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ROLE OF SOLAR ENERGY IN DEVELOPMENT IN BOTSWANA

PUSHPENDRA K. JAIN, NIKOLAI NIJEGORODOV and C. G. KARTHA
Department of Physics, University of Botswana, Private Bag 0022, Gaborone, Botswana

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Abstract—The Republic of Botswana in Southern Africa has one of the fastest growing economies in Africa. However, its remotely isolated rural areas pose problems to rural energy management and development because of (i) poor road links with the urban centres, and (ii) remoteness from the national electrical transmission grid. Development of renewable energy sources, therefore, has a vast potential in Botswana. Solar energy, with excellent sunshine of over 3300 hrs per year, is of paramount importance, the applications of which are already quite significant and are growing at a steady rate. Use of solar energy is incorporated in the National Energy Master Plan, and it has contributed to almost all aspects of development in rural as well as urban areas. They include solar water heating for domestic and commercial uses, solar desalination to provide potable water, passive solar buildings, photovoltaic devices for lighting, water pumping, refrigeration, communication and fence electrification. This paper reviews various applications of solar energy and their contribution to development in Botswana and discusses future prospects of solar energy in Botswana.

1. INTRODUCTION

1.1 *Geography, population and energy sources*

The Republic of Botswana is a land-locked country in Southern Africa, lying between latitudes 17°S and 27°S and longitudes 20°E and 30°E. It shares its borders with Namibia in the west, Zimbabwe in the north and north–east, Republic of South Africa in the south and south–east, and a small stretch of border with Zambia in the north. Gaborone, located at 24.5°S and 26°E, in the south–east is the capital of the country (Fig. 1). The country covers an area of 581,730 square kilometres with an estimated population of 1.35 million. About 26% of the population lives in the urban areas and the rest is the rural population [1, 2]. The country has vast reserves of coal but it is an importer of petroleum products for which it has to depend on road routes through the neighbouring countries. There is no potential for hydro-electric power in the country and all the power generation is from coal.

1.2. *Problems of rural energy management and development*

Transport links with the rural areas are not well developed. In most cases transport to these areas is very expensive because of remoteness, vast distances involved, low population density and poor, undeveloped roads which are generally deep sand tracks requiring four-wheel drive vehicles. Likewise, the rural areas are also far from the electrical transmission grid. Thus the rural areas of Botswana can neither be supplied with electricity economically because of low demand and remoteness of the areas, nor can they be provided with coal and petroleum products regularly and at an affordable price because of the poor road links. The rural population, therefore, largely depends on woodfuel as their only source of energy which is

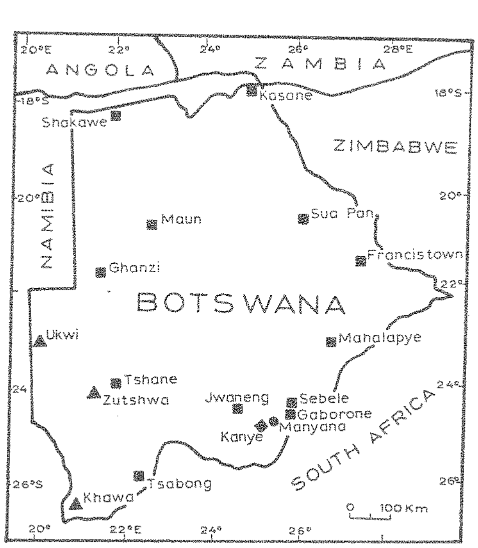

Fig. 1. Republic of Botswana and its neighbours. Places shown have facilities for R&D and have major application sites for solar energy.

scarce and has ecological consequences too. These factors on the one hand pose a severe problem to energy management for the rural areas and their development; on the other, Botswana has one of the fastest growing economies in Africa, the fruits of which can be shared with the poor rural masses only if they have a ready access to the commercial forms of energy for development. In view of these problems, the development of renewable energy sources has a vast potential in Botswana. Of these, solar energy is of particular interest and holds good promise for the future. This paper reviews various applications of solar energy and their contributions to development in Botswana. The next section deals with the potential of solar energy in Botswana. It is followed by sections on solar availability and various applications of solar energy. Applications and potential of other renewable energies are also discussed briefly. The article is concluded with the likely prospects of the use of solar energy for development in Botswana.

2. POTENTIAL FOR SOLAR ENERGY IN BOTSWANA

The factors which favour the development of solar energy in Botswana include: (i) excellent solar conditions. Botswana averages over 3300 hrs of sunshine per year. (ii) Relatively high cost of electricity and other fuels particularly for water heating. Hot water, although it is a basic necessity under Botswana climate, does not warrant recurrent large bills for a household. Use of solar energy is an economic alternative. (iii) The remote rural areas need a dependable source of energy with devices which need little or no skill for day-to-day maintenance, and for which no fuel has to be supplied.

Although at present the contribution of solar energy to the total energy demand in the country is not significant, its demand has shown a very fast rate of growth and has contributed to all round development with notable impact on the lives of people in the last ten years. In 1989 solar energy contributed only 18 TJ to the total of 35,390 TJ consumed in the country [3]. This, when compared to 1981 data whereby the use of solar energy accounted for only 2 TJ out of the total consumption of 26,492 TJ [3], one finds that over the period of 8 years the total energy consumption has increased by a factor of 1.34 but the contribution of solar energy has increased nine fold. This averages to an overall simple increase of 100% per annum in the use of solar energy over the 1981 figure. The contribution of solar energy in the years to come will still remain low but the rate of growth in its usage shall continue to be high. By the year 2010 it is estimated that solar energy will contribute 51 TJ to the total estimated consumption of 45,455 TJ [3]. This is a mere 0.11% of total energy in the year 2010, but it shows a significant rate of growth when compared to 0.05% in 1989. It is mainly the domestic water heating where solar energy has found most application but the role of photovoltaic (PV) devices in the rural development can also not be ignored. Solar water heaters in urban residential areas are a common sight on top of houses (Fig. 2), and they are being disseminated to the rural areas as well.

In spite of many advantages, the capital intensive nature of solar devices remains a major hurdle to the vast usage of solar energy. As a consequence, the solar energy devices in the rural areas, which are mostly PV devices, have been set up by government, semi-government and private organisations for specific applications. The solar water heaters in the residential sector are either privately owned by the tenants or they have been installed by the Housing Corporation as an integral part of the construction of housing units. The use of solar energy is also incorporated in the Botswana Energy Master Plan [3]. The Energy Unit within the Ministry of Mineral Resources and

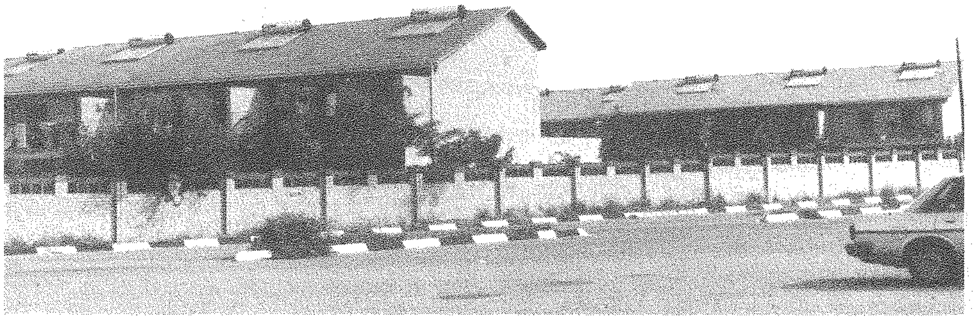

Fig. 2. A newly constructed housing complex in Gaborone with solar water heaters.

Water Affairs (MMRWA), which is responsible for all energy matters in the country, is actively engaged in assessing the potential of and paving the path for a larger use of solar and other renewable energies. The country has a fast expanding solar industry dealing in both thermal as well as PV devices. Most of these firms supply and install imported devices with the exception of a few which manufacture completely or partly or assemble these devices within the country. The applications of solar energy in Botswana include: solar water heating, desalination of water, passive solar building design and photovoltaic devices for rural telephones, lighting in rural schools, clinics and community centres, water pumping, refrigeration and signalling and communication by railways and police departments.

3. SOLAR RADIATION CHARACTERISTICS AND MEASUREMENT

With an average rainfall of less than 475 mm per annum which varies from over 650 mm per annum in the north to less than 250 mm per annum in the south–west, with mostly clear skies, and with almost no industrial pollution in the air, one gets abundant sunshine in the whole of Botswana throughout the year. At present extensive facilities for detailed mapping of solar radiation for Botswana are lacking. The daily duration of sunshine is measured at 23 geographically well-distributed locations. One of the locations, Sebele, 10 km north of Gaborone, is monitored by the Department of Agricultural Research. The remaining 22 are run by the Department of Meteorological Services (DMS). Among these, 10 are agrometeorological or climatological stations and 12 are synoptic stations. The agromet and climate stations have been in operation for four years or less. The synoptic stations include two at Gaborone, one in the town centre at the DMS headquarters and the other at the international airport 15 km north of town, and one each at Francistown, Ghanzi, Jwaneng, Kasane, Mahalapye, Maun, Shakawe, Suapan, Tsabong and Tshane (Fig. 1). The synoptic stations at Jwaneng and Suapan were commissioned in 1988 and 1991, respectively. The other 10 stations and Sebele have data for over 10 years. Solar irradiation is measured only at two locations in and near Gaborone. The station at Sebele measures daily global irradiation on a horizontal surface. The second station which started measurements in November 1988 is located at and monitored by the Botswana Technology Centre (BTC) in the town. The BTC station measures daily global irradiation on a horizontal surface and on a tilted surface at 30° to the north.

The data available from these stations are a fairly good representative of the characteristics and availability of solar radiation in the country (Table 1). Averages reported by Andringa [4, 5] are based on weather records for a ten year period from 1975 to 1984. Bhalotra [6] uses records for different durations of period for different stations. Starting with the year when measurements of solar radiation were started at a station he goes up to 1985 in each case. For example, for Tsabong, records from 1959 to 1985 have been used, but for Kasane which started in 1982, records for only a 3 year period of 1982 to 1985 have been used. This variability in the period over which averages have been calculated by these two authors may explain minor differences in data from one column of the table to another. From the available data the following general conclusions can be drawn about the nature and availability of solar radiation in Botswana.

Table 1. Annual average characteristics of solar radiation for ten locations in Botswana

Location	Sunny days per year [4]	Frequency of 1 to 4 successive days with irradiation below 10 MJ m^{-2} per day [5]: 1	2	3	4	Daily sunshine duration (hours per day) [6]	Total hours of sunshine per year [4]	Cal. global irrad. on a horizontal surface (MJ m^{-2} per day) [6]
Gaborone	304	5	2	0	0	9.0	3230	20.8[a] [7]
Francistown	282	7	1	0	1	8.7	3070	21.3
Ghanzi	316	3	1	0	0	9.2	3390	20.8
Kasane	—	—	—	—	—	8.2	—	20.8
Mahalapye	296	5	2	0	0	8.5	3120	20.7
Maun	306	2	1	0	0	8.9	3320	21.7
Sebele	314	6	1	0	0	—	3320	19.6[a]
Shakawe	299	2	0	0	0	8.6	3130	21.3
Tsabong	330	5	1	0	0	9.7	3510	22.0
Tshane	324	4	1	0	0	9.4	3460	21.8

[a] Measured values.

(i) The number of sunny days (sunshine duration more than half the day), in a year varies from 282 at Francistown in the north–east to 330 at Tsabong in the south–west. For Gaborone it is 304 days which is the national average. Completely overcast days are very few which range from two per year in the west to nine per year in the east.

(ii) The maximum number of consecutive days with global irradiation less than 10 MJ m^{-2} per day is two with a frequency of one to two per year depending on the location. Francistown is an exception which can be expected to have up to four such days in succession once a year. The expected number of consecutive days with irradiation less than 15 MJ m^{-2} per day is more and their frequency is of course higher. This can be expected to occur for up to four days in succession once or twice a year at most of the locations, with a few exceptions of five to seven such successive days once or twice a year at some locations [4, 5].

(iii) The annual average of daily sunshine duration varies from 9.7 hrs per day at Tsabong to 8.2 hrs per day at Kasane, whereas the annual duration of sunshine varies from 3510 hrs per year at Tsabong to 3070 hrs per year at Francistown. The national average is over 3200 hrs of sunshine per year. Monthly average for most of the locations is maximum during the month of August and it varies from 10.4 hrs per day at Ghanzi to 9.2 hrs per day at Mahalapye. The lowest monthly average occurs from January to March, which lies in the range of 6.7 hrs per day at Kasane to 7.9 hrs per day at Mahalapye. For Gaborone average annual duration is 9.0 hrs per day with monthly averages in the range of 9.9 hrs per day in August to 8.1 hrs per day in March and the total average duration is 3230 hrs of sunshine in a year.

(iv) The annual average of measured daily global irradiation on a horizontal surface in Gabarone is 20.8 MJ m^{-2} per day with lower values in winter, and higher values but more day to day variation in summer. The monthly average varies from a maximum of 26.4 MJ m^{-2} per day in December to a minimum of 14.9 MJ m^{-2} per day in June. On a surface tilted at 30° to the north the variation is from 23.2 MJ m^{-2} per day in September to 21.1 MJ m^{-2} per day in June [7]. Thus tilting the surface at 30° to north smooths out the seasonal variation in incident solar radiation and the devices so installed provide nearly uniform output throughout the year. For other locations the daily global irradiation on a horizontal surface is calculated from the sunshine duration using the Angstrom formula. The maximum of calculated monthly averages is 28.4 MJ m^{-2} per day in November and the minimum is 14.3 MJ m^{-2} per day in June, both in Tsabong with an annual average of 22 MJ m^{-2} per day [6]. For the purpose of sizing of the solar devices, the average daily irradiation on a horizontal surface is assumed to be 21 MJ m^{-2} per day throughout the country which gives satisfactory results.

4. SOLAR THERMAL APPLICATIONS

Thermal applications of solar energy in Botswana include hot water systems, passive solar buildings and solar stills.

4.1. *Solar water heaters*

Solar water heaters contribute to the maximum use of solar energy in Botswana. Residential sector accounts for 90% of the heaters in use. Educational institutions, industry, and private and government buildings account for only 10% of the usage. Due to the high cost of electricity, solar water heating in Botswana is now a well-established and accepted technology, the demand for which has been growing steadily. As a result there are several companies in the country which cater to the needs of the consumer and offer a wide variety of products to choose from. The main varieties include direct cooling and indirect cooling collectors, with or without electrical backup and some low cost ones of indigenous design. Mostly the systems are imported but some of the companies manufacture complete or partial systems within the country.

Failure of some systems in the recent past has affected the market for them. The main problems and causes of failure include [8]: (i) calcification and blockage of the cooling channels. The quality of water in Botswana varies from place to place and in most of the cases the ground water is hard. This results in the deposits in the cooling channels in direct cooling systems. (ii) Due to very low night temperatures in winter in some parts of the country, freezing of water causes damage to the panels and the cooling channels. (iii) Damage is caused to the panels due to over heating where the water supply is not reliable and the collector runs dry. (iv) Galvanic action at the joint of two dissimilar metals due to dissolved impurities in the water and pitting corrosion result in leaks and damages. Many of the problems seem to have arisen due to poor installation and maintenance of the systems and due to the use of inappropriate plumbing materials. Some suppliers of the imported systems did not offer adequate maintenance and backup facilities. In order to resolve these problems and to protect the interests of all the parties involved, namely suppliers, installers and the consumers, the Energy Unit has now formulated a code of practice for solar water heating systems in Botswana [9].

Several types of low-cost, batch solar water heaters (Fig. 3) have been developed by the Rural Industries Innovation Centre (RIIC), Kanye [10]. One of the types known as a "brick batch solar water heater" uses a 100–200 l blackened metal drum as the solar collector, encased in bricks from the sides, with a glass cover on the top, and sawdust or fibreglass wool for insulation from the sides and bottom. The other one known as a "blacksmith solar water heater" comprises a blackened, 60 l capacity metal box with a glass cover on the sun-facing side. Both types can provide water heated up to 75°C temperature, and are best suited for rural–domestic use where high-cost conventional systems are beyond the economic means of people. The blacksmith type has the added advantage of portability and does not require plumbing and installation work. It is, therefore, also ideal for camping and safari with the fast expanding tourism industry in the country.

4.2. *Passive solar buildings*

Most parts of Botswana experience extreme high and extreme low temperatures. Temperatures reach over 40°C during day time in summer and below freezing during winter nights. It is also common to reach a difference of up to 20°C in day and night temperatures. Low rainfall and no major water body near or within the country, except Okavango delta in the north, are responsible for a low humidity in most parts of the country throughout the year. Under such climatic conditions, both heating and cooling of buildings is necessary in order to maintain comfortable indoor temperatures. As a general trend in the country the residential buildings are not air-conditioned but the public and commercial buildings are mostly air-conditioned. Due to high cost or inaccessibility of electricity and petroleum products in remote areas, and the scarcity of wood, the use of these fuels for heating or cooling is impracticable. The most appropriate and economic alternative then, is the passive solar building. They hold a big promise for Botswana as has been demonstrated by a few such existing buildings which have been in use for several years now.

The Botswana Technology Centre (BTC) is playing a key role in design and construction of passive solar buildings in Botswana. Its headquarters in Gaborone, constructed in 1984, is one of the few passive solar buildings in the Southern African and SADC (Southern African Development Community, a group of ten countries: Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe) regions. The Centre has three main buildings, the administration block, the library and workshop, with a total covered area of about 400 m^2. The temperature inside the buildings remains comfortable, 20–26°C, throughout the year without the use of space conditioning devices. Other passive solar buildings in Botswana include the BTC guest house and several residences for its staff. Recently, a new workshop building with a floor area of 160 m^2 has been added to the BTC complex. A new and a larger headquarters with covered area of 2000 m^2 and more staff residences are in the final stages of designing and construction. More effort and public awareness is needed so that a larger number of such buildings could be designed and constructed to provide greater

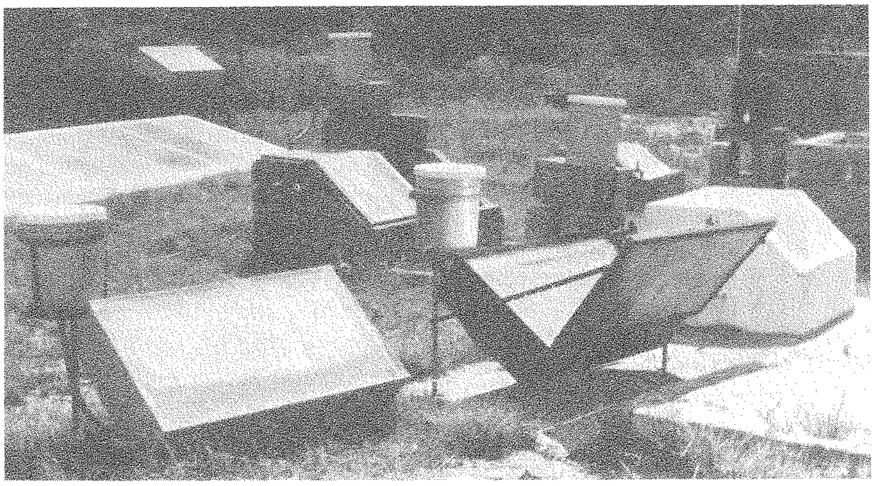

Fig. 3. Some of the batch solar water heaters developed at RIIC, Kanye.

comfort to its occupants while the use of external sources of energy for space conditioning is minimised.

4.3. *Solar stills*

Very little rain, frequent drought and almost non-existent surface water render water a costly and scarce commodity in Botswana. The remote area dwellers in the Kgalagadi District in the south–west of the country particularly face a severe shortage of drinking water. The ground water is found at large depths of about 100 m or more and the water so found in most cases is highly saline and therefore unsuitable for human consumption. In some places the concentration of dissolved solids is so high (at Zutshwa the salinity is seven times that of sea water), that it cannot be used even for watering the cattle or the agricultural patches or for construction. If, rarely, potable water is struck, the yield is small and inadequate to meet the requirements of the community settled in the vicinity of the borehole. These settlements have been dependent on trucked water provided by the district council, the supply of which besides being expensive is not regular because of breakdowns, lack of vehicles and transport problems involving 70 km to 150 km distances on deep sandy roads. Sometimes these settlements go without water for weeks. The use of solar stills to desalinate the available ground water for providing potable water has eased the problem to some extent and has contributed to the improved quality of life in the settlements. The idea of desalination of water was conceived in 1977 by the Rural Industries Innovation Centre (RIIC), Kanye who identified it as an appropriate technology to alleviate drinking water shortage in the remote areas. Consequently a Joint Advisory Group on Desalination for Remote Areas (JAGDRA), consisting of representatives from RIIC, Ministry of Local Government and Lands, Botswana Christian Council, Department of Water Affairs and District Councils, was set up in 1982 to find means to desalinate the available water. RIIC was charged with responsibility of relevant research and development work and personnel training in this area of technology. Several purifying techniques which included wood burning stills, Mexican solar stills, brick solar stills, night sky radiation still and reverse osmosis were tried and field tested. After years of research and development activities, the RIIC findings concluded that the Mexican and brick solar stills are the best suited for application in Botswana.

The Mexican still consists of a moulded fibreglass basin of 1.6 m^2 base area to hold saline water and has gutters on two sides to collect the distillate. The inside base of the basin, manufactured locally, is painted black with pigments used at the moulding stage. This provides an abrasion resistant, efficient solar absorption surface. Slanting glass covers trap and condense the vapours and allow the purified water to run down to the collection gutters. The distillate yield per unit of the Mexican still varies from 9.0 l per day during summer to 4.5 l per day during winter. The brick stills are constructed from brick or cement blocks, painted black inside and have one slanting glass cover on top. The yield is up to 9.5 l per day from a 6 m^2 area with not much seasonal variation. Mexican stills have the advantage that they are prefabricated, easy to install, modular in nature and can be transferred from one site to another if sufficient potable water is found in the area at a later date. The brick stills have to be constructed on site (Fig. 4) which requires transporting all the raw materials including water, involves more manpower and skill, and the still cannot be moved to another site once constructed at a given place. Black paint on the inside of the brick stills adds to the cost and maintenance problems. Use of low cost bituminous paint is found to add taint and odour to distillate even after two years of construction. Epoxy enamel paint has proved to be an appropriate choice, but it is expensive, requires repainting every 3 years or so and has a curing period of several weeks [11–13].

In the first phase of implementation of solar stills developed and tested at RIIC, small scale solar desalination farms were set up in three locations. They included 176 Mexican stills at Ukwi, 64 Mexican stills at Zutshwa which was expanded to 96 stills in 1990 and 32 Mexican plus 10 brick (1 m × 9 m each) stills at Khwa (Fig. 1). The still farm from Ukwi has recently been removed after potable water was struck there. At present small scale desalination facilities to provide drinking water to settlements with a population of up to 300 are readily available. The next phase is to expand the facilities to medium and large scale desalination farms for settlements of up to 1000 people [14]. This expansion requires large capital investments and a larger infrastructure for the training of operators, managers and maintenance technicians. Apart from this desalination has proved its potential in Botswana for providing drinking water to remote area dwellers. In addition, high quality salt is produced at Zutshwa as a bi-product of desalination which is sold to generate cash income to support other developmental activities within the community.

5. SOLAR PHOTOVOLTAIC APPLICATIONS

Photovoltaic conversion of solar energy (PV) in Botswana is used for almost all common applications

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APPLICATIONS

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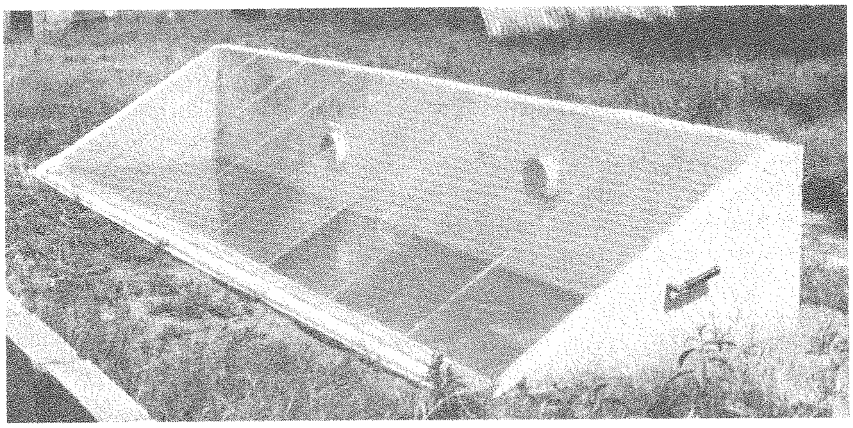

Fig. 4. A brick type solar still developed at RIIC, Kanye.

which include lighting, water pumping, refrigeration, communication and fence electrification.

5.1. *PV Solar lighting*

PV lighting was first installed in 19 primary schools in Kgatleng District in 1986. Following their success they are now used by the Botswana National Library Service (BNLS), rural clinics and community centres. About 700 households in the rural areas and some in Gaborone (Fig. 5) also use PV lighting. All the systems are 12 V DC and include batteries with charge control units.

The use of PV lighting in schools has enabled the communities to draw multiple benefits from the existing school facilities. The lighted rooms are now used at night as reading rooms for school children, for running adult literacy programmes and to hold meetings. All the school systems have been functioning well, without major technical maintenance since their installation in 1986. The first comprehensive inspection of all the school systems was carried out by BTC in 1990 after they had been in use for over four and a half years. Batteries in all the schools, irrespective of their performance, and other minor components like lamps and fuse holders were replaced [15]. The students carry out the day to day non-technical maintenance like keeping the panels clean and lamps dusted.

BNLS started using PV lighting for their village reading rooms at nine locations recently and they are all functioning well [16]. A few rural clinics make use of PV systems for emergency lighting including spot lights for attending to patients and maternity cases at night and to recharge torches for nurses on night

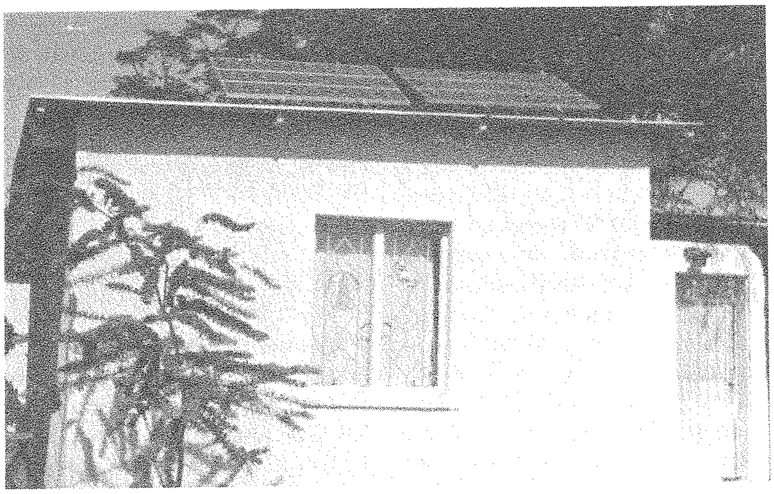

Fig. 5. Some private houses rely totally on PV power for lighting and refrigeration.

duty [17]. Among the private PV lighting systems in Gaborone, the results of a recent survey show that 64% of the systems are in good operational order, 30% are operating with some problems and 6% are completely out of order [18].

The only problem with PV lighting in schools and reading rooms has been the mosquitoes and insects that are attracted to light at night. Use of fly-screens has been unsuccessful because the users often tended to remove them. The Botswana Power Corporation in conjunction with the concerned Ministry is planning a strong approach to rural electrification which may affect the demand of PV systems for lighting. However, for very remote and out of reach places, PV will still remain as the only dependable source of lighting for some time to come.

5.2. *PV water pumping*

PV water pumping has been promoted successfully in some places in Botswana. It shows favourable economics as compared to diesel pumps, and is free from the need to maintain a regular supply of fuel. Since water pumping is not an emergency service and it can be carried out during sunshine hours, its sizing is much simpler and does not require extra backup storage batteries. The only maintenance problems with PV pumping are due to the breakdown of pumps and not the failure of the PV devices.

5.3. *PV solar refrigeration*

The use of PV solar refrigeration in Botswana at present is very limited. The use of solar refrigerators to preserve vaccines and other life saving drugs was introduced in a few clinics [18] but it was not successful due to frequent breakdowns of equipment. A clinic at Manyana experimental solar village, and some veterinary clinics are presently using solar refrigerators.

5.4. *PV solar communication*

PV devices for communication (Fig. 6) are used by the Departments of Telecommunication, Police and Railways. All the communication systems have a 5 day built-in autonomy.

Botswana Telecommunication Corporation is the largest user of PV panels which power the equipment for telecommunication links with the remote rural areas. Use of PV together with most modern equipment make the telecommunication network in Botswana one of the best and most extensive in Africa. It is possible to reach all large and medium sized villages in the remotest part of the country through telephones either by direct dialling or through manual exchanges which provide services during restricted hours. Two types of systems are in use which include rural payphones and microwave repeater stations. All the installations use 12 V or 48 V PV arrays depending on the requirements. There are over 80 rural telephones and about 70 repeater stations with plans for further expansion of the network. At the same time, as and when commercial electricity becomes available in some area, the PV panels are replaced with power from the grid. All the PV systems are equipped with alarms for low voltage which are monitored from the Telecomms headquarters in Gaborone.

Botswana Police force operates its own microwave communication system for data and facsimile transmission which link the country-wide police stations to the headquarters in Gaborone and also provide cross links between major police stations. Out of 19 repeater sites, 13 operate by PV power using 24 V panels, the load varying from 50 W to 170 W. Some sites simply re-transmit the incoming signals, others provide a branching link from the main link to an intermediate police station. Several of the sites are also equipped with VHF radio repeaters for local radio coverage as well as for a national common access radio service [19].

Botswana Railways uses PV panels for hot box detectors, radiocommunication and signalling. Hot box detectors installed along the railway line detect the overheating of the bearings as the trains pass over the device and a message about the condition of bearings is transmitted to the driver on the train. Sensors are situated at 150 m on either side to switch on and off the system to conserve power. Twenty-four volt PV panels provide power to a computer, a radio and the sensors and also provide 110 V AC through an invertor for the hot box detectors. PV radio units are used to facilitate communication links between railway stations along the line where other modes of communication are not accessible. Likewise PV panels also power signals along the line wherever necessary.

5.5. *Fence electrification*

Some wildlife game reserves use PV panels with associated devices to electrify fences to control the movement of wild animals.

6. SOLAR ENERGY RESEARCH AND DEVELOPMENT IN BOTSWANA

The organisations which are involved in R&D work in the field of solar energy in Botswana are the University of Botswana, Botswana Technology Centre, Rural Industries Innovation Centre, Department of Meteorology, Energy Unit and some private consultants and suppliers and manufacturers of solar devices. The work at the University at present is of

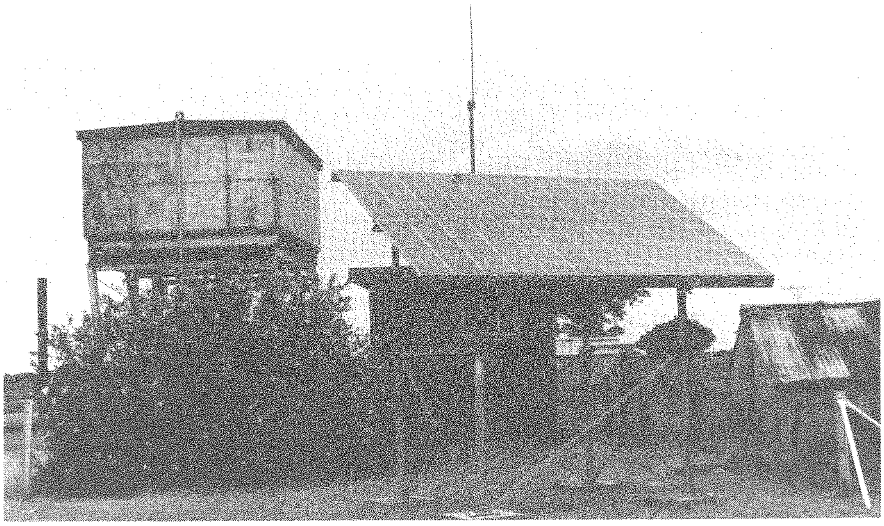

Fig. 6. The communication sector is the largest consumer of PV panels in Botswana.

theoretical nature, mainly of academic interest and for long term use in the application of solar energy. The National Institute of Research and Documentation (NIRD), University of Botswana has been involved in studies on fuel wood and biogas, and is the Coordinator for the African Energy Policy Research Network. BTC's main field of activities are the testing and evaluation of PV systems, consultancy service for sizing and maintenance of solar systems, and the design of passive solar buildings. BTC has developed a battery charge controller for PV systems and is involved in the collection of solar radiation data at its headquarters in Gaborone. Collection of solar radiation data at other locations in Botswana is done by the Department of Meteorology. RIIC, Kanye is responsible for the solar desalination programme in the country. Several types of low cost batch solar water heaters and a thermal water pump have also been developed by RIIC. The pump uses air and water, working alternately on a diurnal cycle with solar heat and nocturnal cooling. On a clear sunny day the experimental model pumps 177 l of water per day from 1.3 m head and can be used for up to 7 m head. The Energy Unit, MMRWA is the planning and management body for the demand and supply of energy in the country and formulates governmental policy on all energy matters. The Energy Unit has set up a Renewable Energy Pilot Project at Manyana, a small village 40 km south–west of Gaborone with a population of about 3000. Various renewable energy technologies and associated devices for their application are installed in the village at a cost of P 700,000 (approximately US $300,000) and their use and performance is monitored. Among the private sector, some companies manufacture complete or partial solar hot water systems locally. Some suppliers of imported devices also have limited manufacturing facilities. Some other private companies provide consultancy services on sizing of the solar systems, their maintenance and other energy matters. Consultancy for the passive solar design of buildings is available in the government as well as in private sector.

7. OTHER RENEWABLE ENERGY APPLICATIONS

The other renewable energies contributed only 1 TJ to the total consumption of 35,390 TJ in 1989. The only ones which need to be considered are the wind energy and biogas, but they too have a very limited scope. The wind speeds in the country range between 1.5 m s^{-1} and 3.5 m s^{-1}. The speed is far too low to generate any amount of electricity economically [3], and windmills can only be used for water pumping. RIIC, Kanye is involved in R&D in wind water pumping, and has developed a model which is better suited to needs in Botswana. Wind pumps can play some role in the agricultural sector but their cost effectiveness depends on the average daily demand. For low demand levels, hand pump, animal driven pump or PV solar pump appear to be more economical whereas for demand exceeding 5 m^3 per day and with favourable wind conditions the wind pump may be a better option.

In view of a large cattle population of over 2.5 million, biogas can be a very potential source of energy for water pumping, cooking, lighting and refrigeration, particularly within the cattle farming and agricultural sectors. Because of free grazing of animals over the large areas of farms the collection of cattle droppings poses a major problem. There are a total of 10 biogas plants in the country with a total generation capacity of 126.75 m^3 of gas per day. The capacity of individual plants ranges from 27.5 m^3 per day to 3.75 m^3 per day. The applications include water pumping, cooking, bakery and a demonstration plant [20]. If 200 biogas digesters could be installed by the year 2000 it could save 3% of the diesel consumed for livestock production [3].

8. CONCLUSIONS

Booming economy, low population, land locked location, vast area, remotely separated rural areas which are not easily accessible, large reserves of coal, excellent sunshine, large mining sector and cattle farming on a large scale are the factors which are most influential to the total energy scene in Botswana. Immediate neighbourhood with the industrially developed South Africa in the south and a large hydro power potential at Zambezi in the countries to the north also have a long term bearing on energy development in Botswana. With the expanding economy in the country as the industrial base expands, it will support the rural development through the growth of rural industries. This will warrant the expansion of the electricity grid to bring electricity to a larger number of rural communities. This in turn would mean the expansion in the generating capacity which, besides being highly capital intensive, has a time lag of 5–10 years. However, there is no significant time lag with the use of solar devices and they are modular in nature. They can be expanded as the need grows. Tapping of solar energy for rural development is, therefore, expected to emerge as an important renewable source of energy in Botswana. There are many other factors which support this outlook. Among them are the remoteness of rural areas, scarcity of wood fuel, abundant sunshine and simplicity of the routine maintenance of solar devices. Above all, solar technology already has a well established base in the country, the potential for which has been demonstrated with a wide range of applications over the past 10 years.

REFERENCES

1. *Facts on Botswana*. Department of Information and Broadcasting, Government of Botswana (1990).
2. *Barclays Business Guide to Botswana*. Barclays Bank of Botswana Limited (1989).
3. *Botswana Energy Master Plan—Final Report*. Energy Unit, Ministry of Mineral Resources and Water Affairs, Government of Botswana (1987).
4. J. Andringa, Pattern of global irradiation in Botswana. In *Advances in Solar Energy Technology* **4** (Edited by W. H. Bloss and F. Pfisterer), pp. 3887–3891. Pergamon Press, Oxford. (Proceedings of the Biennial Conference of the International Solar Energy Society, Hamburg, Germany) (1987).
5. J. Andringa, Some characteristics of the pattern of solar radiation in Botswana. *RERIC International Energy Journal* **11**, 69 (1989).
6. Y. P. R. Bhalotra, *Climate of Botswana, Part II: Elements of Climate—2. Sunshine and Solar Radiation and Evaporation*. Department of Meteorological Services, Government of Botswana (1987).
7. V. J. A. Meeussen, Implementation of photovoltaics in rural Botswana. In *Proc. of the Regional Seminar on Impending Energy Transition and the Role of New and Renewable Energy Systems in Africa*, Lome, Togo (1990).
8. B. Mogotsi, Problems relating to solar water heating in Botswana. Presented at the Solar Water Heating Seminar, Energy Unit, MMRWA, Gaborone (1990).
9. *Code of Practice for Domestic Solar Water Heating in Botswana*. Energy Unit, MMRWA, Gaborone, Botswana (1990).
10. *Batch Solar Water Heaters*. Information Unit, Rural Industries Innovation Centre, Kanye, Botswana (1991).
11. *Proceedings of the small-scale desalination seminar—I.* RIIC, Kanye, Botswana (1987).
12. *Proceedings of the small-scale desalination seminar—II.* RIIC, Kanye, Botswana (1989).
13. R. Yates, T. Wato and J. T. Tlhage, *Solar powered desalination—a case study from Botswana*. International Development Research Centre, Canada (1990).
14. Medium-scale solar desalination for remote areas of Botswana. Project Memorandum, RIIC, Kanye (unpublished) (1991).
15. *Report on the planned maintenance of PV lighting systems at Kgatleng Schools*. Systems and Testing Unit, Botswana Technology Centre, Gaborone, Botswana (1990).
16. *Report on inspection of photovoltaic lighting systems for the Botswana National Library Service*. Systems and Testing Unit, Botswana Technology Centre, Gaborone, Botswana (1991).
17. P. Knudsen, *Photovoltaic energy for health facilities in Botswana*. Ministry of Local Government and Lands, Government of Botswana (1988).
18. *A report on survey of private PV systems in Gaborone*. Systems and Testing Unit, Botswana Technology Centre, Gaborone, Botswana (1991).
19. Photovoltaics and the Botswana Police Force. Private communication (1992).
20. T. Wato Jr, *Biogas technology in Botswana—a sociological evaluation*. RIIC, Kanye, Botswana (1988).