, the club, the mosque, the church and the clinic. This low demand increases the popularity of using stand-alone PV systems, as they do not need fuel and regular maintenance.

The comparison between the three systems is complicated by their different capacities. This reflects the way they are or, are likely to be used in the particular case study. Large PV power stations would be more cost effective than those considered here, and smaller gen-sets would be less cost effective.

PV users must accept that load and activity demand depends on electricity availability, for example using sewing machines, fans, wash machines…etc on days having better solar irradiation.

The experience with conventional systems should be taken into account, as it will lead to easier maintenance than for PV, which is a new technology with a lack of experienced technicians and spare parts. Failures could be a large problem with the PV system However, the systems need very little maintenance and parts are expected to have a long life.

A very attractive solution may fail as a result of a vague operation and maintenance strategy. For example, a PV system installed in 1987 by the Red Crescent for a kindergarten and medical center in Khartoum was providing energy for lighting and water pump until 2002. Some children from the kindergarten broke some cells and the system stopped. Although the system was working for 15 years for free with very reliable electricity, the community leader thinks that the high initial cost of the modules which includes customs and taxes is not justified. He built his view without a long-term study. Now the center is running with stand-alone gen-set which uses a large amount of fuel. Doctors and workers in the centre are very unhappy with the new source of electricity, as it is very noisy for a medical center and provides a poor quality of electricity. Current concerns about the price of oil will only serve to make PV a more attractive option economically.

7.2 Social and Environmental assessment

Installing PV is the best environmental solution but Sudan is not committed to any GHG reduction target. However, as a less developed country, it can benefit from the clean development mechanism (CDM), which is one of the three mechanisms that can be used to reduce emissions. Industrialized countries can sponsor efforts to reduce emissions by, financing eligible projects to receive GHG reduction credits in return. This mechanism could increase the popularity of using PV systems in developing countries.

Use of the PV system forces people to choose high efficiency lamps (compact fluorescent) subsidized electricity leads to use of cheaper tungsten lamps, creating more emissions.

Making a good rural electrification plan could reduce the problem of deforestation since lighting is the second largest firewood consumer and might be the first one in spaces where people usually gather at night for long time like Al-khalwa (religion school). Villagers from Darfor province who are very happy with installing a new solar lighting system in Al-Khalwa said that ten years ago they could collect the wood to light and cook from a small forest near their village but now they must buy the wood which is coming by lorries from other areas as all trees had been cut.

Ignoring cultural aspects leads to failure of projects. For example, it has been proven in Sudan that to keep equipment in good condition you must let the user pay part of the cost or it will be destroyed after a small period because in Sudanese culture there is no respect towards the public resources. A stand alone system that belongs to a household could work better and survive longer than a central system.

Also we must consider the future impact of projects, these can include the following:

Less sharing and changing family structures may be a result of plentiful new resources. The type and population of the village could change as the availability of cheap electricity might encourage migration to the area. It could also increase tension in nearby villages.

All electrification systems could provide significant benefits, especially for women and children, as they mainly will be used for lighting for studying and housework purposes. The lighting system could lead to creation of micro-enterprises that improve livelihood and income. Lighting also can be important for allowing women to work in the evening more productively in home industry (15).

It has been noticed that the use of photovoltaics improves the health in the village. Villagers, who experienced problems with their lungs and eyes from breathing the smoke from the firewood and bad lighting quality, find the quality of lighting from the new solar system more comfortable and easy to use.

The questionnaire indicates women indeed have an important role to play in sustainable energy development. They take care of the modules and that makes them responsible for the lighting in the house, and improves their self-confidence.

Rural electrification encourages people to contact each other. This contact is very important in Sudan that consists of so many tribes. It has been found that the PV technology increases this contact more than the other two systems.

The cost of one mini-grid system could be the cost of installing hundreds of small stand-alone systems in public buildings in many villages. This might lead to better health, education and social services in many villages, with lower quality services to many villages instead of high quality services to one village. This could decrease the amount of migrants, as people searching for higher education and medication levels will not need to travel to the cities; the migration to the capital is a major social problem in the country.

The Kababish people are unlikely to change their lifestyle and stay in one or two places to benefit from a power station. PV could be the best solution for them as it is portable, provides a constant amount of electricity all around the year and is silent; avoiding noise is very important in a nomadic life. However as a result of needs discovered by using electricity and their contact through TV and radio with other cultures, they might tend to settle or become semi-nomadic tribes.

7.3 Strategies and policies

In a country like Sudan where there are no sustainability policies, big projects could be a great risk. A stand-alone system does not need a lot of supervision and maintenance and could be more acceptable than a central system which belongs to the government and needs continuous supervision, and maintenance.

Usually customs and taxes in Sudan are estimated (not fixed). Renewable energy is considered such a new technology that most policy makers do not know about it. For this reason, they still consider it as a product that has high duties, about 60% of the price of the product. For gen-set the total duty is 32% including customs 22% and taxes 10%. Traders do not feel safe to import PV, as sometimes the estimated taxes are 100% of the import price. Electrification by the thermal power station is beyond the remit of custom and tax as it is considered a public project.

Sudanese policy towards rural electrification is encouraging the use of central power stations as fuel is subsidized. If the government makes the cost per kWh from the power generator more transparent and removes the fuel subsidy, the cost of the PV technology is more competitive with distributed generators, but Sudan now has oil and is local. Solar electricity depends totally on expensive imported products from industrialized countries.

Adapting a strategy to use PV modules could lead to economic benefits, modules could be manufactured on a large scale reducing prices and creating jobs, reduces foreign currency requirements, reduces supply lines and builds up local knowledge of the technology, which in turn improves operation, maintenance and troubleshooting.

Developing countries should encourage local participation to ensure the requirements of communities are met and ensure local adaptation of technology to protect the environment and resource base. Industrialised countries should provide overseas development financial and technical assistance in a responsible and sustainable manner.

Choosing a technology for electricity generation should be evaluated economically, environmentally and socially, ignoring one of these elements leads to one or more of the following problems; failure of the project, failure of electrification programmes in nearby villages, and social and economical problems at the national level. Also, developers must have a future view for the village. If they are looking for rapid improvement in living standard and want the village to be a service centre the mini-grid system could be the best solution. But, if they want to develop the local community without changing the living pattern, stand-alone system might be better.

A larger study of environmental and social benefits should be carried out to evaluate the development that can be achieved at the national level by the removal of taxes from renewable resources.

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