An Overview on Renewable Energy Technologies for Developing Countries: the case of Guinea Bissau

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Abstract.

This paper addresses the need for electricity of remote rural communities in developing countries and the possibility to use renewable energy to supply electricity to non-electrified villages in isolated rural regions. An overview of the main available renewable energy technologies is given and the case of Guinea Bissau is studied. Using a software tool developed in previous works the practical case of a photovoltaic water pumping system to supply water to non-electrified villages in isolated rural regions of Guinea Bissau is analyzed. Details, simulations and estimated costs are given.

Key words: Photovoltaic energy, renewable energy, rural electrification, remote communities, PV pumping systems.

1. Introduction

The role of energy is crucial for the development and the economic growth of any country. An estimated two billion people in the world lack access to modern energy carriers and the access to energy varies widely among the countries. Energy use in developing countries is closely linked to a range of social issues: poverty alleviation, health, education, population growth, employment, communication, urbanisation. Finding ways to expand energy services, while addressing the environmental impacts associated with energy use, represents a critical challenge for humanity. In recent years there has been a significant development of alternative energy technologies, both in terms of performance and cost reduction. Moreover, many developing countries - like Guinea Bissau - are particularly well positioned when it comes to development a new generation of energy technologies. Despite the fact that Guinea Bissau has a high hydroelectric potential, the energy situation in the country is characterised by weak consumption of commercial energy, very low access to electricity and no use of renewable energy sources. One of the Guinea Bissau's major challenges as with other developing countries, is increasing the energy supply. Energy needs to become more accessible to large sectors of the population, including the poor, vulnerable people and those living in rural areas, and to contribute more to the social and economic development of the country. Renewable energy such as solar, hydro-electric, biomass and wind can give an important contribution to reduce the problems caused by the consumption of fossil fuels, which include the strategic dependence on petrol producers, high fossil fuel prices, pollution and greenhouse gas emissions [1]. Renewable energy sources could meet the demands of the dispersed rural population which have low energy needs and few resources whilst protecting the natural environment and promoting sustainable development. Guinea Bissau has a significant and varied potential in renewable energy based on 3,000 hours of sun per year, wind speeds of around four metres per second in many areas and on the coast, the Cacheu river, significant vegetal reserves and agricultural products and by-products. However, it is difficult to coordinate the necessary activities in Guinea Bissau to develop renewable energy sources fully. The initial investment needed is often prohibitively high with insufficient financing in place. Local populations and the private sector are not enough involved in the implementation of projects with a lack of awareness of the possibilities for progress. Typically the infrastructure is inadequate to generate sustained supplies to meet local needs. Developing countries such as Guinea Bissau, which are not petrol producers, need to promote the use of renewable energy to ensure access for their population to modern, reliable energy supplies. This form of energy can play a key role in reducing poverty and promoting sustainable development. This paper addresses the need for electricity of remote rural communities in developing countries and analyze a photovoltaic system to supply water to non-electrified villages in isolated rural regions (figure 1). Details, simulations and estimated cost are given.

2. Overview of available renewables energy technologies

The major purpose for small generation plants is to provide small amounts of electric power in isolated areas, where the connection to the electrical grid is hard or impossible due to the location. There is a multiple choice of generation plant, each one having its own advantages and drawbacks, which depend mainly on the specific characteristics of the location. Hence, a list of such advantages and drawbacks is hard to make, and giving the best advice among all possibilities even harder. The main features of selection are the starting and long-term cost, reliability, ecological and environmental legislation and the accessibility to the resources as water, wind, gas, etc. Renewable energies can represent an initial answer to energy poverty and a feasible model for sustainable energy strategies, helping to reduce CO_2 emissions and slowing down the negative global temperature trend. Furthermore, they are not just a must, but also a business opportunity. Different available technologies are briefly described in the following subparagraphs.

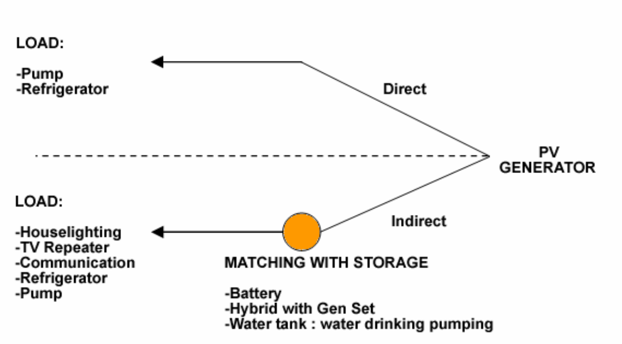


Fig. 1. - Photovoltaic system for rural applications

2.1 Diesel Engine Generators Sets

Diesel generators can be used in many remote settlements, either for a single user or as part of a local distribution network. Such systems may be operated by a power utility or, more commonly, by private enterprises. Rural hospitals, government offices, and police stations in remote areas typically have their own diesel generators. Diesel sets with capacities of 50–500 kilowatts of electricity are widely used in rural areas and have only recently been disseminated in Africa. The electricity produced by diesel sets typically costs $0.30 a kilowatt-hour—two to three times the cost of electricity from grids in urban areas but still cost-effective relatively to grid extension. The high costs of maintenance and of transporting diesel fuel and lubricating oil to remote places make electricity expensive. Despite these costs, electricity is typically highly valued by local populations because of the enormous improvements in living standards that it brings. But while high-cost electricity may be acceptable for satisfying basic needs in households and for some agricultural and cottage industry applications, lower costs are needed to attract a greater job-generating industrial base to rural areas.

2.2 Small Scale Hydropowers

Small-scale hydropower is a locally available source that in some regions can be exploited to deliver electricity or mechanical power (for pumping water and other applications) to rural areas. Small-scale hydropower technology is often divided into three categories: micro hydro (less than 100 kilowatts), mini hydro (100–1,000 kilowatts), and small hydro (1–30 megawatts). However, the potential market for such systems is limited by the availability of water resources. Hydropower plants of 50 kilowatts and more can be used to electrify communities or small regions by establishing mini grids. Costs are highly variable, depending on the site topography, proximity of the site to the main load area, and hydrological conditions. Small-scale hydropower has one drawback: it is almost always obtained from run-of-river plants that lack the reservoir capacity to store water. Consequently, severe seasonal variations in power output may occur, depending on the site hydrology. Thus the long-term viability of small-scale hydropower may depend on backup electricity that is supplied either locally or through the grid.

2.3 Photovoltaics

Photovoltaic technology is cost-effective in providing electricity to rural areas at the smallest scale in areas with no access to grid electricity and where electricity demand is characterised by such low levels and infrequency that even diesel electricity cannot compete. The potential for photovoltaic technology to support rural development arises from the fact that it can be used for household lighting, radios, and television sets, and to refrigerate medicines at rural clinics. One important obstacle to wider rural deployment of photovoltaic technology is the limited financing available for such small systems. Although the current market is strong, there is still a tremendous need to standardise equipment, as well as improve batteries, lighting fixtures, and electronic ballasts used in integrated household photovoltaic systems. In considering measures to support photovoltaic programmes for rural areas, it is important to pay particular attention to the poorest households and to strategies to make the technology available to them. Although significant in improving the quality of life in rural areas, without major cost reductions, photovoltaic technology will be limited mainly to remote household and other small-scale applications and will not be able to compete in the provision of electricity for manufacturing or even most cottage industrial applications. A particular application of photovoltaic technology is the solar water pumping which has several advantages over traditional systems; for example, diesel or propane engines require not only expensive fuels, they also create noise and air pollution in many remote areas. Solar systems are environment friendly, require low maintenance, and have no fuel cost. A solar pump scheme for village water supply is shown in Figure 2.

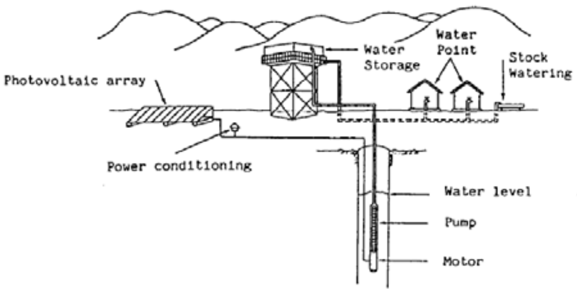


Fig. 2. - Village water supply

With village water supply, a constant water demand throughout the year occurs, although there is a need to store water for periods of low insolation (low solar radiation). In environments where rainy seasons occur, rainwater harvesting can offset the reduced output of the solar pump during this period.

2.4 Wind

There are two promising ways to exploit wind power to meet rural energy needs. The first is household units that provide electricity at scales where neither grid power nor minigrid power from diesel units is cost-effective. The second is village-scale wind-battery-diesel hybrid systems (using wind turbines with capacities typically of 5–100 kilowatts). Household-scale wind turbines (of about 100 watts) offer benefits to wind-rich regions similar to those offered by domestic photovoltaic systems. Where rural households are clustered in villages far from electric grids served by diesel-engine generator sets, an alternative option is to deploy wind turbines in wind-diesel or wind-battery-diesel hybrid configurations, which have been installed in many parts of the world. In regions where diesel fuel is costly, these hybrid systems can lead to lower electricity costs and less air pollution than conventional diesel-engine generator sets.

2.5 Small Scale Biopowers

Biomass-derived producer gas can be used to make electricity at scales comparable to those associated with diesel-engine generator sets. The potential benefits are:

-The capacity to use locally available biomass as fuel instead of oil imported into the region.
-Lower electricity generation costs than with diesel.
-Increased rural income generation, and possibly rural industrialisation, as a result of the lower electricity cost.

The reciprocating compression-ignition (diesel) engine is the main commercially viable engine available for these applications. Biomass-derived technology for reciprocating engine generators running on producer gas is commercially ready. The technology can be cost-effective, either where diesel fuel costs are very high (for example, $0.35–0.40 a litre or more, as is often the case for extremely remote regions) or, with efficient capital utilisation, in regions where diesel fuel prices are more moderate. If the diesel fuel price is $0.25 a litre, a typical system must be operated at full capacity for 3,000 hours a year to break even with a conventional diesel system. About 6,000 hours of annual operation are needed to realise cost savings of 25 percent. Unfortunately, achieving high rates of capital utilisation is often difficult because local electricity demand is typically low and sporadic but peaky, with very little electric load diversity. One promising new technology is the microturbine, which might be deployed with essentially the same gasifiers that have been developed to provide producer gas for use with diesel dual-fuel engine generator sets. Microturbines are gas turbines designed for operation at scales of 50–250 kilowatts of electricity, with electric efficiencies (lower heating value) of 25–30 percent for larger units. The technology appears to be readily adaptable for use with biomass-derived producer gas. Microturbines are less complex (some variants have only one moving part) than reciprocating engines. They can be fuelled with producer gas without de-rating and without the loss of efficiency relevant to operation with natural gas or diesel fuel. Moreover, they do not need costly pilot oil. In regions where crop residues or other low-cost biomass feedstocks are readily available, there are reasonably good prospects that the technology could become widely competitive.

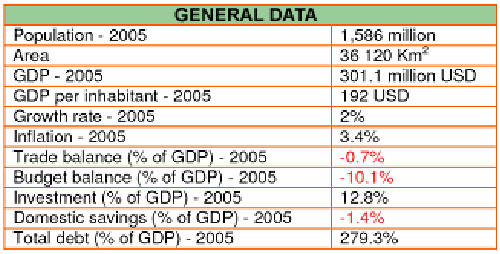
3. Some facts about Guinea Bissau

According to the UNDP (United Nations Development Program), Guinea Bissau (Figure 3) is classified 172nd out of 177 countries featured in the Human Development Index and is one of the poorest countries in the world with under-utilised resources (fishing, mining, agriculture and tourism).

Fig. 3. - Guinea Bissau

The economy is highly dominated by the agricultural sector in which cashew nut represents over 85% of export earnings. However, food self-sufficiency is not reached. Moreover, the insufficiency of transport infrastructure limits the development of new sectors such as bauxite and phosphate mining substantially. Nevertheless, after several years of conflicts, Guinea Bissau has entered a new era since 2005 and the political stabilisation of the country and the return of the international donors in the economical development of the country could open up new perspectives. Table I shows some general data about the country.

TABLE I. - General data about Guinea Bissau



GENERAL DATA	
Population - 2005	1,586 million
Area	36 120 Km^2
GDP - 2005	301.1 million USD
GDP per inhabitant - 2005	192 USD
Growth rate - 2005	2%
Inflation - 2005	3.4%
Trade balance (% of GDP) - 2005	-0.7%
Budget balance (% of GDP) - 2005	-10.1%
Investment (% of GDP) - 2005	12.8%
Domestic savings (% of GDP) - 2005	-1.4%
Total debt (% of GDP) - 2005	279.3%

3.1 The energy profile of Guinea Bissau

Electricity production capacity is low and is only of thermal source. There are strong regional differences in electricity supply and the poor performance and ageing of the electricity infrastructure are resulting in high electricity costs and frequent power cuts with knock-on effects on businesses and economic and social development. Electrification covers only 12% of the country and with electric service costs five times higher than in Senegal. The numerous shortages caused by the Public Company of Water and Electricity (EAGB) have thrusted companies to install electric generators. Moreover only 13% of the Bissau's population has access to water, the supply of which is frequently subject to interruptions by the EAGB due to the poor condition of infrastructures. Surface waters and underground waters represent the main hydraulic potential of the country, while the contamination risks are regular. Guinea Bissau is endowed with several renewable energy resources; in particular it receives good amounts of solar energy.

4. Rural applications: simulation of solar water pumping system

4.1 Generality

The use of photovoltaic (PV) systems can provide the electricity for basic needs in households in remote localities [2]. This can significantly increase the quality of life for people in under-developed rural regions deprived of privileges that developed communities take for granted. In rural villages of Guinea Bissau, power demand is small, people are mostly very poor and they need electricity for just the very basic needs. They work as farmers: so they use electricity for just a few hours at night since they spend all day working on the land. Water pumping systems and electrification of remote villages are two of the most important needs in the rural electrification sector. Often both needs arise at the same time and in the same place: the installation of a PhotoVoltaic Pumping system (PVP) and a Solar Home System (SHS) might be a concept for the satisfaction of those needs. The installation of a Hybrid system composed of PV Modules, Inverters, Batteries and Genset could be another reliable solution. A software tool to evaluate Stand Alone Systems has been developed in our department [3]. The tool includes ready-to-use component models with the potential for user-defined modifications and for the construction of a customer-adapted model. With the developed tool is possible to couple detailed technical models to economic models that account for both investment and operational component costs simplyfing the task of evaluating design options for stand-alone applications. The library includes component subroutines for different power producing equipments, such as photovoltaic generators, batteries, generator sets and others (see figure 4).

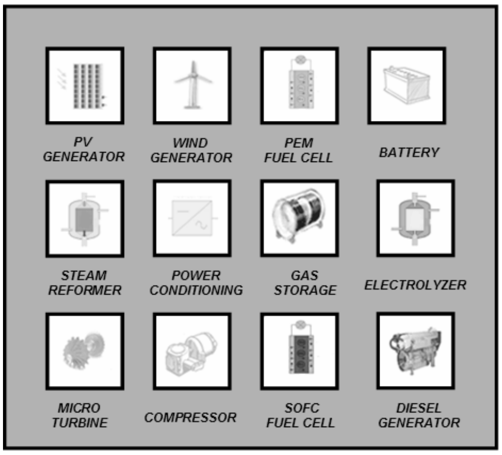


Fig. 4. - Library overview

4.1 Technical factors

The possibility of installing a PVP to meet the drinking water and livestock watering needs of a remote typical rural community in Guinea Bissau has been evaluated using the realized software tool. The characterstics of the rural community under study are shown in Tables II and III.

TABLE II. - Data about the location

Nearest location for weather data	Bissau
Latitude of the location	11.9 °N
Annual solar radiation (tilted surface)	2.05 MWh/m²
Annual average temperature	27.7°C
Water demand for 12 months analysed	10422.6 m³
Wind regime	poor
Equivalent pumping energy demand	669 kWh

TABLE III. - Water use per unit

Water pumping application	**Unit**	**N° of units**	**Water use per unit**		**Daily water required (m^3/d)**
Domestic	Person	500.0	L/d/person	45.0	22.50
Livestock	Head	160.0	L/d/head	40.0	6.40
Total water	m3/day				28.90
Energy demand		Daily	1.85 kWh	Annual	676.65 kWh

The village has a population of about 500 people and 160 livestock and the water source is a well with water at a depth of 20 mt. The PVP do not require energy storage in batteries since water can be easily stored in tanks from wich it can be distributed by gravity feed whenever it is needed. The water needs to be pumped to an elevated tank at a height of 2.8 m. The output of a solar pumping system is very dependent on good system design derived from accurate site and demand data [4-6]. It is therefore essential that accurate assumptions are made regarding water demand/pattern of use and water availability including well yield and expected drawdown. Domestic water use per capita tends to vary greatly depending on availability. The long-term aim is to provide people with water in sufficient quantities to meet all requirements for drinking, washing and sanitation. Present short-term goals aim for a per capita provision of 40-45 litres per day, thus a village of 500 people has a requirement of 20 cubic metres per day [7]. Most villages have a need for combined domestic and livestock watering. The considered PV water pumping system consists of a 1.89 kWp PV array on a fixed structure, a submersible pump and a cylindrical water storage tank (see Table 4). The array is made of 27 monocrystalline modules, each rated at 70 Wp. The water is pumped from the well into the storage tank, from where it is distributed to the village and to livestock watering stations as in the drawing in Fig. 2. The extension of the electric grid to the village was considered cost-prohibitive (as said, electrification in Guinea Bissau covers only 12% of the country with very high electric service costs) and the use of wind energy for water pumping was ruled out because of the poor wind regime at the location. Several water source parameters need to be taken into account and measured where possible. These are the depth of the water source below ground level, the height of the storage tank or water outlet point above ground level and seasonal variations in water level.

TABLE IV. - Water pumping and PV sistem data

Water pumping		
Motor type	-	DC
Pump system efficiency	%	20%
PV system		
PV module type	-	mono-Si
Nominal PV module efficiency	%	11.1%
NOCT	°C	45
PV temperature coefficient	% / °C	0.40%
PV array controller	-	MPPT
Nominal PV array power	kWp	1.89
PV array area	m^2	17.0
Slope of PV array	°	15
Azimuth of PV array	°	0

The pattern of water use should also be considered in relation to system design and storage requirements. Water supply systems should include sufficient covered water storage to provide for daily water requirements and short periods of cloudy weather. Generally, two to five days water demand is stored. Table V shows the annual energy production of the system and Fig. 5 illustrates the horizzontal irradiation and the irradiation at 15 deg through the year. Fig. 6 shows the optimal panel inclination angle.

TABLE V. - Annual energy production

Annual energy production (12 months)	Unit	Estimate
Water delivered	m^3	10.362
Specific yield	kWh/m^2	39,0
Overall PV system efficiency	%	1,9%
PV system capacity factor	%	4,0%
Renewable energy delivered	kWh	**665**

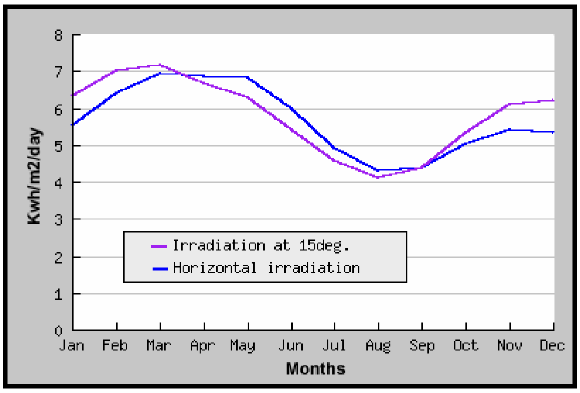


Fig. 5. - Annual irradiation

4.3 Economic aspects

In Table VI the estimated costs of the systems are provided. A range of prices is to be expected, since the total system comprises the cost of modules, pump, motor, pipework, wiring, control system, array support structure and packaging. Systems with larger array sizes generally have a lower cost/Wp. The cost of the motor pumpset varies according to application and duties; a low lift suction pump may cost less than $800 whereas a submersible borehole pumpset costs $1500 or more.

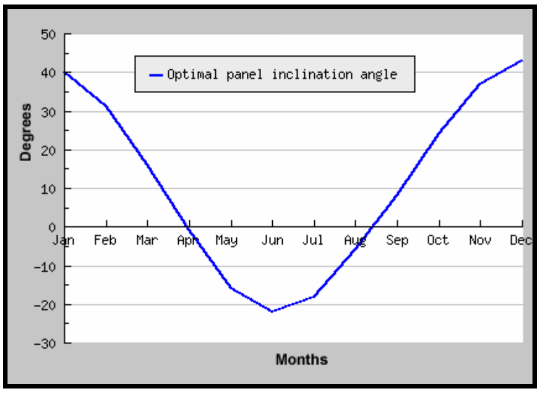


Fig. 6. - Optimal panel inclination angle

TABLE VI. - Estimated capital costs of the system

Description	Unit	Quantity	Unit Cost ($)	Amount ($)
Energy Equipment				
PV module(s)	kWp	1.89	4000	7560
Balance of Equipment				
Module support structure	m^2	17.0	50	850
Water pump	project	1	700	700
Pipes/reservoir	project	1	300	300
Other electrical equipment	kWp	1.89	200	478
System installation	kWp	1.89	100	189
Transportation	project	1	500	500
Total				**10.577**

It can be useful to compare different possible water pumping methods in ordere to understand wich is more suitable for remote applications. Table VII shows the estimated costs and life span for different energy sources (PV, diesel generator, and AC with a new distribution line) used for remote water pumping [8].

TABLE VII. - Comparison of energy options for remote water pumping.

Energy source	***Estimated capital cost***	***Operation cost***	***Maintenance***	***Life span (year)***
PV Systems	6.8 $/Wp	None	Low	10-15
Gen Set	2.5$/W	0.6$/kWh	High	5-10
Electric utility	22$/W	0.05-0.13 $/kWh	Low	N/A

The capital cost of the PV system includes solar panels, pump, controller/inverter, power cables, draw down pipe and accessories. The capital cost of electric utility includes transmission line instead of solar panels and other system components are the same. The capital cost of a diesel generator includes an electric generator instead of solar panels and other system components remain the same. The PV system does not have any operating cost, but electric utility costs 0.05–0.13 €/kWh and diesel costs $0.6/kWh with high maintenance cost. The efficiency of a diesel generator goes down with time, whereas the PV system produces same power throughout its life span. The cost for the diesel generator includes capital cost, fuel for the generator, and fuel for the vehicle used. The AC with distribution line includes capital cost for the pump and/or controller, capital cost for the line ($13,000/km), fuel to visit the system on site twice a week and the electricity cost. The PV system cost includes the capital cost of the system and fuel cost to check on the system once a week. Figure 7 compares the three water pumping methods - solar PV, diesel generator, and AC - with a new distribution line considering each system pumping the same amount of water.

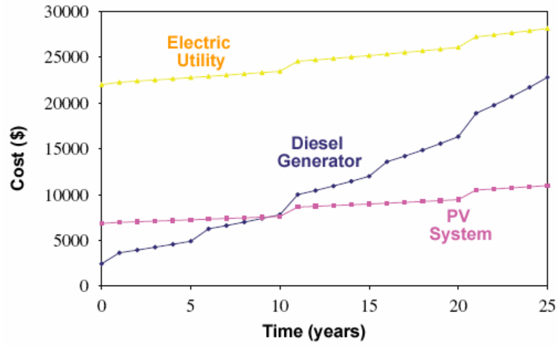


Fig. 7. - Cost comparison among a new utility line, solar pumping system, and diesel generator

Figure 7 is calculated under the following assumptions:

- System capacity: 1000 W.
- Capital costs: PV system 6850$, diesel generator water pumping 2450$, and electric utility with 1.61km new line extension 22000$.
- Transportation costs: PV system 78$/season, diesel generator 500$/season, and utility 150$/season with 10% increase in fuel price every year.
- Fuel cost for diesel generator: 500$ per season.
- Maintenance cost: PV 50$/season, diesel generator 200$/season, and electricity cost for utility is 110$/season.

The sharp rise in the plot indicates the replacement of generator, pump and/or controller. It is evident from the figure that the PV system is the most cost effective for remote water pumping, even though it has higher capital cost than the diesel generator. Electric utility has the highest capital cost, also it has higher operation and maintenance (O&M) cost than the PV.

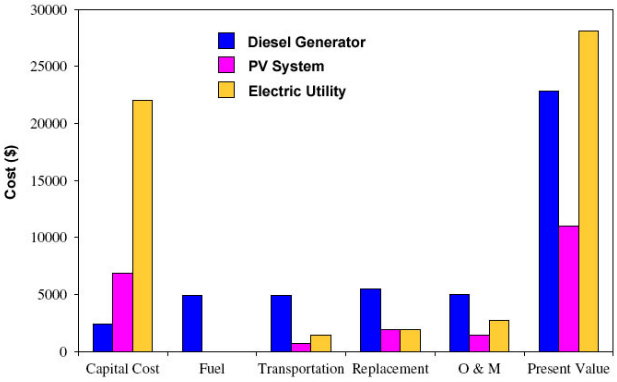


Fig. 8. - Difference in 25 year cost compared to solar PV

The replacement is scheduled after 10 years; for the PV system the replacement is the pump and/ or controller, for the diesel generator, the only option is to buy new generator and the pump, and for the utility connection it is the pump and/or controller, if one is used.

Fig. 8 shows the total life cycle cost comparison over a 25 years period among PV, diesel generator, and utility under the same assumptions above. It can be seen from the figure that the PV system has the lowest life cycle cost, which makes it more suitable for remote applications.

5. Conclusions

The use of renewable energy technologies in developing countries like Guinea Bissau has a huge potential in terms of volume applications with concomitant reduction in costs, providing in clean/reliable power, reduction of greenhouse gases especially carbon dioxide, creation of employment opportunities, community development and bringing about a better quality of life to the small farmer community. One of the main challenges is to make the renewable energy systems more user friendly, and adopt locally available materials for convenience of handling future maintenance problems in order to facilitate the local level O&M, using materials from local suppliers and educating people through workshops, trainings, and demonstrations. A solar water pumping system has been analyzed in this paper and compared with traditional energy sources; this kind of system can be suitable for a small scale remote application where 24 h electrical service is not necessary and presents several advantages over traditional systems.

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